Development of the Bicycle Compatibility Index

DAVID L. HARKEY, DONALD W. REINFURT, AND MATTHEW KNUIMAN

Presently, there is no methodology that is widely accepted by engineers, planners, or bicycle coordinators that will allow them to determine how compatible a roadway is for allowing efficient operation of both bicycles and motor vehicles. Determining how existing traffic operations and geometric conditions affect a bicyclist's decision to use or not use a specific roadway is the first step in determining the bicycle compatibility of the roadway. The Federal Highway Administration sponsored a study in which a methodology for deriving a bicycle compatibility index was developed. This tool can be used by bicycle coordinators, transportation planners, traffic engineers, and others to evaluate the capability of specific roadways to accommodate both motorists and bicyclists. It is intended to provide practitioners with the ability to assess the bicycle level of service present on existing facilities or on proposed facilities and can be used for operational, design, and planning analyses.

The goals of the U.S. Department of Transportation as stated in *The National Bicycling and Walking Study* are (*a*) to double the number of trips made by bicycling and walking and (*b*) to simultaneously reduce by 10 percent the number of pedestrians and bicyclists killed or injured in traffic crashes (*1*). Meeting the first of these goals will require a substantial increase in the number of trips made by bicyclists using on-road or shared facilities. This increased exposure could, in turn, jeopardize the second goal of improved safety unless careful consideration is given to the needs of both bicyclists and motor vehicle operators in the enhancement of existing roadways or development of new roadways. To develop or improve roadways for shared use by these two modes of transportation, one must begin by evaluating existing roadways and determining what is considered *user-friendly* from the perspective of the bicyclist. Presently, there is no methodology that is *widely accepted* by engineers, planners, or bicycle coordinators that will allow them to determine how compatible a roadway is for allowing efficient operation of both bicycles and motor vehicles. Determining how existing traffic operations and geometric conditions affect a bicyclist's decision to use or not use a specific roadway is the first step in determining the bicycle compatibility of the roadway.

In recent years, several studies have been undertaken to develop some systematic means of measuring the operational condition of roadways for bicycling. These efforts have included the development of models based on the geometrics of roadway segments and intersections, pavement conditions, traffic volumes, speed limits, and other variables. Each of these models produces an index that can be compared with a subjectively developed rating scale to assess the specific roadway segment or intersection (*2–4*). Another effort developed a series of recommended lane, shoulder, and bike lane widths that are subjectively assigned based on traffic volumes, motor vehicle operating speeds, type of bicyclist, and other variables (*5*). The one missing element in each of these studies is the lack of recognition of the bicyclists' perspectives. After all, these are the individuals who will ultimately decide whether a roadway meets their personal comfort level for riding in the presence of motor vehicle traffic. The one exception to that is a study recently conducted in which bicyclists rode on a very limited number of routes and provided ratings to indicate their bicycling comfort levels (*6*).

D. L. Harkey and D. W. Reinfurt, Highway Safety Research Center, University of North Carolina, 730 Airport Road, Campus Box 3430, Chapel Hill, NC 27599-3430. M. Knuiman, Department of Public Health, University of Western Australia, M Brock, QEII Medical Centre, Nedlands, 6009, Western Australia.

BICYCLE STRESS LEVEL

In 1978, the Geelong Bikeplan Team in Australia understood the importance of the bicyclist's perspective and incorporated it into a concept known as the *bicycle stress level* to better define the bicycling suitability of roadways from the viewpoint of the bicyclist (*7*). This concept was developed, in part, on the assumption that bicyclists not only want to minimize the physical effort required when choosing a roadway on which to ride, but that they also want to minimize the mental effort, or *stress,* that results from conflict with motor vehicles, interaction with heavy vehicles, and having to concentrate for long periods of time while riding on high-volume and high-speed roadways.

The team members drew on their personal bicycling experience with specific roadways to quantitatively define the concept. The variables considered to have the most impact on the stress level of a bicyclist were curb lane width, motor vehicle speed, and traffic volume. For various combinations of these three variables, team members assigned values from one to five to reflect the amount of stress they experienced when riding under those conditions. A value of one indicated a very low level of stress, whereas a five indicated a very high level. Although the values developed are subjective (based on the experience of team members), it was the first attempt to use the perspective of the bicyclist to assess the compatibility of roadways for bicycling.

In 1994, Sorton and Walsh (*8*) used the *bicycle stress level* concept in an effort to relate bicyclists' perspectives on various types of roadways to specific geometric and traffic-operating conditions. Their project represented the first attempt to gather perspectives from people other than research team members; thus, the results were not based solely on the subjective interpretations of researchers. Employing segments of videotape from different street environments, three groups of bicyclists (experienced, casual, and youth) were asked to rate several urban and suburban roadway segments with varying degrees of traffic volume, motor vehicle speeds, and curb lane, shoulder, or bicycle lane widths. The ratings were to reflect the level of stress they would experience (i.e., how uncomfortable they would be) riding on a specific segment with respect to each of the variables noted above. The results from this effort showed that bicyclists can recognize differences in the levels of traffic volume, motor vehicle speed, and lane width, and that these differences are consistently reflected in their comfort or stress level.

