Road Condition Index (RCI) Development For Cycling Systems for Cycling Systems´ Quality Assessment in Urban Areas

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Abstract

this research aims to develop an index, called Road Condition Index (RCI), to be used to assess the quality of cycle systems in order to assist transport system planners in the implementation and evaluation of cycle systems; in addition to increasing the ability of managers and professionals in decision making, presenting criteria for analysis. The RCI was developed based on findings about the use of bicycles as a sustainable mode of transport, the precepts of environmental psychology and the methods of assessing the level of service applied to transport. Thus, eight (8) indicators were defined to compose the RCI, namely: width of the road, speed, topography, conflicts (parking lots, intersections without signs), vehicle flow, amenities, pavement (quality) and land use. In the end, the RCI was standardized in a similar way to the one proposed by Eastman and Jiang (2010), which it is possible to classify the segments in A, B or C. On this scale if the calculated value of the RCI for the segment is between 0 to 0.33 is considered bad (C). From 0.33 to 0.67, the segment presents a good situation (B). When the index is higher than 0.68, there is a very good situation (A).

Keywords: Cycle system. Road condition index. Environmental psychology. Service level.

Introduction

Urban mobility issues have reached alarming levels. In addition, intervention policies, according to which motor vehicles prevail over other transportation modes, have been proposed. However, they bring along issues that go beyond their infrastructure implementation process, such as environmental and health issues resulting from poor air quality; large number of traffic accidents; traffic jams; high occupation index in urban areas to the detriment of walking or using other displacement modes; lack of parking lots; high energy consumption and noise pollution; social segregation, lack of accessibility, and stress.

Bicycles are an alternative mobility option capable of leading to personal, social or environmental benefits such as public spaces' preservation, smaller parking areas, low noise level, non-use of fossil fuel and affordability to the population (FHWA,1999).

Despite all positive bicycle use-related features, bikeway infrastructures remain incipient, mainly due to issues such as lack of investments and shortage of guidelines including bicycles as viable displacement alternative to guide policies focused on encouraging the use of non-motorized transportation modes (KIRNER, 2006).

The number of studies focused on investigating individuals' behavior and factors capable of influencing bikeway-related demand in Brazil has been progressively growing. The ones developed by Pezzuto (2002) and Kirner (2006) stand out among them. Several methods were suggested to assess the service level of bikeways implemented in other countries; among them, one finds Davis (1987), Epperson (1994), Sorton and Walsh (1994), Dixon (1996), Landis et. al. (1997), Hunter et. al. (1999), HCM (2000) and TRB (2000). Each of these studies had a specific aim and covered different issues, namely: accidents with bicycles, bikeway features, signaling, traffic volume and ground conditions.

However, knowledge about bicycle users' behavior remains incipient, mainly in Brazil, as reported by Davis and Wicklatz (2001), who found that routes used by bicyclists did not comprise built bikeways and bike lanes, mainly because their infrastructure was built adjacent to motor-vehicle roads that were often jammed.

Hence, it is essential conducting behavioral research at the time to define and implement cycling systems, since most studies in the field focus on investigating traffic-related accidents, safety behaviors (use of bike helmet) and individuals' perception about bicycle image.

Accordingly, Gunther (2003) has advocated that mobility, understood as exploitation, is essential for human development and well-being, since it provides affordance1[1] in different physical spaces covered by individuals and encourages certain behaviors based on their inter-relationship. According to Everett and Watson (1987), it is necessary psychologically understanding transportation as the sum of individual behaviors; thus, it must be taken into consideration from a human-technological perspective (Delabrida, 2004) aimed at associating cyclists' psychological behavior with their relationship with road systems in order to help introducing the bikeway mode in urban transportation and city planning processes.

Thus, the aim of the current study was to develop an index to assess the quality of cycling systems to help transportation systems' planners to implement and evaluate these systems, as well as to help increasing managers and professionals' decision-making skills, based on analysis criteria. The aforementioned index was developed based on findings on the use of bicycles as sustainable transportation mode, by taking into consideration environmental psychology precepts and methods focused on assessing service levels applied to transports.

Theoretical Background

1 affordance: concept that can be defined as what is offered or provided by the environment so that people behave, either in an intuitive manner or based on previous experiences (LEWIN, 1975). Affordance concerns what the environment offers to the body in order to interact with it in a synergistic manner (GUNTHER, 2003).

This section presents the theoretical background substantiating the development of the Road Condition Index (RCI) used to assess the quality of cycling systems in urban areas.

Bicycles seen as sustainable transportation mode

The significant use of individual vehicles leads to increased traffic flow in the road system of different cities and generates issues such as traffic jams, accidents, loss of space, atmospheric pollution, noise and high energy consumption. All these issues have adverse effects on the urban natural environment and help degrading populations' quality of life (RAMOS, 2008).

Bicycles belong to a set of sustainable transportation modes capable of guaranteeing mobility and accessibility to users. These modes can be used by the urban society in a democratic manner (RAMOS, 2008).

It is perfectly noticeable that improvements observed in human health, air quality and dependence on fossil fuel-driven transports are directly influenced by the number of bicycle-based trips, which can be encouraged by investments, planning and infrastructure supply (RAMOS, 2008).

Socioeconomic and environmental advancements are often achieved when individuals use bicycles as regular transportation means, namely (Hamer, 2017):

- Evolution in human health and safety: replacing individual vehicles by bicycles increases citizens' safety;
- Environmentally friendly transportation: reducing environmental impacts by decreasing particulate matter emissions to the air;
- Decreased dependence on fossil fuels: using bicycles reduces the use of motor vehicles;
- Equity: advancements in society's interactions and safety, by simultaneously enabling lower-cost and more accessible urban transport;

- Efficiency: using bicycles requires less space and lower investments in infrastructure than those demanded by motor vehicles; it can also help reducing traffic jams.

