Bicycle Stress Level as a Tool To Evaluate Urban and Suburban Bicycle Compatibility

ALEX SORTON AND THOMAS WALSH

The available information for establishing criteria to determine the bicycle compatibility of roadways is limited. Existing bicycle-compatible roadway procedures do not provide a complete picture of bicycling conditions from the different points of view of the various types of bicyclists. Such procedures also fail to account for the varying levels of difficulty bicyclists experience under different traffic conditions. The authors have employed *bicycle stress level* as a method to supply this missing information and thus provide the full range of criteria needed to determine the bicycle compatibility of roadways. Bicyclists on streets seek to minimize mental stress. They want to avoid conflict with motor vehicles and the strain of having to concentrate for long periods of riding along narrow, high-speed, high-volume roads. The authors have established bicycle stress levels ranging from 1 to 5 to account for traffic variables of volume, speed, and curb lane width. Level 1 indicates no problems for bicyclists; Level 5 suggests major problems. The highest and lowest stress levels are based on a thorough review of traffic engineering literature, the rationale being that if conditions are bad for motorists, they will be worse for bicyclists. Stress Levels 2 to 4 were prorated between the two extremes. The stress levels defined in the present study were validated by a group of volunteer bicyclists who watched videotaped segments showing a wide range of on-street traffic conditions and rated them according to the traffic variables described above.

Allocating portions of the existing street network for bicyclists represents a potentially cost-effective means of developing a bicycle network. The use of existing streets, wherever feasible, would provide bicyclists with the most direct and convenient access available. Identifying, analyzing, and selecting the best streets and design treatments, however, is a complex task because of the complexity of combined motor-vehicle and bicycle operation. To arrive at sound decisions on the appropriate locations of bicycle usage, it is necessary to

1. Identify the major factors affecting bicycle and motor vehicle operation,
2. Arrive at a general understanding of the basic interrelationships between these factors, and
3. Establish a process or methodology by which to record and evaluate existing conditions with respect to these factors (*1*).

There are no empirical data available to establish uniform location and design criteria for bicycle-compatible roadways. This gap in current principles and guidelines can only be filled by conducting comprehensive research projects and monitoring activities. Meanwhile, there is a pressing need to establish a methodology by which the key factors affecting bicycle and motor vehicle use can be recorded and analyzed. Decisions can then be made based on prudent professional judgment, taking into consideration widely varying local conditions and the widely varying abilities of bicyclists.

Two categories of bicycle-compatibility roadway analysis procedures have been established:

1. Procedures that assume that bicyclists are unable to share the roadways with motor vehicle traffic except under low volume and speed conditions; these procedures were developed by transportation professionals, in most cases nonbicyclists, and tended to try separating the bicyclist from the road or street (*2*); and
2. Procedures that assume that experienced bicyclists can share the roadway with motor vehicle traffic because they can tolerate higher volume and speed conditions; these procedures were developed by experienced bicyclists who rode their bicycles on the roadway with motorized traffic (*3*).

These procedures have several shortcomings:

1. They fail to recognize that there are different types of bicyclists with differing roadway riding preferences and abilities.
2. They use average daily traffic (ADT) as a variable in the analysis procedures. ADT may not be a good indication of whether a roadway is bicycle compatible because it is a measure of the road's daily volume, which fluctuates from hour to hour. Peak hour volume (PHV) is a better indicator. If bicycles can share the roadway during the peak hours, then off-peak hours will be even less of a problem (*4*).
3. There is no rational basis for these procedures. They cite neither documented research nor operating experience. They are entirely subjective, based on the authors' opinions.
4. The procedures make no distinction between urban and rural roadways. In urban and suburban areas, the average bicycle trip is usually under 5 mi long. Rural bicycling trips are usually made for recreation and touring and are usually longer than 5 mi. On rural roads, bicyclists cannot readily divert to other roadways as easily as they can on urban streets because the distances between intersecting and parallel roads are much greater. Other variables that must be considered in rural areas include higher vehicle speeds, truck turbulence, passing sight distances for motor vehicles, and riding times longer than 20 to 30 min, to mention only a few (*1,5*).

