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The use of the bicycle compatibility index in identifying gaps and deficiencies in bicycle networks

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Abstract. Currently, no methodology is widely accepted by engineers, planners, or bicycle coordinators that allow them to determine how compatible a roadway is in providing efficient operation of both bicycles and motor vehicles. Previous studies reported a number of approaches to obtain an appropriate level of service; some authors developed the bicycle level of service (BLOS) and other authors developed the bicycle compatibility indexes (BCI). The level of service (BLOS) for a bicycle route represents an evaluation of safety and commodity perceived by a bicyclist reported to the motorized traffic, while running on the road surface. The bicycle compatibility index (BCI) is used by bicycle coordinators, transportation planners, traffic engineers to evaluate the capability of specific roadways to accommodate both motorists and bicyclists and to plan for and design roadways that are bicycle compatible. After applying BCI and BLOS models for the designed bicycle infrastructure network in the city of Dej, one can see that only few streets are Moderately Low compatible compared to the others with a high degree of compatibility that recommends to include them in the bicycle infrastructure network.

1. Introduction

A sustainable transport system must provide mobility and access to all urban inhabitants, offering a safe, cozy and comfortable transport. Achieving this goal is difficult because the transport demand is generated by social groups that are not only different but often have conflicting interests. The same road space is claimed by motorists, public transport and non-motorized users [1].

Despite the advantages offered by non-motorized travels by bicycle in local perception, they are often undervalued, considered to be unsophisticated compared to motorized travels, being viewed as a symbol of impoverishment, as a ludic element or aimed at those with adequate physical condition. Non-motorized travels contribute to social harmonization and integration, mitigate inequalities and disparities (between drivers and pedestrians, expensive and cheap vehicle keepers, driver and passenger etc.), facilitate the mobility of the socially disadvantaged and promote people contact, interaction and social inclusion, dialogue and human relationships in a greater way than the travels by car [2]. If one analyses the transport modes from ecological point of view (pollution, risk of accidents, energy and space consumption), without requiring a calculation of the economic impact of the different transport modes' advantages or disadvantages, it is reasonable to pay attention to bicycle travels and to provide them financing as they deserve [3],[4].

The evolution of the last years' studies in relation to awareness of the role the sustainable mobility plays in increasing the residents' quality of life in urban areas led to the need for implementing



Sustainable Urban Mobility Plans. Also, their development is necessary because, on European Union's demand, the existing of a Sustainable Urban Mobility Plan becomes mandatory for local governments wishing to access European funds in Transport. A Sustainable Urban Mobility Plan is consonant with the investigation of European experience and with the research in mobility integrated field that fundaments a new model of practice and institutional, legislative and regulatory reformulations, technological innovations, creating new regulatory and planning instruments in all areas involved in managing mobility: urbanism and urban planning, transport, traffic, economy, sociology, ecology etc., according to European standards that were not implemented until now.

The Bicycle Level of Service (BLOS) for a route is an evaluation of comfort and safety perceived by a bicyclist regarding the motorized traffic while he runs on a roadway corridor. He identifies the quality of service on the roadway. Previous studies showed a series of approaches to obtain this level of service; some developed the Bicycle Level of Service (BLOS) and some the Bicycle Compatibility Index (BCI).

In the frame of the Sustainable Urban Mobility Plan for the city of Dej elaboration we analyzed the properties of the bicycle network. Severe constrains were given in the planning of the bicycle network due the geometric characteristics of the road infrastructure and the existing built environment. Consequently, the length, the density and the connectivity of the bicycle network are very low. In this paper we present a model based on Bicycle Compatibility Index (BCI) and Bicycle Level of Service (BLOS) developed to evaluate the gaps and deficiencies in bicycle network designed for city of Dej.

Previous studies showed a series of approaches to obtain the quality of service on the roadway for bicycle facilities; some developed the Bicycle Level of Service (BLOS) and some the Bicycle Compatibility Index (BCI) [5], [6]. Both measures offer an evaluation of comfort and safety perceived by a bicyclist regarding the motorized traffic while he runs on a roadway corridor.

The Bicycle Compatibility Index (BCI) and The Bicycle Level of Service (BLOS) can be applied to all categories of roads and contain those variables that the bicyclists regularly use.

BCI and BLOS have been used in various applications:

- Evaluating the "friendship" between the roadway and the bicycle;
- Assisting the bicyclists in selecting a direct and safe travel route;
- Identifying the gaps and deficiencies in a designed bicycle network.

2. The Bicycle Compatibility Index and The Level of Service of a bicycle route

The BCI model was developed to evaluate safety and comfort in bicycle travels, perceived by the user, taking into consideration the traffic on the road. It has been applied to plan the modernization of road infrastructure, ensuring the un-motorized trips in many American cities from States as Florida, New York, Maryland, Virginia and Delaware etc.