Cycling infrastructure implementation in cities' mobility system has economic impact on their surrounding areas. The scale of advantages that can be achieved by implementing this modal distribution in urban contexts comprises increased social well-being, urban reorganization due to reduced automotive flow, social exclusion suppression and local ventures' valorization (RAMOS, 2008).

Service Level Seen as Criterion to Implement and Assess Cycling Systems

Several methodologies - known as Service Levels (SL) - focused on assessing the quality of cycling systems in infrastructure-oriented urban regions were developed to help improving the urban space intended for bicycles (seer Hamer, 2017). These methodologies apply qualitative analysis based on parameters such as comfort, vehicle drivers' convenience, freedom to choose the driving speed, and obstacles emerging throughout the route such as distance from other vehicles and roads (TRB, 2000).

Some methods adopt indices associated with pathways' convergence and aspects linked to spatial behavior (Hamer, 2017). Table 1, which was developed by Monteiro and Campos (2011), presents a summary of cyclists' analysis methods.

Methods proposed by Dixon (1996) and HCM (2000) stand out as theoretical bases used to build the herein proposed index.

Dixon (1996) developed a counting structure to assess bikeways' service level in Gainesville County, Florida State, United States. The model aimed at assessing cyclists' allocation on arterial and collector roads, in urban areas. It was based on the principle, according to which, a group of variables must exist in a given road system to attract non-transport supporters.

Table 1 - Service level analysis

Authors / year	Study	Bikeway safety variables
Epperson and Davis (1994)	Service level assessment based on method focused on calculating the Road Condition Index (RCI).	Speed limit Outer lane width Mean daily traffic volume Number of traffic lanes Pavement quality
Sorton and Walsh (1994)	Assessing the quality of bicycle trips based on the association between the features of routes used by cyclists and the stress they are subjected to.	Traffic volume Motor vehicle speed Bikeway width
Botma (1995)	The analysis applied to the quality of bicycle paths must take into consideration conflicts among cyclists themselves.	Volume of bicycles
Dixon (1996)	Scoring system used to evaluate cycling lanes.	Conflicts on the bikeway Speed difference between motor vehicles and bicycles Bikeway maintenance
Landis et al (1997)	Classification of cycling routes based on cyclists' viewpoint.	Traffic volume Number of lanes Speed limit Pavement condition Mean width of the outer lane
HCM (2000)	Analysis of bicycle facilities' capacity and service level.	Vehicle input density Speed difference between bicycles and motor vehicles
Monteiro and Campos (2011)	Proposition of indicators to assess the quality of spaces intended for cyclists.	Safe crossings through signaling or footbridges Safe distance from the flow of motor vehicles Volume of vehicles on the lane, in the case of cycling lanes Number of accidents Number of entryways for vehicles Vehicle flow speed

Source: Monteiro and Campos (2011).

Dixon's (1996) methodology takes into consideration six analysis factors, namely: facilities for bicycles, conflicts, non-obstructed sight distance, improvements in cycling intersections, speed difference between vehicles and bicycles, motorized service level, road maintenance and specific initiatives to improve cycling transport (Table 2).

Segments were scored and classified as Service Level "A" to "F", wherein, (A) safe and attractive pathways; (B) suitable for any cyclists; (C) suitable for most cyclists; (D) suitable for experienced cyclists; (E) require care for cyclists; and (F) improper.

According to Hamer (2017), the methodology proposed by the Highway Capacity Manual (TRB, 2000) can be used to assess both the capacity and service level of bicycle facilities. The aforementioned author has also emphasized that the use of such a methodology enables identifying the effects of pedestrians, traffic signs and interaction between cyclists on bicycle facilities' service level – these effects are measured based on events that have taken place in these facilities (encounters and overtaking). The proposed method takes into consideration facilities presenting uninterrupted flow of bicycles - i.e. cycling lanes separated from vehicle traffic, without interruptions -, as well as terminal points like facilities with interrupted flow, such as cycling lanes crossing intersections with, or without, traffic lights.

Table 2 – Service Level Scoring System for the analyzed segment.

Category	Criteria	Scores
Bicycle facilities (Maximum value = 10)	Cycling lane - external lane ≤ 3.66m Cycling lane - external lane 3.67m - 4.27m Cycling lane - outer lane ≥ 4.27m Bikeway	0 5 6 4
Conflicts (Maximum value = 4)	Few garage entrances and intersections Lack of barriers Lack of side parking Presence of central flower beds Non-obstructed sight distance Cycling intersections' treatment	1 0.5 1 0.5 0.5 0.5
Speed difference between bicycles and motor vehicles (Maximum value = 2)	> 48km/h 33 – 48km/h 24 – 32km/h	0 1 2
Service level for motor vehicles (Maximum value = 2)	SL = E or F (6 or more traffic lanes) SL = D (less than 6 traffic lanes) SL = A, B or C (less than 6 traffic lanes)	0 1 2
Road maintenance (Maximum value = 2)	Severe or frequent issues Small and less frequent issues Lack of issues	-1 0 2
Initiatives aimed at cycling transport (Maximum value = 1)	No initiatives Existing Initiatives	0 1

Source: Dixon (1996).

Environmental Psychology and Transport

Defining Environmental Psychology is not an easy task. According to Fisher et. al. (1984), describing it is easier than defining it. Based on Heimstra and McFarling (1978), much is said about air and water pollution, natural environment destruction, noise and overpopulation. Such a diverse set of topics require investigative contributions from different disciplines and professionals who set an interface with architecture, urban and regional planning, civil and sanitary engineering, geography, sociology, biology, park and forest management. The common ground of all these fields lies on relationships between man and physical environment.

Moser (1998) has added the investigative value of environmental psychology, which refers to individuals' behavior, with focus on the interrelationship between individuals and the physical/social environment, which is mediated by individual perceptions, assessments and attitudes towards the environment.