To be of the widest use, a bicycle-compatible road analysis procedure should provide ratings based not only on road charac-

A. Sorton, Transportation Engineering Division, Northwestern University Traffic Institute, 405 Church St., Evanston, Ill. 60208. T. Walsh, Madison Department of Transportation, 215 Martin Luther King Jr. Blvd., Madison, Wisc. 53701-2986.

teristics but also on the full range of bicycling competency. The ratings should be easily understood by all types of bicyclists and nonbicyclists, and data for all bicycle road compatibility procedures must be readily available. Existing bicycle-compatible roadway procedures do not meet these criteria. A procedure is needed that satisfactorily explains the effects of traffic volume, speed, and curb lane width on the different types of bicyclists wanting to use the roadway.

BICYCLE STRESS LEVEL CONCEPT

The concept of *bicycle stress* was first developed by the Geelong Bikeplan team in Australia (*6*). The team evaluated lane-sharing width on high-traffic-volume roads, but their analysis did not provide a complete picture of road bicycling from the bicyclist's point of view. In particular, the lane-sharing analysis failed to measure the extent to which roads are difficult or harassing to ride along, relative to traffic speed, volume, and curb lane width. The only measure used in the evaluation was a simple "adequate" or "inadequate."

Providing this information would have enabled the Geelong team to pinpoint those roads that are least comfortable to bicycle on. Measures to provide improvements or alternative routes according to this priority could then have been proposed.

In this paper, the idea of bicycle stress has been used to provide these data.

It is well known that bicyclists choose routes that will cost them the least amount of effort. They save energy by following the flattest route, one that will enable them to avoid stopping and slowing as much as possible.

However, conserving physical effort is only part of the story. Bicyclists also seek to avoid conflict with motor vehicles, harassment from heavy traffic, and the strain of having to concentrate for long periods while riding along narrow, high-speed, high-volume roads. In other words, they want to minimize not only physical effort but also mental stress.

The Geelong Bikeplan did not reflect the different stress levels of individual roadway variables, nor did it consider the different types of bicyclists. To overcome this deficiency, the authors propose to identify the stress levels for each roadway variable, as well as for the different types of bicyclists. They will also indicate how the roadway variables can predict the stress levels experienced by the different types of bicyclists.

Types of Bicyclists and Definition of Stress Levels

Bicyclists can be divided into clearly defined categories (*1,7*):

1. Child (recreation or play, primary school): The cognitive skills of primary school children are not fully developed. Children under the age of 10 have little knowledge of traffic laws and should only ride under supervision when they are on or near streets.
2. Youth (secondary school): The bicycling skills of secondary school students vary greatly. For older students (14 years and over), most bicycling takes place on the street.
3. Casual (recreation, utility, shopping, etc.): Casual bicyclists tend to give high priority to avoiding congested, heavily trafficked streets. Nevertheless, some will use busy streets if there are compensating conditions, such as bike lanes or wide curb lanes.
4. Experienced (commuting, touring and recreation): The on-street bicycling skill level of experienced bicyclists allows them to use the most direct and convenient routes, which often are the arterial or collector streets.

Bicycling stress levels range from 1 to 5, which bicyclists can relate to varying traffic conditions. (Children under age 10 should not be considered in this analysis process.) Stress Level 1 indicates that the traffic variables are so favorable that all types of bicyclists should have little or no problem. Stress Level 5 suggests that the traffic variables are so poor that all types of bicyclists will perceive the road or street as presenting a major problem.

Table 1 relates the five bicycling stress levels to the types of bicyclists appropriate for each on the basis of their riding competency and preferred riding environment. Again, this analysis is not intended for use with bicyclists under 10 years of age, who should only ride under supervision when on or near streets.