There are six BLOS, from A to F, that are determined taking into consideration the following indicators: daily traffic volume, number of lanes, vehicles' speed limit, number of freight vehicles, type of the running surface and average width of cross section. The last levels indicate the need of constructing new infrastructures dedicated to bicycles [7].

The Bicycle Compatibility Index (BCI) was first developed by Road Safety Research Center from North Carolina University for Federal Road Research Administration. BCI is promoted as a procedure to evaluate the "bicycle compatibility" with the road. The main variables like bandwidth, traffic volume and travel speed in addition to the secondary variables are introduced in an equation to obtain a number that is evaluated on a linear scale to determine the compatibility of the bicycle with the road from A (the best compatibility level) to F (the worst compatibility level).

The disadvantage of this approach is that the intersections and discontinuous routes are not taken into consideration. The level of compatibility for a bicyclist varies from Very High to Very Low. In table 1 there are presented the values of BCI associated to LOS [6].

The BCI reflects the comfort level of a bicyclist on the basis of observed road geometrics, surrounding land use and operational characteristics of roadways. From the table 1, it is clear that the lower the BCI value the greater will be the level of comfort a bicyclist experiences. LOS A

(represented by an index $\leq 1,50$) indicates that a roadway is extremely compatible (or comfortable) for the average adult bicyclist while LOS F (represented by an index $> 5,30$) is an indicator that the roadway is extremely incompatible (or uncomfortable) for the average adult bicyclist.

Table 1. Bicycle Compatibility Index (BCI) ranges associated with level of service (LOS) designations and compatibility level qualifiers [6]

LOS	BCI range	Compatibility Level
A	$\leq 1,50$	Extremely High
B	1,51-2,30	Very High
C	2,31 – 3,40	Moderately High
D	3,41 – 4,40	Moderately Low
E	4,41 – 5,30	Very Low
F	$>5,30$	Extremely Low

This model predicts the overall comfort level rating of a bicyclist using eight significant variables and an adjustment factor (AF) to account for three additional operational characteristics. The variable with the largest effect on the index is the presence or absence of a bicycle lane or paved shoulder (BL); the presence of a bicycle lane (paved shoulder) that is at least 0.9 m wide reduces the index by almost a full point, indicating an increased level of comfort for the bicyclist. Increasing the width of the bicycle lane or paved shoulder (BLW) or the curb lane (CLW) also reduces the index as does the presence of residential development along the roadside (AREA). On the other hand, an increase in traffic volume (CLV and OLV) or motor vehicle speeds (SPD) increases the index, indicating a lower level of comfort for the bicyclist. The presence of on-street parking (PKG) also increases the index [6].

The other three variables with a potential impact on the comfort level of bicyclists are influenced by the percentage of large trucks or buses, vehicles turning right into driveways, and vehicles pulling into or out of on-street parking spaces.

To determine these variables one must know the following entry data [8],[9]: number of lanes, lane widths, curb lane width or width of the motor vehicle travel lane closest to the curb, bicycle lane (paved shoulder) width, land use adjacent to the roadway, motor vehicle speed, hourly traffic volume by lane in one direction of travel, large truck volume, presence and density of on-street parking, parking lane and percentage of parking occupancy, parking time limits and percentage of right turning traffic.

Thus, the equation used to determine BCI, presented in Eq. 1, is based on Ravadá model [10]. To develop BCI there were selected eight independent variables linked to bicyclists' levels of comfort and three variables considered to be adjustment factors.

$$BCI = 3,67 - 0,966BL - 0,410BLW - 0,498CLW + 0,002CLV + 0,0004OLV + 0,22SPD + 0,506PKG - 0,264AREA + AF \quad (1)$$

Where:

BL represents the presence of a bicycle lane or paved shoulder > 0.9 metres (No = 0, Yes = 1)

BLW - bicycle lane width [m]

CLW - curb lane width [m]

CLV - curb lane volume – vehicles per hour in one direction [veh/h]

OLV - other lane(s) volume same direction [veh/h]

SPD - 85th percentile speed [km/h]

PKG - presence of parking lane with more than 30% occupancy (No = 0, Yes = 1)

AREA - type of roadside development (Non-residential = 0, Residential = 1)

AF - adjustment factor, $AF = Ft + Fp + Fr$

Ft - adjustment factor for truck volume (ranges from 0 to 0.5)

The suggested routes cover about 18 km of bicycle lanes located on the following streets: 1 Mai Street, Mărășești Street, 22 Decembrie 1989 Street, Bobâlna Street, Nicolae Titulescu Street, Șomcutului Street, Avram Iancu Street, Ecaterina Teodoroiu Street, Crângului Street, Nichita Stănescu Street (Figure 2).