BICYCLE LEVEL OF SERVICE

The *Highway Capacity Manual* (*9*) defines levels of service (LOS) as ". . . qualitative measures that characterize operational conditions within a traffic stream and their perception by motorists and passengers." The terms used in describing each LOS (designated as A through F, with LOS A being the most desirable) include *speed* and *travel time, freedom to maneuver, traffic interruptions,* and *comfort* and *convenience.*

The concept of LOS was introduced to qualify the operational characteristics associated with various levels of vehicles or people passing a given point during a specified time period. For this reason, LOS has, in reality, been a qualifier of conditions related to vehicle or person throughput rather than a qualifier of conditions related to individual comfort level. This fact is revealed by examining the measures of effectiveness (MOEs) used to define the ranges of LOS for various types of facilities. For freeways, the MOE is density (passenger cars/mile/hour); for signalized intersections, the MOE is average stopped delay (second/vehicle); and for arterials, the MOE is average travel speed (mph). Each of these MOEs is directly related to vehicle throughput.

For bicycles, LOS criteria are not defined in the *Highway Capacity Manual.* The discussion on bicycles is limited primarily to the impact of bicycles on motor vehicle LOS. If the implied definition of LOS (i.e., as related to vehicle throughput) is used, there are very few on-street facilities in the United States where LOS criteria would be needed simply because of the low bicycle volumes. However, the descriptive terms for LOS used in the written definition are applicable to bicycle transportation. For a bicyclist, the qualitative terms *comfort* and *convenience* and *freedom to maneuver* are critical factors with respect to determining their quality of service on a given facility.

Referring back to the definition for LOS, the user's perception of the operational conditions is an important element with respect to assigning an LOS designation to a facility. The *bicycle stress level* concept incorporates the perceptions of bicyclists to assess the bicycle compatibility of roadways on a five-point scale. In many ways, each point on the scale can be thought of as representing a different LOS for bicyclists. For example, a roadway with a very low stress level would be considered by bicyclists to offer a high degree of comfort, which would be represented by the LOS A designation.

In the current study, the bicycle compatibility index (BCI) reflects the comfort levels of bicyclists based on observed geometric and operational conditions of a variety of roadways. The correlation of these comfort levels with the conditions of the roadway in the development of the BCI model allows the user to determine bicycle LOS for roadway segments by incorporating these geometric and operational characteristics into the model.

OBJECTIVE AND SCOPE

The objective of the current study was to develop a methodology for deriving a bicycle compatibility index that could be used by bicycle coordinators, transportation planners, traffic engineers, and others to evaluate the capability of specific roadways to accommodate both motorists and bicyclists. The BCI methodology was developed for urban and suburban roadway segments (i.e., midblock locations that are exclusive of intersections) and incorporated those variables that bicyclists typically use to assess the "bicycle friendliness" of a roadway (e.g., curb lane width, traffic volume, and vehicle speeds).

This research effort expanded on the work of Sorton and Walsh (*8*) and the Geelong Bikeplan Team (*7*) to produce a practical instrument that can be used by practitioners to predict bicyclists' perceptions of a specific roadway environment and, ultimately, determine the level of bicycle compatibility that exists on roadways within their jurisdictions. The developed tool will allow practitioners to evaluate existing facilities to determine what improvements may be required, as well as to determine the geometric and operational requirements for new facilities to achieve the desired level of bicycle service.

DEVELOPMENT AND VALIDATION OF THE METHODOLOGY

The methodology used in obtaining the perspectives of bicyclists in this study consisted of having participants view numerous roadway segments captured on videotape and rate these segments with respect to how comfortable they would be riding there under the geometric and operational conditions shown. The advantages of using this video-based methodology included

- There were no risks to bicyclists. In other words, bicyclists did not need to ride in or be exposed to conditions that they would consider uncomfortable or unsafe. This fact allowed the inclusion of conditions, such as large trucks or buses on very narrow lanes, that could not be safely evaluated using on-the-road bicyclists.
- Specific variables could be presented to bicyclists in a controlled environment. For example, all subjects were exposed to the same exact number of vehicles (i.e., traffic volume) or to the same special conditions (i.e., right-turning traffic or heavy vehicles). This form of variable control is virtually impossible by having bicyclists actually ride on the roadway. Bicyclists riding the same segment during two different time periods may be exposed to different levels of traffic volume, traffic composition, or other factors, and, thus, their ratings of the same segment of roadway would be based on different operating conditions.
- The number of operational and geometric conditions to which subjects were exposed was much greater than could have been experienced in the field. For example, the participants in the pilot study described below rated the 13 sites in less than 15 minutes from the video, but it took almost 3 hours to drive to and rate all 13 locations in the field. If all geometric and operational conditions desired for the study are in several cities (as was the case in this effort), it is simply impractical to present all conditions to a group of bicyclists.
- The same set of geometric and operational conditions were examined and rated by bicyclists in several municipalities. This advantage allowed the direct comparison of ratings between bicyclists in different regions of the country or communities that vary with respect to bicycling facilities or "bicycle friendliness."