Applying Urban and Suburban Stress-Level Evaluation Methodology

The process for evaluating an existing street system can be viewed as a series of three steps:

1. Select those physical roadway variables that are most significant in affecting bicycle use. On two-way roads, data should be collected for each direction of travel.
2. Evaluate the suitability of all street segments for bicycle use on the basis of the variables identified above. This is done by finding the stress level for each variable for on-street segments. The overall average stress level can then be determined.
3. Select and rank all street segments on the basis of the future improvements needed to fit bicycle traffic and on the type, cost, and political feasibility of those improvements. This selection is accomplished by relating the overall average stress level of the road segment variables to the relevant bicyclist type and then determining what improvements, if any, should be made.

Given the increasing demands on staff personnel in recent years, local public agencies need to develop an accurate rating and evaluation mechanism that will require the minimum possible effort (*1*).

PRELIMINARY ASSESSMENT OF MAJOR CORRIDORS AND CANDIDATE STREETS

A first step in planning and designing bicycle-compatible roads is to identify the corridors through which bicycle travel is likely to be greatest. Analysis of area riding environment and bicycle user information should enable satisfactory identification, evaluation, and preliminary analysis of appropriate corridors or streets.

Typical corridors in which the provision of bicycle-compatible roads and facilities should be considered will cover an area two to six blocks wide, depending on local conditions. There are two key factors in identifying corridors with respect to bicycle movement.

TABLE 1 Suggested Interpretation of Bicycling Stress Levels

Stress Level	Interpretation
1 (Very Low)	Street is reasonably safe for all types of bicyclists (except children under 10).
2 (Low)	Street can accommodate experienced and casual bicyclists, and/or may need altering* or have compensating conditions** to fit youth bicyclists.
3 (Moderate)	Street can accommodate experienced bicyclists, and/or contains compensating conditions** to accommodate casual bicyclists. Not recommended for youth bicyclists.
4 (High)	Street may need altering* and/or have compensating conditions** to accommodate experienced bicyclists. Not recommended for casual or youth bicyclists.
5 (Very High)	Street may not be suitable for bicycle use.

* "Altering" means that street may be widened to include wide curblane, paved shoulder addition, etc.

** "Compensating condition" can include street with wide curb lanes, paved shoulders, bike lanes, low volume, etc.

1. As is the case with motorists, most trips bicyclists make are "destination" trips. All riders tend to seek the most direct, convenient route. Therefore, existing primary motor vehicle travel corridors may already be oriented to destinational riding.
2. Traditionally, bicyclists do not care to deviate more than two blocks out of their way in order to use a street or facility (*8*).

The three-step rating methodology proposed earlier can be carried out in two phases (*1*).

Phase I (Primary Variables)

Phase I is a rapid initial assessment of potential bicycling corridors to determine the general implications of allowing bicycle access on candidate streets. Three primary variables—curb lane traffic volume, speed of motor vehicles, and curb lane width—are evaluated to determine their effects on bicyclists.

Phase II (Secondary Variables)

Phase II is a more detailed evaluation of selected variables on alternative streets within a corridor to determine the bicycle compatibility of candidate streets. These secondary variables are number of commercial driveways per mile along the street, parking turnover, and percentage of heavy vehicles using the road. Heavy vehicles include trucks, buses, and recreational vehicles.

Because of limited funds, the present research was conducted for the three primary variables only. This paper will therefore include discussion of the development of the methodology, how the research was conducted, and the results of the research.

PROPOSED METHODOLOGY: PRIMARY VARIABLES

The proposed methodology was extrapolated from transportation engineering literature covering motor vehicles and then related to the bicycle stress level process. (The logic behind this extrapolation is that if there are problems for motor vehicles, these will be bigger problems for bicycles.)

As mentioned earlier, a curbside lane-sharing evaluation should take account of the following primary variables: traffic volume in the curb lane, curb lane width, and traffic speed. These three primary variables will determine the street compatibility rating for the different groups of bicyclists on the basis of stress level.

Traffic Volume Versus Stress Level

The quantity and character of motor vehicle traffic flow in the curb lane are primary determinants of bicycle compatibility.