According to Everett and Watson (1987), transport is a challenging factor for environmental psychology. Although it is applied to the everyday life of different cities, it remains poorly explored. Thus, it is necessary developing psychological understanding about transport, after all, all individuals use it, in one way or another. In addition, it is necessary taking into consideration that the transport phenomenon is the sum of individuals' behaviors in urban contexts; therefore, it should be taken into consideration from a more human perspective than from an exclusively technological one.

Environmental Psychology can contribute to this topic due to its angle of study, since it investigates "the interaction between individuals and their physical environment". During these interactions, individuals change the environment and have their behavior and experience changed by it (GIFFORD, 1987).

It is possible understanding how individuals relate to a particular transport mode in a given physical environment, as well as the dynamics established based on it, namely: the impact transport has on people's lives and how these people change both the environment and themselves, based on this relationship. According to Hamer (2017), the intervention relationship takes into consideration three Environmental Psychology aspects: (I) physical space; (II) behavior; and (III) reciprocal bond between (I) and (II). Thus, one can understand that:

I.Physical space is the acuity of physical environments, and its different senses (sight, hearing, among others), but it comprises several stimuli at the same time (GUNTHER, 2003);

II.Human behavior and conduct can be admitted both individually and in groups, so that the individual environment does not take place in separate, but in the company of others, in a conjunction known as social environment (GUNTHER, 2003);

III.Reciprocal link is based on bidirectional associations, on the effect people have on the environment and vice versa, as well as on the return activity between individuals' behavior and experience in the physical environment (GUNTHER, 2003).

Psychological Variables of Urban Mobility

Psychology is understood as referring to conduct and experience in physical space skills. On the other hand, the idea of mutual connection is typical to the specific trend of environmental psychology (HEIMSTRA; MCFARLING, 1978).

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However, the aforementioned three aspects can help other research fields, which are all potentially identifiable by the following elements: behavior, space and reciprocity. It is the reason why they require the inclusive label of environmental psychology in studies about urban mobility (GUNTHER, 2003).

According to Gunther (2003), "environment" encompasses different forms of physical space, as well as objects that - due to their affordances - change the person-physical space relationship. Size and degree of control over physical space are not just an end in themselves; they are important aspects of individuals' quality of life. The degree of mobility affects one's access to: (a) material goods, and subjectively and objectively relevant ideas, and (b) environmental affordances (Hamer, 2017).

Gunther (2003) has incorporated the foundation of physical space to urban environment through mobility, as well as presented four concepts of physical environment associated with individuals' conduct and experience, namely: personal space, territoriality, privacy and density/crowding (GUNTHER, 2003).

Personal Space

Personal space – which is a concept proposed by Sommer (1969) - refers to an area with invisible boundaries surrounding people's bodies. It is a portable territory reflecting two different uses: the first one refers to the emotionally charged zone around each individual; the second use refers to processes through which individuals define and personalize the spaces they live in.

According to Lee (1977), every person has a spatial area around its body, whose borders only exist "in its mind" and whose intrusion by others is undesirable. Vilaça (2008) has completed this thought by stating that personal space dimensions are associated with individuals' life story, as well as with special circumstances lived by individuals holding such a space. On the other hand, according to Stokols (1996), the perception about, and adjustment to, interpersonal distance are highly influenced by cultural traditions and standards.

Gunther (2003) has emphasized that individuals' personal space is shaken as their displacement in the territory leads them to coexist with the personal space of others. Equally, and conversely, aspects of each other's personal space can make their mobility easier, or stifle it.

Control over personal space takes place by regulating the distance kept by an individual from others; individuals can present different personal-space needs. Hall (1966) described the four spatial zones mostly used in social interactions: intimate (0.50m), personal (0.50-1.50m), social (1.50-3.50) and public (3.50-7.00m). They are influenced by different actions one wishes to perform, as well as aim at protecting these actions' intimacy and safety.

Territoriality

Gifford (1987) described territoriality as a block of actions taken by individuals or group of individuals, based on identified, attempted or real control over a realistic physical space, object or idea, which can lead to habitual occupation, defense, personalization and demarcation.

According to Heimstra and McFarling (1978), territoriality is another aspect of human spatial behavior, which is often hard to be separated from the maintenance of personal space. A person establishes a given territory, either by using features of its space or by changing it, by setting markings and boundaries.

According to Hamer (2017), studies about territoriality aim at investigating territory domain and defense relationships at different levels, as well as at correlating concepts of places' attachment and identity. The social focus lies on how spaces are understood based on affective and cognitive bonds (status, identity, family stability) and on how they function as basis for territory holder's identity, in order to understand attachment and identity-of-the-"place" relationships (SOMMER, 1969). In addition to these social attributions, territory also has physical protection and control functions (PAIVA, 2013).

Altman (1975) has designed three territory types: primary, secondary and tertiary. Primary territories are connected to well-being and survival; they are visited for extended periods-of-time and have a more specific feature, such as house, bedroom and worktable. Secondary territories have lower transition than the primary ones; they present average (temporary and transitory) length of stay, such as restaurants, clubs and schools. Tertiary territories such as streets, sidewalks, and parking spaces are public spaces, although they can be a priority for anyone.

Privacy

According to Altman (1975, p. 18), privacy is the "selective control over the access to oneself or to one's group". It is an acceptable set of regulatory mechanisms that are strongly determined by social standards (LEE, 1977).

Satisfaction with one's privacy depends on whether, or not, a person wants to relate to other people in a given context. It happens because each person needs different privacy levels in different places and contexts (PAIVA, 2013). The appropriation of space and its materialization through constructive elements such as walls, windows, gardens and doors, define the privacy condition. Moreover, it can be controlled depending on matters of personal interest (VILAÇA, 2008).