Before proceeding with this methodology in the full-scale data collection effort, a pilot study was undertaken with the primary objective of validating the video technique, that is, determining how well the participants' comfort ratings of various geometric, traffic volume, and speed conditions recorded when watching a videotape compared with the participants' comfort ratings when observing the locations in the field. With limited resources, only those conditions believed to be the most difficult to discern on the videotape were included in the pilot effort. Preliminary observations by project staff showed that differences in motor vehicle speeds and volumes were relatively easy to recognize on the videotape. Similarly, it was easy to determine the differences between cross sections with and without a paved shoulder or bicycle lane. The most difficult of the cross-section elements to determine from the videotape was lane width when there was no paved shoulder or bicycle lane. Thus, the pilot study included only roadway segments with standard or wide curb lanes and no paved shoulders or bicycle lanes, that is, the most difficult situations for viewers to differentiate.

A total of 13 locations were selected for inclusion in the pilot survey. Curb lane widths ranged from 3.1 to 5.5 m; 85th percentile speeds ranged from 48 to 72 km/h; and traffic volumes ranged from 3,550 to 26,650 vehicles per day. The sites selected also represented an extensive range of combinations of these variables, from low-speed, low-volume, narrow-lane locations to high-speed, high-volume, wide-lane locations.

A total of 24 participants were included in the pilot phase of the study. Each participant provided comfort level ratings for each of the 13 locations while watching the video containing 40-second clips from each site and while standing along the roadside at each location. The scale used in rating the sites was a six-point scale in which a one indicated that they would be extremely comfortable riding a bicycle under the conditions shown, whereas a six indicated that they would be extremely uncomfortable riding under the conditions shown.

Since each of the 24 participants (subjects) viewed the 13 sites both from the videotape and in the field, the most stable and reliable analyses are based on the 312 (24×13) combined pairs (video versus field) of observations. The results indicated that the participants' video ratings matched reasonably well to the field ratings for all four variables examined (overall, speed, curb lane width, and volume). The number of exact matches for the 312 site-by-participant pairs ranged from 30.8 percent to 43.6 percent, depending on the variable. However, the percentage of pairs that differed by no more than one rating level increased dramatically and ranged from 81.1 to 87.2 percent. These numbers and the corresponding statistics produced as part of the analysis indicate that the great majority of the video and field ratings were in substantial agreement. Overall, the results from the data analysis showed the video methodology to be a valid technique for obtaining realistic perspectives of bicyclists as related to their comfort levels under varying roadway conditions.

DATA COLLECTION

The sites selected for the study were located in several cities that represent a range of geographic conditions present in the United States and included

- Eugene and Corvallis, Oregon;
- Cupertino, Palo Alto, Santa Clara, and San Jose, California;
- Gainesville, Florida;
- Madison, Wisconsin; and
- Raleigh and Durham, North Carolina.

Many of these cities have a variety of on-street bicycle facilities that range in widths, traffic volumes, and motor vehicle speeds. This variety in facility types made it feasible to maximize the number of conditions included in the video survey.

Altogether, 67 sites were selected for inclusion in the video survey. The geometric and operational characteristics ranged considerably across the 67 sites and included (*a*) curb lane widths from 3.0 to 4.7 m, (*b*) motor vehicle 85th percentile speeds from 40 to 89 km/h, (*c*) traffic volumes from 2,000 to 60,000 vehicles per day, and (*d*) bicycle lane/paved shoulder widths from 0.92 to 2.44 m. Other characteristics that varied included a number of intersecting driveways, type of roadside development (e.g., residential, commercial), type of street (e.g., arterial, collector), number of through travel lanes, and the presence or absence of gutter pans, sidewalks, and medians. Sites with on-street parking were also included to examine the effect of such designs on bicyclists' comfort levels.

The sites selected were filmed for 15 minutes between 9:00 a.m. and 4:00 p.m. to maximize the range of volume conditions present. For each location, a 40-second clip was selected that was representative of the conditions during the 15-minute period. Several additional clips were also selected to represent other conditions that were believed to have an impact on the comfort level of bicyclists, including the presence of (*a*) large trucks/buses, (*b*) right-turning vehicles, and (*c*) parking vehicles. All of the clips selected were randomly placed on a videotape in preparation for the survey.

The survey was conducted in Olympia, Washington, Austin, Texas, and Chapel Hill, North Carolina. Altogether, 202 individuals participated and ranged in age from 19 to 74 with 60 percent of the participants being male. The bicycling experience levels also ranged from the savvy experienced commuter bicyclist to the very timid occasional recreational rider. The survey itself consisted of each individual providing four ratings using the six-point comfort level rating scale. Ratings were provided based on the *volume* of traffic, the *speed* of traffic, the *width* or space available to ride their bicycle, and, finally, an *overall* rating, which included these three variables plus any additional factors that influenced their level of comfort.