The ADT on a given street in a given 24-hr period can and does fluctuate dramatically. In determining the number of lanes required for motor vehicles, traffic engineers and designers usually carry out a capacity analysis using the peak hour volume (PHV) or an operational check of existing conditions. The same must be done in a bicycle compatibility roadway analysis (*2*). Traffic planners use ADT, which is usually based on the PHV. Since the authors are traffic engineers who evaluate streets under peak hour conditions, PHV is used here. ADT can be substituted, since PHV is directly related to ADT. The direct relationship between ADT and PHV can be delineated by applying the *K*-factor, or that portion of the ADT that occurs during the peak hour. A typical *K*-factor for an urban area is 10 percent. The PHV in vehicles per hour (vph) is computed as shown below (*2*). The worst-case scenario for bicyclists occurs during peak periods. Therefore, peak periods must be used to determine whether bicyclists can use a given street.

$$PHV \text{ (vph)} = ADT \times K\text{-factor}$$

Curb lane volume is determined by dividing the PHV by the number of through lanes on the street. This assumes a 50/50 split on a two-way street. If the directional split is different, as is often the case during the peak hours, the known split should be used for the analysis.

Example: Two-Lane Urban Street (Two-Way)

ADT = 10,000

K-factor (urban condition) = 0.10

PHV = 10,000 × 0.10 = 1,000 vph two way

Curb lane volume = 1,000/2 lanes (50/50 split) = 500 vph

Determining the amount of traffic volume that a bicyclist is willing to tolerate in the curb lane can be described in the form of stress level. Curb lanes on urban streets are at maximum capacity or maximum traffic flow volume when there are 450 to 800 vehicles per hour per lane (vphpl) (*2,9*). To be on the conservative side, in this study 450 vphpl was considered to result in a stress level of 5. When the motor vehicle volume is low (less than 50 vphpl), the condition can be described as Stress Level 1. A two-way residential street may have an ADT of 1,000 vpd. This is equal to 50 vphpl (1,000 × 0.10)/2 = 50 vphpl.

Shown below are the suggested stress levels for volumes in the curb lane:

Stress Level	*Curb Lane Volume (vphpl)*
1	≤50
2	150
3	250
4	350
5	≥450

Curb Lane Width Versus Stress Level

Curb lane width is a critical variable because it delimits the bicyclist's operating space. Curbside lane width is the distance from the joint between the curb and gutter and the first full travel lane adjacent to it. With parked vehicles it is measured from the side of a parked car to the first lane line. Where on-street parking exists, it is assumed that 2.4 m (8 ft) is required; the curb lane is determined by measuring from the 2.4-m mark to the first lane line. When a paved shoulder is adjacent to the travel lane, the curb lane width is the travel lane plus the width of the paved shoulder.

Research by the Maryland Department of Transportation suggests that a curb lane width of 4.6 m (15 ft) or greater can accommodate bicyclists and cars in the same lane for speeds of 65 kph (40 mph) and less. This includes a 0.3-m (1-ft) curb and gutter section (*10*). The *Highway Capacity Manual* (*4*) indicates that on urban streets with a curb lane of 4.3 m (14 ft) or wider, bicycles do not affect motor vehicle traffic when sharing the same lane. On a lane width of 3.3 m (11 ft) or less, a bicycle is equivalent to one passenger car because the car has to leave the curb lane to pass the bicycle (*2*). Thus for a 4.6-m curb lane (not including the gutter), the stress level is considered 1, and for a 3.3-m curb lane (not including the gutter) the stress level would be 5. Gutter sections tend to vary in width and are not considered part of the total curb lane width.

Applying the stress level concept to the curb lane width results in the following suggested relationships (1 m = 3.3 ft):

Stress Level	*Curb Lane Width (m)*
1	≥4.6
2	4.3
3	4.0
4	3.7
5	≤3.3

Traffic Speed Versus Stress Level

The high-speed effect of vehicles passing too close to a bicycle can cause loss of control and is especially unpleasant when accompanied by spray in wet weather. The degree of the speed effect on bicyclists on narrow curbside lanes depends on motor vehicle speed and size. The speed that is used in the evaluation should be the actual 85th-percentile speed no matter what the posted speed limit is (*2*). At a speed of 75 kph (45 mph), the turbulence of large motor vehicles starts to affect the stability of bicyclists using the roadway (*8*). It is recommended that at speeds of 75 kph or higher, the stress level be considered 5. On residential streets posted for speed limits of 40 kph (25 mph), the stress level is 1.