Figure 2. Road network dedicated to bicycle use for the city of Dej

For the ten streets one applies the BCI model to identify the deficiencies and the gaps in bicycle infrastructure network for Dej city. In order to obtain the necessary attributes for BCI and BLOS computation [6],[8],[9], [10], we used GIS procedures (see Figure 3).

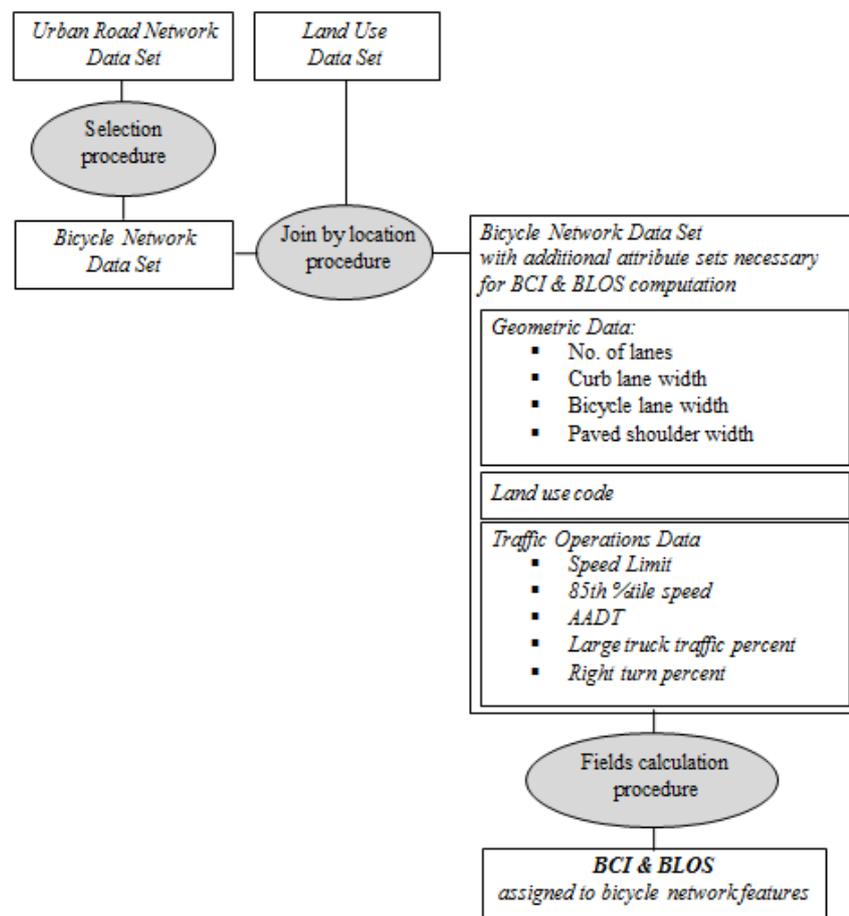


Figure 3. Flow diagram of BCI and BLOS data preparation process

The resulted attributes for the selected streets witch are proposed for bicycle network are summarized in table 2 and table 3.

Table 2. Geometric and roadside attributes for streets witch are proposed for bicycle network in city of Dej ([11], [12])

Feature		Geometric and Roadside Data				
FID	Name	No. of Lanes (one direction)	Curb lane Width [m]	Bicycle Lane Width [m]	Paved Shoulder Width [m]	Residential Area [y/n]
1	Nicolae Titulescu Street	1	3,5	1	0	y
2	Şomcutului Street	1	3,5	1	0	y
3	Nichita Stănescu Street	1	3	0	0	y
4	Crângului Street	1	4	0	0	y
5	Mărăşeşti Street	1	5	0	0	y
6	Bobâlna Street	1	3	0	0	y
7	1 Mai Street	2	3,5	0	0	y
8	Ecaterina Teodoroiu Street	1	5	0	0	y
9	Avram Iancu Street	2	3,5	0	0	y
10	22 Decembrie 1989 Street	2	3,5	0	0	y

Table 3. Traffic operations and parking attributes for streets witch are proposed for bicycle network in city of Dej (source: [11, 12])

Feature		Traffic Operations Data					Parking Data		
FID	Name	Speed Limit [km/h]	85 th %tile Speed [km/h]	AADT [veh/day]	Large Truck (HV) [%]	Right Turn (R) [%]	Parking Lane [y/n]	Occup. [%]	Time Limit [min]
1	Nicolae Titulescu Street	50	60	1993	0,015	0,1	n	0	0
2	Şomcutului Street	50	60	2700	0,015	0,1	n	0	0
3	Nichita Stănescu Street	40	50	2560	0	0,1	n	0	0
4	Crângului Street	50	60	10019	0.020	0,1	n	0	0
5	Mărăşeşti Street	40	50	2736	0	0,1	n	0	0
6	Bobâlna Street	30	40	1853	0	0	n	0	0
7	1Mai Street	40	50	5770	0,020	0,1	n	0	0