MODEL DEVELOPMENT

Determining the key roadway and traffic variables that may influence a bicyclist's decision to ride or not ride on a given roadway and incorporating those variables into a model were the primary objective of the data analysis. The analysis approach was to use regression modeling to determine all main effects, search for significant square and interaction terms, and, ultimately, eliminate all variables that were not significant at the level of $p \leq .01$.

The geometric and operational variables collected in the field or from the video clips and incorporated in the regression modeling included

- Number of lanes and directions of travel;
- Curve lane, bicycle lane, paved shoulder, parking lane, and gutter pan widths;
- Traffic volume;
- Speed limit and 85th percentile speed;
- Driveway density;
- Presence and type of sidewalks and medians; and
- Type of roadside development.

Using these variables as independent variables and the mean rating for each roadway segment (across subjects) as the response variable, a regression model was developed to predict the overall comfort level of bicyclists, as shown in Table 1. This model predicts the overall comfort level rating of a bicyclist using the eight significant

TABLE 1 Bicycle Compatibility Index Model, Variable Definitions, and Adjustment Factors

$$\textbf{BCI} = 3.67 - 0.966\textbf{BL} - 0.410\textbf{BLW} - 0.498\textbf{CLW} + 0.002\textbf{CLV} + 0.0004\textbf{OLV} + 0.022\textbf{SPD} + 0.506\textbf{PKG} - 0.264\textbf{AREA} + \textbf{AF}$$

where:

BL = presence of a bicycle lane or paved shoulder ≥ 0.9 m
no = 0
yes = 1

BLW = bicycle lane (or paved shoulder) width
meters (to the nearest tenth)

CLW = curb lane width
meters (to the nearest tenth)

CLV = curb lane volume
vehicles per hour in one direction

OLV = other lane(s) volume - same direction
vehicles per hour

SPD = 85th percentile speed of traffic
km/h

PKG = presence of a parking lane with more than 30 percent occupancy
no = 0
yes = 1

AREA = type of roadside development
residential = 1
other type = 0

AF = $f_t + f_p + f_{rt}$

where:

f_t = adjustment factor for truck volumes (*see below*)

f_p = adjustment factor for parking turnover (*see below*)

f_{rt} = adjustment factor for right turn volumes (*see below*)

Adjustment Factors

Hourly Curb Lane Large Truck Volume[1]	f_t	Parking Time Limit (min)	f_p
≥ 120	0.5	≤ 15	0.6
60 - 119	0.4	16 - 30	0.5
30-59	0.3	31 - 60	0.4
20-29	0.2	61 - 120	0.3
10-19	0.1	121 - 240	0.2
< 10	0.0	241- 480	0.1
		> 480	0.0

Hourly Right Turn Volume[2]	f_{rt}
≥ 270	0.1
< 270	0.0

[1] Large trucks are defined as all vehicles with 6 or more tires.
[2] Includes total number of right turns into driveways or minor intersections along a roadway segment.

(at $p \leq .01$) variables shown and an adjustment factor (AF) to account for three additional operational characteristics. The basic model (excluding the adjustment factor) has an R^2-value of 0.89, indicating that 89 percent of the variance in the index or comfort level of the bicyclist is explained by the eight variables included in the model. In other words, the model is a reliable predictor of the expected comfort level of bicyclists based on these eight variables describing the geometric and operational conditions of the roadway. 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) 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 with at least 30 percent of the spaces occupied (PKG) also increases the index.

To better understand the effects that changes in the variables within the model can have on the BCI value, an example is provided in Table 2 and described below. A typical two-lane urban street segment in a commercially developed area with 250 vehicles per hour is established as the baseline condition. The lane widths are 3.4 m and the 85th percentile speed of traffic along this segment is 56 km/h. Under these conditions, the BCI is 3.68. If this same street were in a residentially developed area, the BCI would be 3.42, or 7.2 percent less. If this street segment contained on-street parking, the BCI would be 4.19, or 13.8 percent greater. If the segment were a multilane street with comparable volumes in the lanes other than the curb lane, the index increases by just 1.6 percent to 3.74.

TABLE 2 Example of the Effects of Variable Changes Within the Bicycle Compatibility Index Model

Base Condition: 2-lane street in commercially developed area with 3.4-m lanes, 85th percentile speeds of 56 km/h, and traffic volumes of 250 vehicles per hour (vph)

Change/Condition	BL	CLW	BLW	PKG	SPD	CLV	OLV	Area	BCI	% Change
Base Condition	0	3.4	0	0	56	250	0	0	3.68	--
Increase lane width by 0.3 m	0	3.7	0	0	56	250	0	0	3.53	-4.1
Decrease volume by 100 vph	0	3.4	0	0	56	150	0	0	3.48	-5.4
Decrease speed by 8 km/h	0	3.4	0	0	48	250	0	0	3.52	-4.7
Add on-street parking	0	3.4	0	1	56	250	0	0	4.19	+13.8
Same street in residential area	0	3.4	0	0	56	250	0	1	3.42	-7.2
Multilane street w/ OLV=150 vph	0	3.4	0	0	56	250	150	0	3.74	+1.6
Add a 1.2-m bicycle lane	1	3.4	1.2	0	56	250	0	0	2.22	-39.6

Changes or improvements to the baseline conditions of the roadway segment with respect to motor vehicle speeds, traffic volumes, and lane widths can also dramatically change the BCI. As shown in Table 2, an increase in the lane width of 0.3 m decreases the index by 4.1 percent to 3.53. Similar reductions can be achieved by reducing the 85th percentile speeds by 8 km/h or the traffic volume by 100 vehicles per hour. The most dramatic effect occurs with the addition of a 1.2-m bicycle lane to the existing facility; this change reduces the BCI value by almost 40 percent to 2.22.