Motor vehicle speed as it relates to bicycle stress level is shown below (1 kph = 0.6 mph):

Stress Level	*Motor Vehicle Speed (kph)*
1	≤40
2	50
3	60
4	65
5	≥75

Example

The following example analysis will explain the stress level concept as discussed previously. For this example, assume a two-lane suburban arterial street (two way), 3.7-m (12-ft) lanes, ADT =

15,000 vpd, and speed = 75 kph (45 mph).

PHV (street) = 15,000 × 0.10 = 1,500 vph

PHV (curb lane) = 1,500 vph/2 = 750 vphpl

Curb lane width = 3.7 m (12 ft)

Motor vehicle speed = 75 kph (45 mph)

Volume stress level =	5
Curb lane stress level =	4
Speed stress level =	5
TOTAL =	14
Overall stress level = 14/3 =	4.7

This street does not seem to be compatible with young and casual bicyclists. It also may not be compatible for experienced bicyclists.

VALIDATION OF BICYCLE STRESS LEVEL PROCEDURE

The city of Madison, Wisconsin, Traffic Engineering Division was interested in validating the bicycle stress level procedure for bicyclists who use their city streets. The city applied for and received a $4,000 grant from the Wisconsin Department of Transportation to carry out the validation study. The grant money was used to pay a technician to collect the data. The authors agreed to donate their time to develop the process and survey instrument and to analyze the survey results.

It was decided that only the primary variables would be studied (motor vehicle volume, motor vehicle speed, and curb lane width). Twenty-three Madison street segments were selected, representing the range of variables bicyclists encountered when using the street system. After various options had been explored, it was decided that the selected segments would be videotaped. Taking 35-mm slides was considered, but the idea was discarded because a still picture cannot show movement or speed of vehicles. Videotaping from the front passenger seat of a motor vehicle was tried and abandoned because the video camera could not be held steady enough. The survey vehicle also blocked vehicles behind it from passing in the same lane. Finally, the video camera was mounted on a tripod that was placed behind the curb of the street segments being studied. It was positioned so that it could record the traffic in the curb lane in the downstream direction—the same direction in which a bicyclist would be moving if he or she were using the street.

The primary variables on the 23 street segments were as follows. The speeds on the selected streets ranged from a low of 40 kph (25 mph) to a high of 75 kph (40 mph). The widths of the curb lane ranged from 3.3 m (11 ft) to 5.5 m (18 ft). The curb lane volume ranged from a low of 60 vph to a high of 670 vph.

A questionnaire was developed. The first part contained questions about the bicyclist to determine his or her type, age, and sex; typical bicycle trips made; riding environment used; and the number of trips and miles traveled during an average week (*11*).

The second half of the questionnaire dealt with the 23 videotaped street segments. For each street segment, the participants were asked to respond to a specific question about one of the primary variables. Participants were asked to watch a video clip of each segment of the selected streets and then rate a specific primary variable on the basis of the bicycle stress level concept. Participants then rated the vehicular volume in the curb lane for eight street segments. The next seven segments, different from the previous eight, dealt with speeds of motor vehicles. The last eight segments dealt with the width of the curb lane.

Before watching each video clip, participants were instructed to indicate how comfortable they would feel with a specific primary variable that they would be asked to evaluate in the clip. They were told that a 1 would indicate that they were very comfortable riding with this variable condition and a 5 would indicate that they would not want to ride with this variable condition under any circumstances. They were further instructed to rate the specific variable condition between 2 and 4 for conditions they believed did not meet the extremes.