8	Ecaterina Teodoroiu Street	40	50	11591	0,020	0,1	y	0,30	0
9	Avram Iancu Street	40	50	13705	0,020	0,1	n	0	0
10	22 Decembrie 1989 Street	50	60	7783	0,020	0,1	y	0,30	0

After applying the BCI model for every street from the designed bicycle infrastructure network in the city of Dej using data from table 2 and 3 and Eq.1, the BCI values, the level of service and the bicycle compatibility level can be seen in table 4 and figure 4 which shows the bicycle compatible level for each link based on BCI and BLOS scores.

Table 4. The bicycle compatibility level for the designed bicycle infrastructure network ([6], [8], [9], [10], [11], [12])

Street	BCI	Level of service	Bicycle Compatibility Level
Nicolae Titulescu Street	1,83	B	Very High
Șomcutului Street	1,90	B	Very High
Nichita Stănescu Street	3,29	C	Moderately High
Crângului Street	2,46	C	Moderately High
Mărășești Street	2,32	C	Moderately High
Bobâlna Street	3,00	C	Moderately High
1 Mai Street	3,14	C	Moderately High
Ecaterina Teodoroiu Street	3,90	D	Moderately Low
Avram Iancu Street	3,77	D	Moderately Low
22 Decembrie 1989 Street	4,00	D	Moderately Low

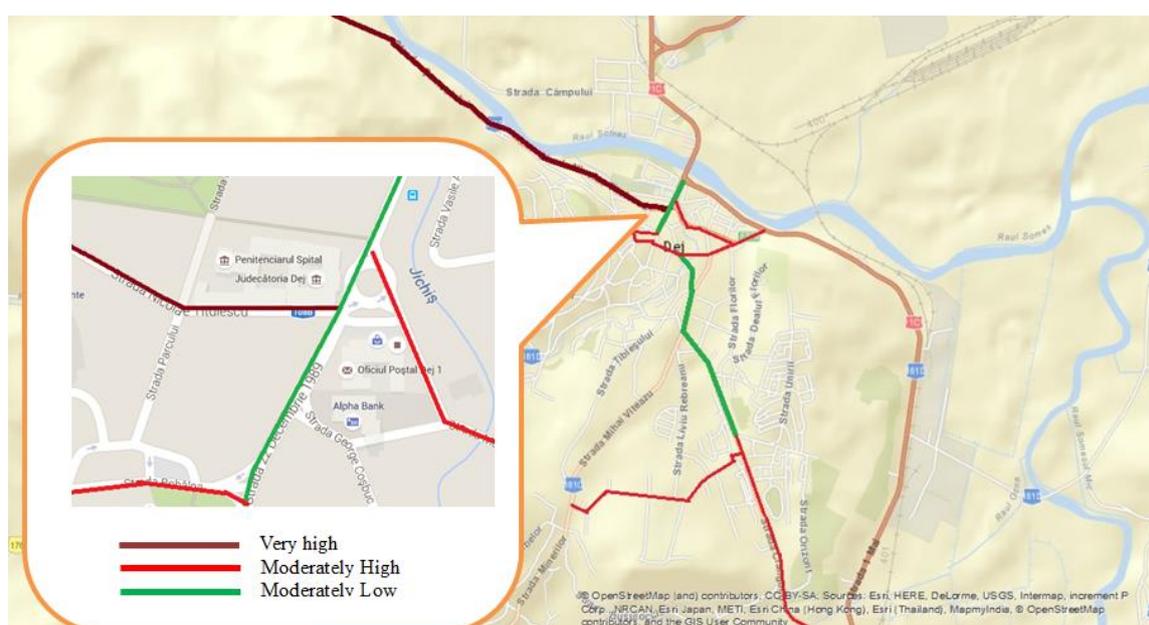


Figure 4. Bicycle Compatibility Level with the streets from the designed bicycle infrastructure network in the city of Dej

4. Conclusions

BCI and BLOS are useful indicators in measuring the appropriateness of roadways for bicycle travel. After applying BCI and BLOS models for the designed bicycle infrastructure network in the city of Dej, one can see that only three streets are Moderately Low compatible compared to the other seven that have a high degree of compatibility that recommends including them in the bicycle infrastructure network.

Ecaterina Teodoroiu Street, 22 Decembrie 1989 Street și Avram Iancu Street have a level of service D which means that the bicyclist will not enjoy a high comfort on these, thus being considered as deficiencies of the bicycle infrastructure network. Therefore, if the bicycle lanes can't be placed on these streets, they will be placed on the asphalted sidewalks that have a width of approximately 3.50 meters and can support both the pedestrians and the bicyclists.

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