In addition to the eight primary variables included in the BCI model, three additional variables defining specific operating conditions were also examined. These supplemental variables were identified during the pilot phase of the study as having a potential impact on the comfort level of bicyclists and included the presence of (*a*) large trucks or buses, (*b*) vehicles turning right into driveways, and (*c*) vehicles pulling into or out of on-street parking spaces. An analysis of the overall comfort level ratings made when viewing the video clips illustrating these conditions showed all three of these variables to significantly increase the comfort level rating, thus indicating a lower level of comfort when these conditions were present. For all bicyclists, the overall mean rating increased by 0.5 when large trucks or buses were present. When there were vehicles pulling into or out parking spaces, the average rating increased by 0.6. And finally, the presence of right-turning vehicles resulted in an increase in the mean rating of 0.1.

Although the presence of these three specific operating conditions was not evaluated across all possible combinations of geometrics and operations, the results of the limited sample indicate a need for adjustment to the BCI model when large trucks or buses are present, when there are a large number of vehicles pulling into or out of on-street parking spaces, or when there is a high volume of right-turning vehicles. Thus, a series of adjustment factors that can be added to the model were developed for each of these scenarios (see Table 1). These factors were developed based on the theory that the conditions shown to the survey participants represented worst-case scenarios, and, subsequently, the increase in the overall mean comfort level rating represented the maximum adjustment that would be required.

LEVEL OF SERVICE CRITERIA

Once the BCI model was developed, bicycle level of service criteria were established based on the results of applying the model to the sites included in this study. As previously noted, the *Highway Capacity Manual* does not define level of service criteria for bicycles. However, the LOS definition states that it is the user's perception of the operational conditions within the traffic stream that dictates the ranges of qualitative measures included in each LOS designation. The perceived comfort level of bicyclists within a given set of operating conditions on the roadway is exactly what the BCI model produces. Thus, for bicycle LOS, the measure of effectiveness should be the BCI. Subsequently, each LOS designation should be defined by a range of values produced by the model. To remain consistent with the *Highway Capacity Manual*, six LOS designations (A through F) were defined as follows.

The distribution of overall mean comfort level ratings (averaged across all subjects) by site were first examined. The site with the lowest rating produced a mean of 1.24; the site with the highest rating resulted in a mean of 5.49. The conditions included in the video survey and rated by the participants included a broad range of conditions. These sites were selected to range from environments that would be comfortable for every adult bicyclist to those that would not be comfortable for even the most experienced commuter bicyclist. Likewise, the participants in the study ranged from the very timid casual bicyclist who might ride once a month and only on off-street facilities to the most savvy experienced commuter who rode every day in all types of traffic conditions. With this in mind, the extreme values noted above (1.24 and 5.49) are believed to represent the extremes that might be expected in practice. Shown in Figure 1 is a line drawn between these two extreme points that approximates the distribution of participant scores. On the lower end of the scale,

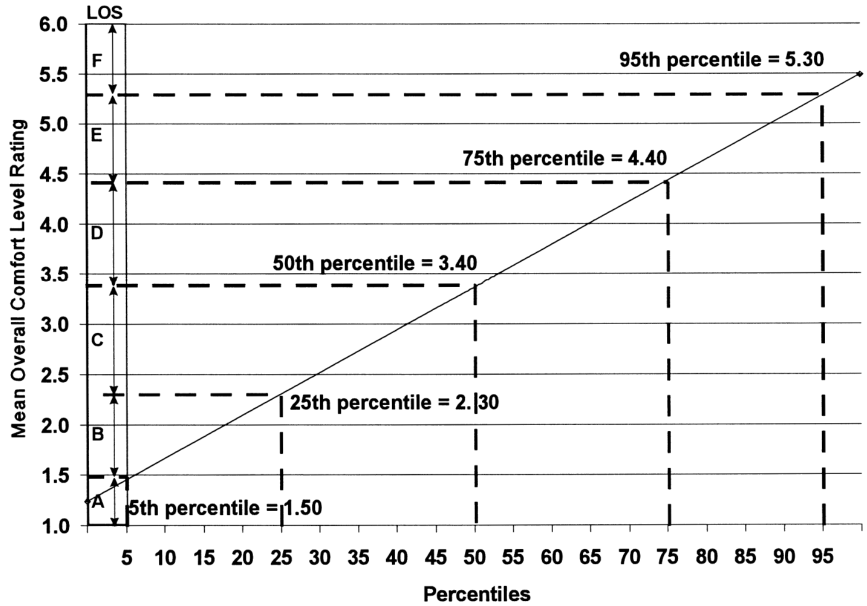

FIGURE 1 Distribution of bicycle compatibility index scores used in establishing level of service designations.