The 40 adult bicyclists who volunteered to take part in the survey were employees of the Wisconsin Department of Transportation in Madison. The remaining 21 bicycle participants were members of a Madison church youth group, ranging in age from 10 to 15. After the 61 participants were stratified into the three types of bicyclists, the sample sizes of two groupings were deemed not large enough to achieve statistically valid results. Thus, the results that were achieved for the street segments were merely indicators of the different types of bicyclists' perceptions of traffic conditions.

SURVEY RESULTS

There was an interesting outcome of the analysis of the survey results. Although the respondents were divided into three types of bicyclists (youth, casual, and experienced), over two-thirds of the total indicated that they were experienced when asked, "What type of bicyclist do you consider yourself, experienced or casual?"

This was highly unlikely, since experienced bicyclists make up only approximately 5 percent of the total bicyclist population. Thus, other items on the questionnaire were used to categorize bicyclists by type. Bicyclists were considered experienced if they commuted regularly, rode on arterial and residential streets, rode frequently, and bicycled more than 20 mi per week. According to those guidelines, eight bicyclists were experienced. Bicyclists were categorized as casual if they did not ride on arterial streets, used the bicycle for recreation, used sidewalks, rode infrequently, and rode less than 5 mi per week. There were 32 casual bicyclists. Youth bicyclists, or those between the ages of 10 and 15 years, numbered 21.

The respondents' stress level ratings of all 23 street segments were combined and averaged within each category of bicyclist. The differences in overall average stress level among the three types of bicyclists are shown below:

Stress Level	*Average Value*
Proposed	2.61
Experienced	2.54
Casual	2.82
Youth	2.82

The proposed average stress level is lower than the average stress level of either the casual or youth bicyclists but slightly higher than that of the experienced bicyclists. This suggests that the proposed average stress level of each primary variable may have to be modified for each type of bicyclist. Casual and youth bicyclists seem to have the same perception of roadway primary variables. In an effort to verify this finding, each primary variable was analyzed for each type of bicyclist and compared.

Shown below are the average stress levels by type of bicyclist for motor vehicle volume on eight street segments:

Stress Level	*Average Value*
Proposed	2.89
Experienced	2.32
Casual	2.42
Youth	2.52

The results suggest that the three types of bicyclists vary in the way they perceive stress levels for traffic volume and that the proposed stress level for volume may be too low. Bicyclists in all three categories might be willing to accept higher volumes for a given stress level, which in turn might require increasing the curb lane volume for each stress level.

A linear regression line is a straight line that runs through or past the data points on a path while staying as close as possible to all of them. Regression analysis determines how an independent variable (such as volume, speed, or curb lane width) affects a dependent variable (such as stress level). It can be used to identify data that may have predictive capabilities. R-squared represents the validity of the relationship between the independent and dependent variables. The closer to 1 this value is, the better the independent variable predicts the dependent variable. A value close to zero means that the independent variable is not a useful predictor of the dependent variable.

Figure 1 shows the plots of the linear regression lines for the average stress level versus curb lane volume for the different types of bicyclists. These plots indicate that stress level versus curb lane volume for all types of bicyclists is upwardly linear from low to high volume. The R-squared values for the regression lines are 0.94, 0.95, and 0.91, respectively, for experienced, casual, and youth bicyclists. This seems to indicate that the differing types of bicyclists can correlate the varying volumes to the stress level ranges. All bicyclist types gave a higher stress level rating to curb lane volumes above the 450-vphpl limit proposed in this study. This suggests that the volumes for the stress levels may have to be raised.

The average stress levels for curb lane width on six street segments are shown below. Two street segments containing bicycle lanes were not used because this would have biased the results; such streets had lower stress levels for all types of bicyclists than did streets without bicycle lanes (but having similar volumes, speeds, and curb lane widths).

Stress Level	*Average Value*
Proposed	2.25
Experienced	2.68
Casual	3.21
Youth	2.81

Again, experienced bicyclists show higher tolerance for narrower lanes than do either casual or youth bicyclists, who may need a wider lane. The proposed average stress level for curb lane width is much lower than the stress level for either of the other variables. This suggests that the proposed lane widths versus stress level may have to be adjusted.