Density or crowding

Density refers to the number of people per unit of space, i.e., density is an exact quantity. Crowding, on the other hand, refers to a psychological condition comprising stress and the need to move away from a position that is personally identified as dense (BELL et al., 1996).

The concept of "crowding", which was translated into Portuguese as ajuntamento, apinhamento or superpovoamento, corresponds to a situation perceived as uncomfortable due to the invasion of one's personal space. Situations such as these

can be interpreted as stressful, as well as determine adverse behaviors, according to which, the environment is perceived as threatening source (TUAN, 1983).

Several conditions can affect individuals' reactions to the different degrees of density they are exposed to, namely: aspects of people and groups, age, gender, relationships' purposes, people's preference for being in crowded places, and the cultural reasons for it (MORVAL, 2007).

Individuals' behavior in the environment can be affected by several factors that can trigger adverse reactions such as anxiety, distress and desire to leave the environment. These reactions depend on how individuals had their space affected, on how they perceive this situation, as well as on their personal desires, previous experiences and on the cultural pressures they are exposed to (MORVAL, 2007).

Mobility-related Implications and Environmental Psychology

According to Kohlsdorf (1996), the understanding of "places" refers to planning and designing urban areas, as well as to the importance of professionals who develop evaluations and projects based on the sense of technical relevance. However, decisions made produce real spaces perceived and occupied by users, based on a sensitive knowledge of connotative nature. It is necessary understanding cognitive level features as attributes capable of defining the receptive morphological qualities that must be integrated to places' culture and expectations.

Therefore, this path should call up "the legibility and imaginability" presented by Lynch (1997); it must be done through urban elements that bring attractiveness to pathways, such as low impact economic activities and afforestation integrated to urban landscape as element of pathways' good environmental quality.

According to People-Environment Studies developed by Gunther (2003), mobility, seen as real conduct or past experience, enables approximations to affordances in several physical spaces travelled by people. Thus, mobility is the link enabling mutual relationship between persons and physical spaces. The affordance indicating psychological interaction refers to bicycle users' safety relationship with environmental and physical features.

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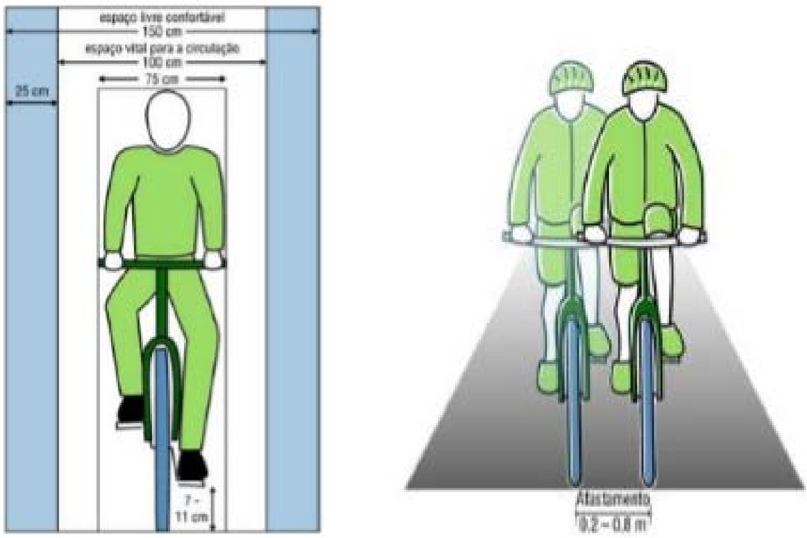
Paiva (2013) presented four environmental psychology variables that can be associated with bicycle use, namely: personal physical space, territoriality, privacy and density (crowding).

Control over personal space is established through safe dimensions for bicycle traffic on the lanes. The space for moving (dynamic envelope) changes depending on the circulation speed on the slope. Cyclists travelling at low speed tend to avoid moving in a straight line. Speed equal to, or faster than, 10 km/h is enough to maintain comfortable circulation without losing balance. The additional distance for speed equal to 10 km/h is 0.2 m, whereas deviation increases at speed lower than 10 km/h - for example, speed close to 6 km/h requires deviation of 0.8m (Figure 1). High speed in downward pathways forces individuals to consider additional width; on the other hand, cyclists overtaken by motor vehicles should keep mean distance of 1.5 m from them.

Figure 1 – Reference circulation spaces for cyclists.



Source: Cycle Infrastructure Design (2010). Fonte: Cycle Infrastructure Design (2010).

The Brazilian Traffic Code (BRASIL, 1997) establishes the minimum dimensions necessary for cycling projects. The lateral distance to be kept from motor vehicles guarantees greater “privacy” and safety for bicycle users. According to Paiva (2013), these measures are adopted in most reference manuals such as Aashato (1999), GEIPOT (2001), Brasil (2007) and Sustrans (2014).

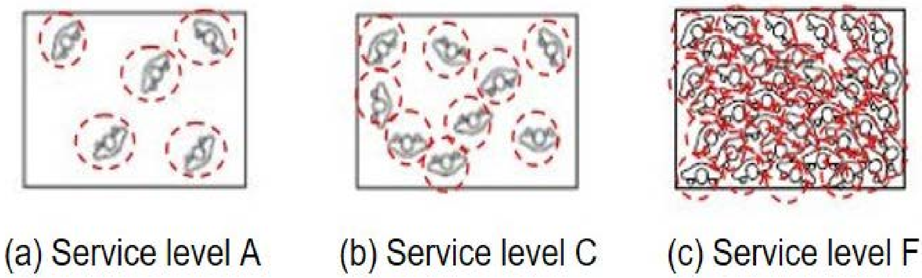
According to Delabrida (2004), privacy refers to control over other people’s access to individuals and to their group in circulation routes. The road context is comfortable for motor vehicle users in comparison to that of cyclists. Besides providing greater safety to drivers, vehicle’s inner environment keeps them more comfortable.