the extreme value of 1.24 represents the point at which virtually all bicyclists feel comfortable riding under a given set of roadway conditions. On the upper end, the extreme value of 5.49 represents the opposite, that is, the point at which virtually no bicyclists feel comfortable riding. In between these extremes, percentiles along the line can then be selected and used to represent the break points between the various LOS designations. Although the selection of these break points is arbitrary (as are the break points used in the *Highway Capacity Manual* for other LOS designations), they have been chosen to reflect the full range of site conditions and bicycling experience levels present in most urban and suburban areas.

The 50th percentile along the line corresponds to a mean overall rating of 3.40. Since there are six levels of service (A through F), the rating corresponding to the 50th percentile (3.40) was selected as the break point in the middle of the scale between LOS C and LOS D (see Table 3). The break points between the other levels were selected to reflect a slightly greater concentration of scores surrounding the 50th percentile and a very low concentration at the extremes. Extending 25 percent from either side of the 50th percentile results in a 75th percentile along the line corresponding to a mean overall rating of 4.40 and a 25th percentile corresponding to a value of 2.30. These values were selected as the breakpoints between LOS D and LOS E, and LOS C and LOS B, respectively. To define the breakpoint between LOS E and LOS F, the 95th percentile was selected. From Figure 1, this percentile corresponds to the mean overall rating of 5.30. On the other end of the scale, the 5th percentile was selected as the breakpoint between LOS A and LOS B, equivalent to a mean overall rating of 1.50.

TABLE 3 Bicycle Compatibility Index Ranges Associated with Level of Service Designations and Compatibility Level Qualifiers

LOS	BCI Range	Compatibility Level[1]
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

[1] Qualifiers for compatibility level pertain to the average adult bicyclist.

OTHER ISSUES

In developing the BCI model, several other issues were addressed, including the effect of bicycling experience level on perceived comfort levels. Using the results from a questionnaire completed by the participants, the bicyclists were stratified into three groups based on their riding habits, such as number of bicycle trips per week and types of facilities used (e.g., major roadways versus bicycle paths). A comparison of the comfort level ratings of these three groups showed that "casual recreational" bicyclists produced a significantly higher overall mean comfort level rating (3.1) across all sites than "experienced recreational" or "experienced commuter" bicyclists (2.7 and 2.6, respectively). As a result of these differences, separate BCI models were produced for each of the three groups in addition to the model for all bicyclists (*10*). However, in real-world applications, it is most likely that bicyclists of all experience levels will ride or have the opportunity to ride on any given segment of roadway. Thus, it is recommended that the BCI model developed for all bicyclists and shown in Table 1 be used for all applications. Should the practitioner know that the large majority of riders on a specific route to, indeed, be casual bicyclists, the roadway could be designed for a higher LOS and, thus, be more accommodating for less experienced bicyclists (*11*).

Another issue addressed was that of possible regional differences in the perceptions of bicyclists. If bicyclists in different geographic regions of the country perceive comfort levels differently, then separate models would need to be developed to reflect these differences. An analysis of the comfort level ratings across subjects in the three survey cities showed no differences in the mean overall comfort levels for the four variables rated (speed, volume, width, and overall). This lack of differences indicates that the perceptions of individuals with respect to bicycle compatibility are the same in the three regions in which the survey was conducted, and that the BCI model should be applicable across all regions of the country.

CONCLUSIONS

The bicycle compatibility index model and the subsequent level of service designations provide bicycle coordinators, transportation planners, traffic engineers, and others the capability to assess their roadways with respect to compatibility for shared-use operations by motorists and bicyclists. The tool also allows practitioners to better plan for and design roadways that are bicycle compatible. Specifically, the BCI model can be used for the following applications:

- *Operational Evaluation.* Existing roadways can be evaluated using the BCI model to determine the bicycle LOS present on all segments, where a segment is defined as a section of roadway between intersections where the geometric and operational characteristics remain constant. This type of evaluation may be useful in several ways. First, a bicycle compatibility map can be produced for the bicycling public to show them the LOS they can expect on each roadway segment. Second, roadway segments or *links* being considered for inclusion in the bicycle network system can be evaluated to determine which segments are the most compatible for bicyclists. In addition, *weak links* in the bicycle network system can be determined, and prioritization of sites needing improvements can be established based on the index values. Finally, alternative treatments (e.g., addition of a bicycle lane versus removal of parking) for improving the bicycle compatibility of a roadway can be evaluated using the BCI model.
- *Design.* New roadways or roadways that are being redesigned or retrofitted can be assessed to determine whether they are bicycle compatible. The planned geometric parameters and predicted or known operational parameters can be used as inputs to the model to produce the BCI value and determine the bicycle LOS that can be expected on the roadway. If the roadway does not meet the desired LOS, the model can be used to evaluate changes in the design necessary to improve the bicycle LOS (see example below).
- *Planning.* Data from long-range planning forecasts can be used to assess the bicycle compatibility of roadways in the future using projected volumes and planned roadway improvements. The model provides the user with a mechanism to quantitatively define and assess long-range bicycle transportation plans.