Figure 2 shows plots of the linear regression lines of the average stress level versus curb lane width for the different types of bicyclists. The R-squared values for the regression plots are 0.47, 0.36, and 0.13 for experienced, casual, and youth bicyclists. These values indicate that all three types of bicyclist are experiencing difficulty in correlating width with stress levels using this procedure. Again, the number of segments is very low for this type of analysis. It would be desirable to look at a larger number of street segments to see if the results might be similar. The position of the video camera might have prevented the video image from showing vehicle width properly. It would be worth experimenting with different camera positions to determine whether this can be

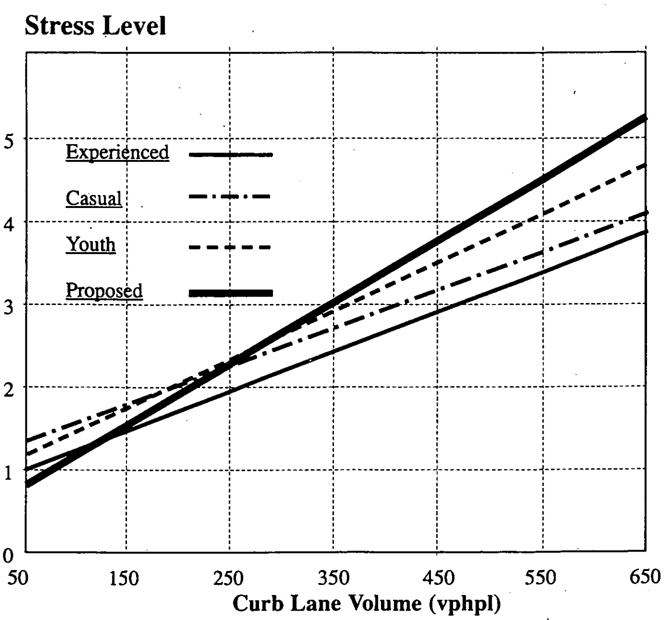

FIGURE 1 Volume versus bicycle stress level.

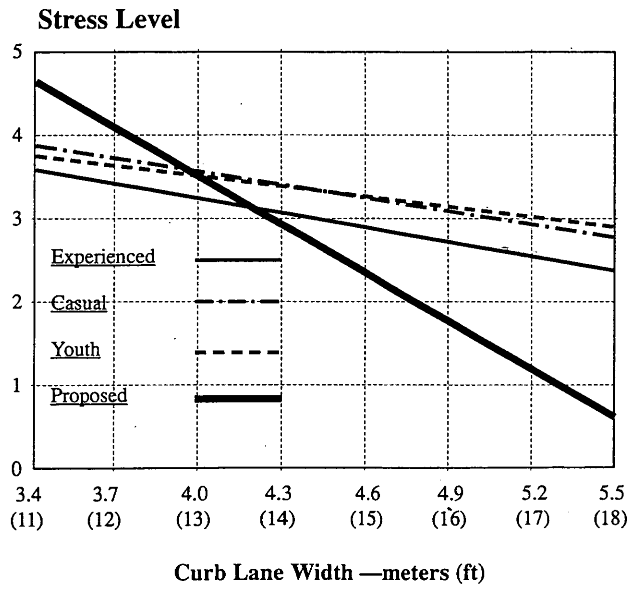

FIGURE 2 Width versus bicycle stress level.

improved upon. Again, these plots show that stress level versus width is upwardly linear from wide to narrow. The plots also indicate a difference in perception between the experienced and casual bicyclist for narrow lane widths and a lesser difference for wide lanes. The perceptions of the youth bicyclist fall somewhere between those of the casual and experienced bicyclists.

The results of the speed stress level for five street segments are shown below. Again, two street segments containing bicycle lanes were not used in this analysis, for the reasons stated earlier.