The density:crowding ratio affects individuals’ displacement by cycling, since the number of vehicles can significantly increase at specific times and it can cause traffic jams.

Sockza (2005) described traffic jams as stressful situations. According to the aforementioned author, stress is a psychological dimension observed in urban daily life, since 80% of drivers who experienced traffic jams reported to act in an aggressive, anxious and irritated manner. Road overdensity reduces the space available for individuals to move and reach their destination.

Paiva (2013) has associated the service level in the HCM manual (2000) with spatial behavior categories. The HCM manual (2000) addresses drivers' comfort and convenience against vehicle speed, impedances during changes between lanes, and distance between vehicles on the lanes. The Service Level (NS) of a given road ranges from "A" to "F". Level "A" corresponds to non-obstructed lane; it means that drivers can reach its limit speed. SL decreases, as the traffic volume increases, until it reaches its saturation level "F". Figure 2 represents the personal space occupied by individuals as pedestrians and the regulation of distances maintained between users on the analyzed road – the overlapping lines represent the invasion of individuals' personal space.

Figure 2 – Representation of personal space occupied by pedestrians.



Source: TRB (2000) adapted apud Paiva (2013).

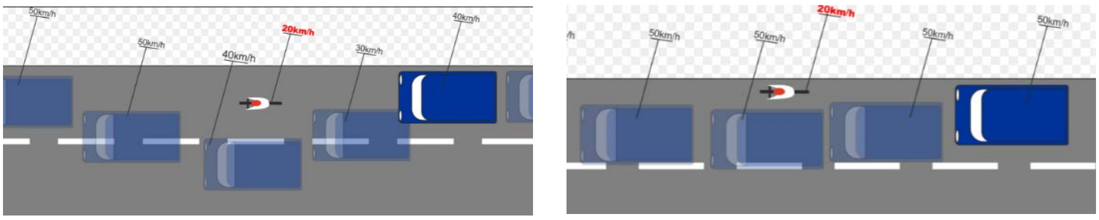
Figure 3 shows the personal space of motor vehicles in a similar way as the personal space of pedestrians presented by Paiva (2013).

Figure 3 – Representation of personal space occupied by pedestrians.

Source: TRB (2000) adapted apud Paiva (2013).

Environments presenting large crowds (SL = “F”) can be seen as stressful. Such an association is also established with regards to bicycle users, since this vehicle type exposes users to the risk of suffering with the impact of collisions (see Figure 4). Another relevant factor lies on vehicle speed and on its aerodynamic force, which can affect bicycle users, influence the feeling of having their personal space invaded and lead to users’ crowding.

Figure 4 – Representation of cyclists’ personal space in densification context.



Source: Paiva (2013).

Based on the premises presented above, Paiva (2013) has summarized the factors interfering in individuals’ conduct by taking into consideration four spatial behavior categories, as shown in Table 3.

Table 3 – Factors influencing spatial behavior categories.

Categories	Influenced by
Privacy (Control over other people’s access to cyclists)	Human interest in interacting with other people, gender, personality, individuals’ personal conditions and standards established by society.
Density - Crowding (Number of individuals in a given environment)	Number of individuals in a given environment, cultural aspects, gender, proximity to strangers, stress and motivation making cyclists leave a given location depending on the number of individuals in a given environment.
Territoriality (Cyclists’ attitudes aimed at defining the physical space and organizing interactions)	Sense of ownership and exclusive use, status/power, cultural aspects and difficulty in controlling spaces.
Space apprehension (Ability to bring legibility and imaginability to the space)	Sense of ownership and exclusive use, status/power, cultural aspects and difficulty in controlling spaces.

Source: Paiva (2013).

Developing the Road Condition Index (RCI) to Assess the Quality of Cycling Systems

This section shows the developed Road Condition Index (RCI), based on the following stages:

- Stage I: Selecting indicators
- Stage II: Quantifying indicators
    - Ranking and measuring indicators
    - Selecting interviewees
    - Applying the matrix to respondents
    - Defining evaluation indices
- Stage III: Defining the tool to evaluate the Road Condition Index (RCI)

Stage I: Selecting indicators

The first stage focused on selecting indicators among the referential ones presented in the theoretical framework of the current study. It was done based on measurements validated by cyclists, and by professionals working in the technical field, as presented by the Analytic Hierarchy Process (AHP). Parameters for each item were established at different value scales. It was done by respecting the weight of each reference, based on the Environmental Psychology approach (GUNTHER, 2003) and on the geometric parameters set for bikeways.

It is worth emphasizing the study by Monteiro and Campos (2011), who synthesized variables presented by Service Level analysis methods. Hamer and Almeida (2016) added cyclists' spatial behavior categories investigated by Environmental Psychology to these criteria. (Table 4).

Gunther (2003) stated that mobility, seen as behavior, provides access to affordances in different physical spaces covered by individuals. Based on it, Hamer and Almeida (2016c) presented indicators for cyclists' spaces based on the "safety" interface of bicycle users, as shown in Table 5.

Table 4 - Service Level Assessments and Environmental Psychology Criteria.

Methodology (Aim)	Variables	Privacy		Territoriality
		Personal Space	Crowding	
Epperson (1994) and Davis (1987)	Traffic volume/daily average		x	
Safety indices	Number of lanes		x	
	Speed limit	x		
	Pavement conditions	x		
	Fat. Localiz. Estac . slope and intersections			x
Sorton and Wash (1994)	Traffic volume	x		
Stress level, rush hour	Motor vehicle speed		X	
	Road width		x	
Dixon (1996)	Infrastructure			x
Assessing cyclists' accommodation in arterial and collector roads	Conflicts/parking - insertions			x
	Speed difference among vehicles		x	
	SL of motor vehicles/signaling			x
	Road maintenance	x		
	Specific programs best cycling transport			x
Landis et al (1997)	Mean daily traffic volume		x	
Assessing the bicycle service level from cyclists' viewpoint	Number of lanes Speed limit	x	x	
	Rate of heavy vehicles		x	
	Number of non-controlled vehicle accesses			x
	Pavement condition	x		
HCM (TRB, 2000)	Traffic flow/volume		x	
Assessing capacity and SL based on cycling infrastructure	Speed	x		
	Speed difference Bicycle x motor vehicle	x		

Source: Monteiro and Campos (2011) adapted by Hamer and Almeida (2016).