Provided below is a brief example of how the BCI model can be applied in the assessment of design alternatives for a roadway that is being planned for reconstruction. A minor arterial that connects a suburban area to the major arterial used for commuting into and out of downtown is being widened from two lanes to four because of an increase in projected volumes. The development along the roadside is a combination of retail businesses and light commercial industries. The current annual average daily traffic (AADT) on the roadway is 10,000 vehicles with 2 percent truck traffic, and the projected AADT in 5 years is 16, 000 vehicles with the same percentage of trucks. Motor vehicle speeds on the facility currently have an 85th percentile of 50 km/h; with the additional lanes, this value is expected to increase slightly to 55 km/h. The original proposed highway department design (see Figure 2) within the 20-m right-of-way included 3.6-m-wide lanes, a 1-m-wide planting strip on each side, and 1.8-m-wide sidewalks. No paved shoulders or bicycle lanes were included in the design.

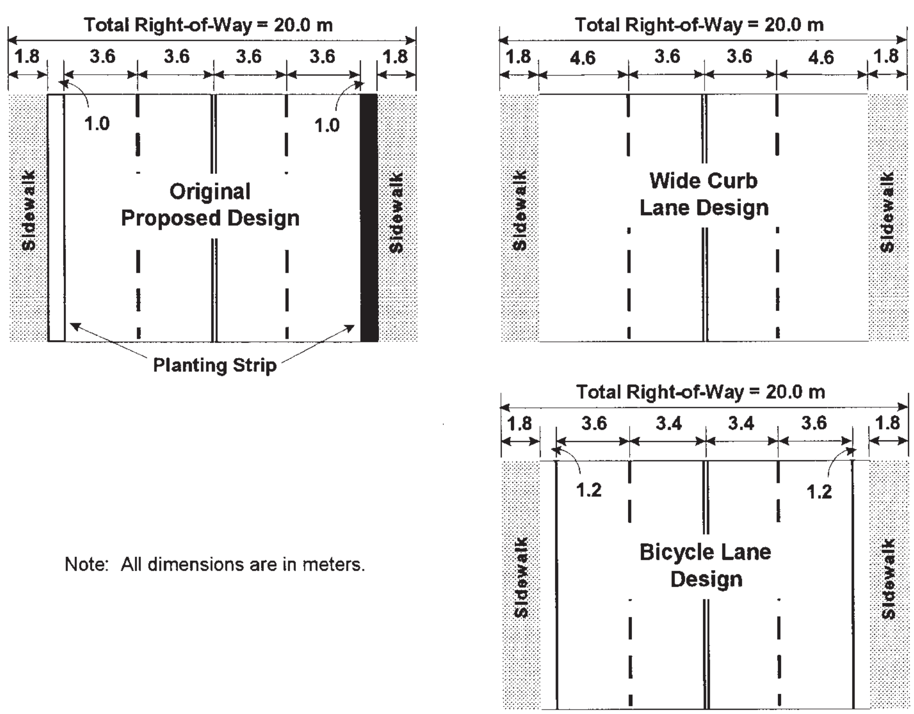

FIGURE 2 Proposed geometric design options for the reconstruction of a minor arterial.

TABLE 4 Bicycle Compatibility Index Computations and Levels of Service Associated with the Geometric Design Options in the Example

Design Option	BCI Model Variables									BCI	LOS
	BL	BLW	CLW	CLV	OLV	SPD	PKG	AREA	AF		
Original Proposal	0	0.0	3.6	672	448	55	0	0	0.1	4.71	E
Wide Curb Lane	0	0.0	4.6	672	448	55	0	0	0.1	4.21	D
Bicycle Lane	1	1.2	3.6	672	448	55	0	0	0.1	3.24	C

Using the BCI model, the bicycle LOS for the proposed route can be determined as follows. First, the projected AADT of 16,000 vehicles must be converted into an hourly volume. The highest hourly volume on this roadway is during the peak hour with an estimated 1,600 vehicles traveling in both directions during this hour. It is also known that the directional split during the peak hour is 70-30, that is, 70 percent of the vehicles are traveling in one direction during the peak hour. Thus, 1,120 vehicles per hour ($0.7 \times 1{,}600$) is the directional volume to be used. Since this volume will be distributed across two lanes with 60 percent of the traffic in the curb lane, two final calculations are made to determine the lane volumes as follows:

$$\text{Curb lane volume (CLV)} = 1{,}120 \times 0.6 = 672$$

$$\text{Other lane volume (OLV)} = 1{,}120 \times 0.4 = 448$$

The truck traffic on the roadway was projected to be 2 percent of the AADT. Using the same assumptions for directional splits and lane distributions, the number of trucks per hour in the curb lane becomes 13 (0.02×672). From Table 1, the adjustment factor (f_t) for this level of truck volume is 0.10.