Stress Level	*Average Value*
Proposed	2.40
Experienced	3.00
Casual	3.34
Youth	3.01

These results show a difference between the experienced bicyclist and the casual bicyclist in their perception of speed, with little if any difference between experienced and youth bicyclists. There are several possible reasons for this unexpected result: (*a*) there were too few street segments for this analysis, (*b*) youth bicyclists may have higher risk-taking behavior characteristics, and (*c*) youth bicyclists may not be able to judge speeds as competently as experienced drivers of vehicles. The proposed average stress level is lower than that shown for all three types of bicyclists. This suggests that the proposed stress level for speed might have to be modified upward.

Figure 3 shows the plots of the best-fit regression lines of average stress level versus speed for the different types of bicyclists. The plots indicate an apparent difference between casual and experienced bicyclists at lower speeds. At higher speeds the lines converge at 75 kph (45 mph). The youth bicyclist regression line is almost the same as that of the experienced bicyclist. The R-squared values of these regression plots are 0.80, 0.64, and 0.90 for the experienced, casual, and youth bicyclists, respectively. There is fairly high correlation for speed and stress level for the experienced and youth bicyclists but the correlation is not quite as high for the casual bicyclist. It is surprising that youth bicyclists had the highest R-squared value. This may be due to the low number of street segments evaluated.

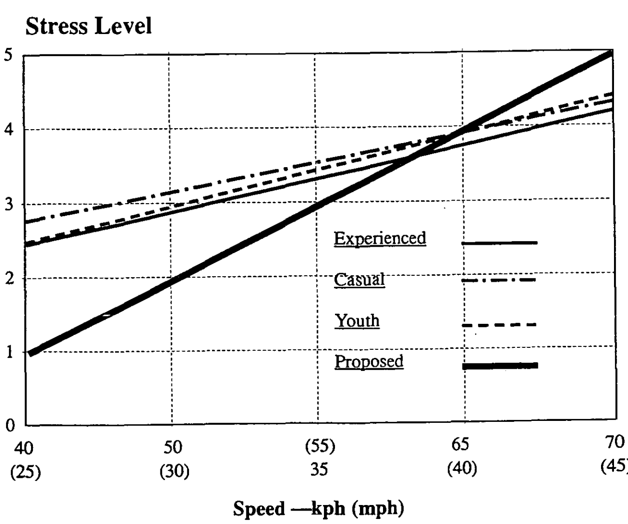

FIGURE 3 Speed versus bicycle stress level.

CONCLUSIONS

The following conclusions were drawn:

1. The bicycle stress level analysis procedure shows promise in evaluating urban and suburban streets for bicycling compatibility.
2. This procedure seems to indicate that different types of bicyclists can recognize the variation in the three primary on-street traffic variables from low to high. Bicyclists apparently relate their perception of the variation in the form of stress level.
3. The hypothesis that there are differences in how the various types of bicyclists perceive primary on-street variables could not be confirmed or rejected. The sample sizes of the three types of bicyclists were not large enough to be validated statistically, nor was the number of street segments used to evaluate the three primary variables.

FUTURE RESEARCH

Future research should be as follows:

1. The same survey should be conducted with a sufficient number of bicyclists in each of the three bicyclist categories to ensure that the results can be statistically analyzed. All 23 street segments should be analyzed for all three primary variables by all the bicyclists.
2. Similar surveys could be conducted in cities having larger or smaller populations than Madison, Wisconsin. It may be that bicycle stress level depends on the population size of urbanized areas.
3. Several of the Madison streets with wide curb lanes used in this study have been restriped to include bicycle lanes. It would be of interest to determine whether striping a bicycle lane on an existing street with wide curb lanes lowers bicycling stress levels. The present research indicates that stress levels for all types of bicyclists with respect to speed and width variables seem to drop for street segments with bicycle lanes as compared with similar segments without bicycle lanes.
4. It should be determined at what specific overall stress levels the different types of bicyclists would stop utilizing streets as well as the distances they would be willing to ride on the basis of the overall stress levels of streets.
5. The videotape stress level procedure should be validated by surveying bicyclists riding on streets with differing variables.

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