Table 5 - Propositions of variables for cyclists' space analysis.

Indicators	Variables
	Personal space and crowding
Perception about security / mobility	Incidence of heavy vehicles
	Incidence of bikeway or cycling lane
	Volume of vehicles/cyclists
	Road flow speed
	Bikeway or road width
	Intersections and crossings
	"Safe" distance from motor vehicles
Perception about security / location	Territoriality
	Area occupation density
	Land use (trade, leisure, work) Public security
Road safety / comfort	Bicycle infrastructure
	Terrain unevenness
	Visibility on the route and in intersections
	Pavement evenness
	Parking lot and insertions
	Signaling, afforestation, lighting

Source: Hamer and Almeida (2016c).

Thus, 8 indicators were defined to form the Road Condition Index (ICV), namely: road width, speed, topography, conflicts (parking lots, intersections lacking signaling), vehicle flow, amenities, paving (quality) and land use.

Measuring Indicators for Road Condition Index Preparation Purposes

This stage comprised the following activities: ranking and measuring indicators, selecting interviewees, applying the matrix to interviewees and defining evaluative indices; these activities are described below.

Ranking and Measuring Indicators

A survey with bicycle users and professionals working in the technical field was carried out to rank and measure evaluative road condition level indicators. The Analytic Hierarchy Process (AHP) developed by Saaty (1991) was applied in this case.

AHP enables making simple qualitative and quantitative assessments, since it establishes hierarchical relationships by taking into consideration several elements to be analyzed and by judging them according to a specific scale of values. This scale is based on the principle that analysts' experience and perception can be measured in decision-making processes. This mathematical process aims at representing the human mind through successive peer comparisons among different elements forming the analysis structure (SOARES, 2006). According to Costa (2002), the method is based on three principles:

- Building Hierarchies: the problem is structured in hierarchical levels in order to help better understanding and evaluating it. Applying this methodology requires both criteria and alternatives structured in a hierarchical way. The first hierarchical level accounts for the overall purpose of the problem, whereas the second level corresponds to the criteria and the third one concerns the alternatives.

- Defining Priorities: it is based on humans' ability to perceive the association among observed things by comparing them based on the intensity of their preference for one element over the other, on an equal basis (pair to pair), in order to compose a judgment matrix based on using the scales presented in the following numerical scale: 1 (equal importance), 3 (moderate importance), 5 (strong importance), 7 (very strong importance) and 9 (extreme importance) of one element over another. The number of judgments needed to build a generic judgment matrix A is n (n-1)/2, wherein n is the number of elements belonging to this matrix. The elements of A are defined based on the following conditions:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \cdots & 1 \end{bmatrix}, \text{ onde: } \quad \begin{array}{l} a_{ij} > 0 \Rightarrow \textit{positiva} \\ a_{ij} = 1 \therefore a_{ji} = 1 \\ a_{ij} = 1/a_{ji} \Rightarrow \textit{reciproca} \\ a_{ik} = a_{ij} \cdot a_{jk} \Rightarrow \textit{consistência} \end{array}$$

It is done to standardize judgment matrices, as well as to calculate average and global priorities.

- Logical consistency: it consists in establishing relationships in a coherent way, so they relate well to each other and show consistency (SAATY, 2001). Thus, AHP is used to calculate the Consistency Ratio of judgments, which is denoted by CR = CI/RI, wherein RI is the Random Consistency Index obtained for a reciprocal order-n matrix, which presents non-negative elements and is randomly generated. Consistency Index (CI) is denoted by CI = (λmax –n)/(n-1), wherein λmax is the highest judgment matrix eigenvalue. According to Saaty (2001), the consistency condition of judgments is CR ≤ 0.10. Values higher than this one indicate failure in peer review or problem structuring (TREVIZANO and FREITAS, 2005).

Selecting Interviewees

According to Saaty (1991), the decision-making process suggested by AHP is carried out by decision makers and decision analysts; there are not specific aspects within AHP.

Road interventions were carried out by experts in the technical field of transport, since the current research aims at understanding the urban road environment conditions perceived by cyclists during their commuting trips, as well as their relationship with the built environment. Thus, the current sample comprised 10 respondents among cyclists and experts.

Six (6) cyclists were selected to be interviewed to help identifying the time spent on the bicycle. Participation was voluntary, and it aimed at finding different behavioral parameters, which were separated into two groups: individuals who used the bicycle for regular trips for more, or lesser, than three years.

The selection of the four (4) professionals to be interviewed was based on the criterion “homogeneity in the training of transport experts (master’s and doctorate degree) who lived, and/or worked in the transport sector, in the investigated area - i.e., Goiânia City.

Applying the Matrix to Interviewees

Interviewees were introduced to definitions and concepts, as well as instructed on how to complete the matrix, before its application. The matrix content was previously sent by e-mail to interviewees, but it was only completed throughout the interview.

The proposed indicators were based on item 3.1, namely: road width, speed, topography, conflicts, amenities, paving and land use. Thus, the average priorities of each interviewer were found, and their matrix inconsistency degree < 0.1 was validated.

Defining Evaluative Indices

It was necessary tabulating all respondents' answers about the eight analyzed indicators, along with the consistency index (CI) of each questionnaire, in order to define the evaluative indices. Thus, the arithmetic mean of the assessed indicators was calculated by measuring the criteria adopted to elaborate the Road Condition Index.