Using this information and the other data provided, the BCI for the original proposed design was computed, as shown in Table 4. The calculated BCI was 4.71, which, based on the LOS criteria shown in Table 3, results in a bicycle LOS E or a very low level of compatibility for bicycling.

Since this particular roadway presently accommodates a fair volume of commuting bicyclists and is an important link in the bicycle network, it is desired to provide bicycle LOS C or better. Thus, two optional designs are proposed that fit within the 20-m-wide right-of-way. The first option is the wide curb lane design in which the planting strips are eliminated and the curb lanes are increased to 4.6 m in width; all other dimensions remain the same. As shown in Table 4, this design results in a BCI of 4.21, which is equivalent to LOS D and indicates a moderately low level of compatibility for bicycling. Although this is an improvement, it does not increase the LOS to the desired level.

The second optional design incorporates a 1.2-m-wide bicycle lane, as shown in Figure 2. Again, the planting strips have been eliminated and the original sidewalk width is maintained. The curb lane widths of 3.6 m are also maintained, but the interior lanes are reduced slightly to 3.4 m. The BCI for this option is computed to be 3.24, as shown in Table 4. This value equates to LOS C, which indicates a moderately high level of compatibility for bicycling and meets the desired bicycle LOS requirements for the roadway.

This example was provided to illustrate the practical use of the BCI model in evaluating alternative designs to ultimately arrive at a design that could be considered "bicycle friendly." Other examples associated with various aspects of planning and design issues, as well as detailed instructions on how to apply the model, can be found in the implementation manual for the BCI (*11*).

ACKNOWLEDGMENTS

The authors wish to acknowledge Carol Tan Esse of FHWA for her technical assistance, and also the following individuals whose assistance with site selection, participant recruitment, and logistical arrangements was invaluable in the conduct of this research study: Arthur Ross, pedestrian and bicycle coordinator for the city of Madison, Wisconsin; Tom Huber, pedestrian and bicycle coordinator for the Wisconsin Department of Transportation; Mike Dornfeld, bicycle coordinator for the Washington State Department of Transportation; Rick Waring, former pedestrian and bicycle coordinator for the city of Austin, Texas; Dianne Bishop, bicycle coordinator for the city of Eugene, Oregon; Glenn Grigg, former traffic engineer for the city of Cupertino, California; Linda Dixon, senior transportation planner for the Delaware Department of Transportation; and Marcie Stenmark, former bicycle coordinator for Gainesville, Florida.

REFERENCES

1. Zeeger, C., et al. *The National Bicycling and Walking Study: Transportation Choices for a Changing America.* Report FHWA-PD-94-023. FHWA, U.S. Department of Transportation, 1994.
2. Davis, J. *Bicycle Safety Evaluation.* Auburn University, City of Chattanooga, and Chattanooga-Hamilton County Regional Planning Commission, Chattanooga, Tenn., June 1987.
3. Epperson, B. Evaluating Suitability of Roadways for Bicycle Use: Toward a Cycling Level-of-Service Standard. In *Transportation Research Record 1438,* TRB, National Research Council, Washington, D.C., 1994, pp. 9–16.
4. Landis, B. W. Bicycle Interaction Hazard Score: A Theoretical Model. In *Transportation Research Record 1438,* TRB, National Research Council, Washington, D.C., 1994, pp. 3–8.
5. Wilkinson, W. C., A. Clarke, B. Epperson, and R. Knoblauch. *Selecting Roadway Design Treatments to Accommodate Bicycles.* Report FHWA-RD-92-073. FHWA, U.S. Department of Transportation, 1994.
6. Landis, B. W., V. R. Vattikuti, and M. T. Brannick. Real-Time Human Perceptions: Toward a Bicycle Level of Service. In *Transportation Research Record 1578,* TRB, National Research Council, Washington, D.C., 1997, pp. 119–126.
7. *Geelong Bikeplan.* Geelong Planning Committee, Geelong, Australia, 1978.
8. Sorton, A., and T. Walsh. Bicycle Stress Level as a Tool To Evaluate Urban and Suburban Bicycle Compatibility. In *Transportation Research Record 1438,* TRB, National Research Council, Washington, D.C., 1994, pp. 17–24.
9. *Special Report 209: Highway Capacity Manual.* TRB, National Research Council, Washington, D.C., 1994.
10. Harkey, D. L., D. W. Reinfurt, M. Knuiman, and J. R. Stewart. *The Bicycle Compatibility Index: A Level of Service Concept.* Report FHWA-98-072. FHWA, U.S. Department of Transportation, 1998.
11. Harkey, D. L., and D. W. Reinfurt. *The Bicycle Compatibility Index: A Level of Service Concept Implementation Manual.* Report FHWA-98-095. FHWA, U.S. Department of Transportation, 1998.

Publication of this paper sponsored by Committee on Bicycling.