Defining the RCI Assessment Tool

Criteria used by Dixon (1996) to investigate Service Level (see item 2.2) were adapted to help defining the tool used to evaluate highly demanded segments. As previously presented in Stage I, eight indicators were defined in the current case to compose the RCI, namely:

I. Lane width: its aim is to assess cyclists' safety and comfort in relation to the distance from motor vehicles, as well as to the width of traffic lanes, based on measurements taken in the field or in the GIS software. The survey conducted to find the roads' dimension has considered the total width/number of lanes in the investigated sites as the effective road width. Table 6 presents the first parameters used to indicate the road system to be used, based on the road hierarchy and mean speed of the road presented by Brasil (2007) and CBT (1997).

Table 6 - Variables suggested for space analysis focused on cyclists.

Routes and sections in cities	Degree of restriction in the use of bikeways	Recommendations for using bicycles	Maximum speed according to CTB
Expressway (1st category)	Total	Side bikeway	>100km/h
Expressway (2nd and 3rd categories)	Total	Side bikeway	80km/h
Arterial road (1st and 2nd categories)	Partial	Bike lane	60km/h
Tunnels	Total	Side bikeway	Varying
Viaducts, bridges and elevated highways	Partial	Bikeway or bike lane (segregation)	Varying
Collector road	Partial	Bikeways, bike lanes or shared traffic	40km/h
Local road	Partial	Bikeways, bike lanes or shared traffic	30km/h

Adapted source: Brasil (2007) and Brasil (1997).

Thus, one can analyze the reference width set for each cycling system type to be implemented, based on the comparative analysis among AASHTO (1999), Geipot (2001), Brasil (2007) and Sustrans' (2014) manuals.

The most favorable minimum effective width in the lane next to the curb must be at least 4.20 m for shared lanes, based on DNIT (2010). According to TRB (2010), urban roads present acceptable width of 3.00 m.

Another infrastructure type (bikeway or bike lane) can be adopted when the road is wider than 4.20 m. According to parameters adopted in the Netherlands and in France, the minimum width adopted for bike lanes is 1.80 m, whereas that of bikeways is 2.0 m (BRASIL, 2007).

Thus, it is possible establishing the minimum effective width for each infrastructure type: shared lane (4.20 m), bike lane (4.80 m) and bikeway (5.00 m). Therefore, crowding contexts, which increase the risk of accidents due to insufficient road width, recorded similar values.

II. Speed: it was calculated based on the difference between cyclist's mean speed - i.e., 15km/h (BRASIL, 2007) - and the maximum speed allowed for motor vehicles. The greater the difference between vehicles and cyclists' speed, the higher the risk of accident (DIXON, 1996; SUSTRAN, 2014) due to lack of local indication (plate). Data presented by DNIT (2010) were herein used as reference.

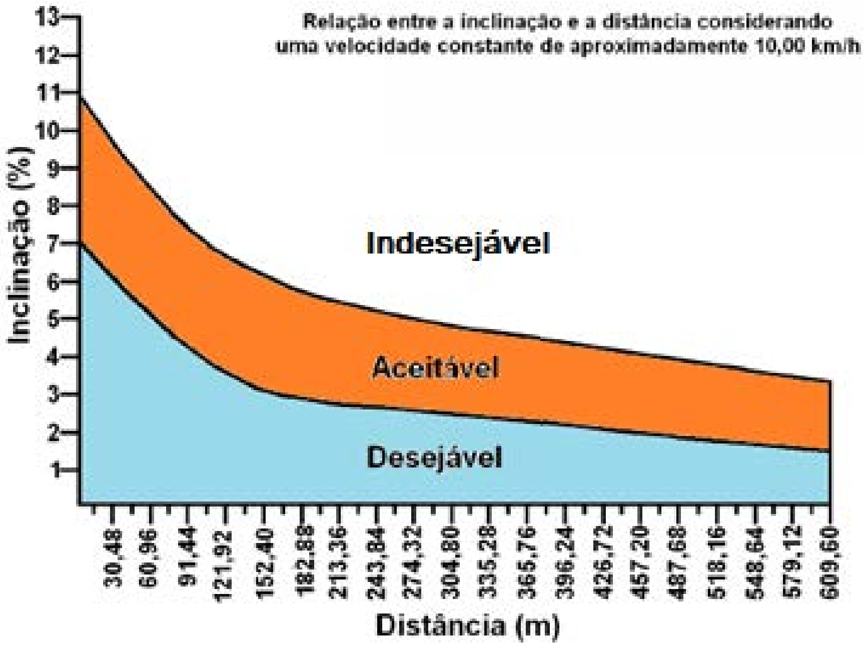
III. Paving: this factor checks the road surface maintenance conditions by including construction problems that lead to maintenance issues such as potholes and cracks. It does not include network maintenance issues (road operators) or temporary accumulation of materials, such as leaves, among others.

IV. Service level for vehicles/vehicle flow: Service Level for motor vehicles affects bicycles' Service Level, since the volume of motor vehicles and traffic jams caused by them affect the comfort and safety of cyclists traveling along a given road. Based on the model, the incidence of a large number of traffic lanes discourages cyclists, regardless of the road's SL. Therefore, the current study adopted low flow reference for roads with one lane; medium flow, for roads with two lanes; and high flow, for roads with more than three lanes.

V. Amenities: this item evaluates afforestation incidence in order to mitigate the heat and to provide greater thermal comfort. In addition, the lighting in the evaluated site was checked to find out whether it provides safety to cyclists, or not.

VI. Topography: this factor helps measuring the effect of steep slopes along the roads on cyclists. The suggested parameters always relate slope to the ramp's length. Topography was categorized into three criteria: desirable, acceptable and undesirable (Figure 5) - which were introduced by the American Manual titled The ABCD's of Bikeways (USA, 1979) – by taking into consideration the structure at the site.

Figure 5 - Road slope / maximum distance ratio.



Source: USA Manual (1979).

Therefore, whenever it is not possible smoothing the road profile in a given project, it is recommended looking for alternative routes or smoothing the uphill movement by implementing intermediate plateaus for resting purposes (GEIPOT, 2001). The most favorable score must be taken into consideration for downhill contexts.

VII. Signaling: the presence of both vertical and horizontal signaling is essential to prevent accidents. Places presenting vertical and horizontal signaling recorded maximum score, whereas places lacking both signaling types recorded low score.

VIII. Conflict: this variable assesses the ease of sight between cyclists and drivers in order to avoid accidents in the following contexts:

a) Lack of parking space on the side of the road: it may discourage cyclists from using this lane, since door opening and people getting out of vehicles can create safety issues.

b) Lack of entrance to garages and intersections: turns to garages, and intersections in roads lacking traffic lights, can pose risks to cyclists. According to the criterion established by Dixon (1996), the entire segment of roads presenting more than 22 entrances or intersections per 1.6 km is not scored.

c) Lack of barriers: physical or operational elements (drainage elements, bus stops, intersections with large number of turns to the right) are barriers to cyclists, who are forced to invade the road or sidewalks in some specific section.

In order to enable the efficient evaluation of routes, one must divide the assessed segments into as many sections as necessary, based on the homogeneity of physical features, such as road width, topography, morphology and speed. Variables used to assess RCI are shown in Table 7.

Table 7– Variables used to assess the Road Condition Index.

Variables/indicators	Criteria	Reference values	Weight
Minimum effective width	Shared roads	<4.20 ≥4.20	0 1
	Bike lanes	<4.80 ≥4.80	0 1
	Bikeways	<5.00 ≥5.00	0 1
Speed difference between motor vehicles and bicycles	≥48km/h 32 to 48km/h 24 to 32km/h (Dixon, 1996)		0.5 1
Conflicts	Lack of parking space on the side of the road Lack of garage entrances and intersections Lack of barriers		0.33 0.33 0.33
Road maintenance	Serious or frequent issues Mild or occasional issues No issue		0 0.5 1
Vehicle flow	High flow - more than 3 traffic lanes Medium flow - from 2 to 3 traffic lanes Low flow - 1 traffic lane		0 1 0.5
Amenities	Lighting Afforestation – natural shading during part of the day		0.5 0.5
Topography (Uphill)	Undesirable Acceptable Desirable		0 0.5 1
Signaling	Nonexistent Existing (vertical and/or horizontal)		0 1
Total value (categories) Segment index = sum of scores in all eight categories Segment weight = segment length/lane length Adjusted segment index = segment index x segment weight Index of sections = sum of adjusted indices of segments in sections			1.00

Source: The authors (2020).

Each analyzed segment receives a score that can reach up to 1.0 point; this score corresponds to segments that mostly need, and present the best conditions for, improvements. The standardization process analogous to the one proposed by Eastman and Jiang (2010), according to whom segments are classified as A, B or C, should be adopted in these cases. Based on this scale, the segment is in poor condition if the index value calculated for it ranges from 0 to 0.33; it is in good condition if the value ranges from 0.33 to 0.67,; and the segment is in very good condition if the value is higher than 0.68 (see Table 8).

Table 8 – Classification of road segments.

Index	Classification	Segment features
0 to 0.33	C – poor condition	Bad segment, not recommended, section needing major interventions or modifications.
0.34 to 0.67	B – good condition	Good segment, recommended for use within the cycling system, interventions can be carried out based on indicators presenting low evaluation results.
0.68 to 1.00	A – very good condition	Very good segment, requiring little or no intervention in segments presenting low results.

Source: The authors (2020).

Conclusion

The urban mobility policy in place in most Brazilian cities was guided by, and towards, individual motorized transport. However, this model already shows signs of exhaustion due to constant traffic jams and issues faced by these cities. Urban issues caused by transport planning processes prioritizing the use of motor vehicles over other means of transportation have indicated that bicycles are a viable and sustainable alternative for urban transport in Brazilian cities. However, most of the Brazilian bicycle fleet does not circulate, mainly due to lack of safety to cyclists in these cities and of public policies aimed at this transport type.

Thus, the current study has developed a tool capable of contributing to cycling systems' planning and evaluation. It was done to enable effective actions focused on promoting the use of bicycles, without burdening public authorities. Moreover, these actions are attractive to bicycle users, since they integrate technical requirements for cycling systems' implementation to users' behavioral perspective based on the Environmental Psychology. Thus, an easy-to-apply index was herein developed; it encompasses indicators capable of helping decision-making processes, as well as enables identifying the most efficient route or section to make cycling infrastructure implementation easier.

It is worth emphasizing that the herein adopted indicators were selected based on parameters and criteria adopted for methods used to evaluate the service levels of different bikeways (behavioral focus), as well as on the association among Environmental Psychology criteria presented by Hamer and Almeida (2016b). Eight criteria prevailed and they were integrated to the Road Condition Index (RCI) analysis (Table 6).

According to Delabrida (2004), the transport and mobility phenomenon results from the sum of individuals' behaviors in urban contexts; however, this topic remains poorly explored by Psychology, which acknowledges its multidisciplinary nature. The interdisciplinarity path taken in the current research helped better understanding the dynamics set between individuals and physical environments. Thus, it helped better understanding individuals' relationship with means of transportation, as well as the dynamics established in such a relationship. Such an understanding provided a new perspective about the urban environment, based on the search for more attractive environments.

Future studies about the herein investigated topic should:

- Analyze the influence of the number of working and/or study places on areas of influence;

- Identify socioeconomic features to define efficient land use patterns for bikeway implementation purposes;
- Apply the Analytic Hierarchy Process in other cities, where other indicators and priorities can be identified.

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