Bicycle Interaction Hazard Score: A Theoretical Model

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A calibrated and transferrable model is needed to estimate bicyclists' perception of the hazards of sharing roadway segments with motor vehicles. Such an interaction hazard (perception) model would help overcome one of the barriers to the development of a sequential bicycle travel demand simulation or forecasting model. An interaction hazard model would also greatly aid planners in the priority ranking of competing roadway segments for on-road bicycle facilities by providing an objective and stable supply-side measure of bicycle facility need. In addition, a model would assist planners to objectively assess the overall bicycle "friendliness" of their road networks as well as provide a uniform tool to assist in the development of bicycle suitability maps. The theoretical interaction hazard score (IHS) model described in this paper represents an opportunity, after statistical calibration (and the possible incorporation of roadway grade and curvature terms for application in hilly terrain), to fulfill the aforementioned needs. On the basis of consensus group evaluation, the IHS model incorporates the appropriate exposure variables that describe actual and perceived interaction hazards to bicyclists sharing parallel facilities with motor vehicles.

Very few calibrated and transferrable models exist to estimate bicyclists' perceived hazard of sharing specific transportation facilities with motorized vehicles. Likewise in short supply are calibrated and transferrable models to estimate road segments' potential hazard of use by bicyclists. There are several urgent application needs for a single calibrated and transferrable model that addresses both of the aforementioned problems. These needs range from bicycle planning tools such as travel demand forecasting and objective measures of the urban area's road bicycle-friendliness to end-user products such as priority ranking of construction projects and bicycle (route) suitability maps.

One of the most urgent needs for a bicyclist-motorist interaction hazard model is to overcome one of the current barriers to developing a sequential bicycle travel demand simulation or forecasting model. This barrier is resident in the trip assignment step of the classic four-step transportation system model. Unlike the relatively straightforward trip assignment algorithm for motorized vehicles, which includes impedance factors such as travel distance and (if selected) capacity constraint, route selection by bicyclists is not influenced by capacity constraints but is strongly influenced by the perceived hazards of sharing the roadway (i.e., interaction) with motorized vehicles. This essential component of the trip assignment algorithm can only be implemented by the system-wide use of a data-based, segment-specific "travel penalty" or impedance-type measure such as an interaction hazard score.

As the bicycle mode share of travel increases as a result of new facility construction (*1,2*), increased funding of bicycle improvements is likely. Currently, even some of the most advanced priority-ranking systems for on-road bicycle facilities suffer from not having the capability to differentiate among projects with equal use demands. Often the choice between projects is made in the absence of an objective evaluation of perceived motorist-bicycle interaction hazard, a major factor (in addition to a demand evaluation) in determining the need for a parallel on-road bicycle facility. Because significant construction of bicycle facilities is possible with recently increased funding sources such as the 1991 Intermodal Surface Transportation Efficiency Act and the 1990 Clean Air Act Amendments, a more defined, objective, and defensible supply-side evaluation component is needed to rank bicycle project priority.

Finally, an objective tool to assist in the development of bicycle suitability road maps is needed. Current practice includes the subjective evaluation of roadways to determine their "friendliness" to bicycle use. Consistent evaluations of the roads is virtually impossible without the same people being involved in subsequent years. A numerical and objective evaluation tool is needed.

THEORETICAL STRUCTURE OF MODEL

There has been some work in recent years both in modeling the *actual* hazard of road segments for bicycle use and in estimating bicyclists' *perceived* hazard of sharing specific road segments with motorized vehicles. The first modeling effort, the Auburn-Chattanooga bicycle safety evaluation index (*3*), also known as the Davis model (see Figure 1), sought to predict bicycle accidents (or crashes) using variables such as average annual daily traffic, number of travel lanes (to establish curb-lane volume), and pavement and location (land use intensity) factors. Its failing in meeting the goal of predicting accidents [as evidenced by a low correlation coefficient (*4*)] was its lack of incorporating bicycle volumes as a normalizing, or exposure, variable. However, it is considered a pioneering effort in that it provided the genesis of thought that led to modeling efforts to estimate bicyclists' perception of the hazard of sharing specific road segments with motorized vehicles. Both modeling efforts are typified by the initial version of the Broward County Bicycle Facilities Network Plan roadway condition index (RCI) (*4*) and the Florida Bicycle Coordinator's recently consensus-developed segment condition index (SCI) model. Their equations are nearly identical to that of the Davis model. Their shortcoming is in the subjective methodology used to assign values to variables, particularly in the estimation of pavement and location factors. Common also to both these modeling initiatives is the lack of research funding for statistical calibration.

The model described in this paper is called the interaction hazard score (IHS) model. Its theoretical forebears include the RCI

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AADT/ (L*2500) ÷ S/35 ÷ (14-W)/2 + PF + LF = SAFETY INDEX

AADT =  AVERAGE ANNUAL DAILY TRAFFIC
L    =  NUMBER OF TRAVEL LANES
S    =  SPEED LIMIT (MPH)
W    =  WIDTH OF OUTSIDE LANE (W > 14, FACTOR = 0) (FEET)
PF   =  PAVEMENT FACTOR
LF   =  LOCATION FACTOR
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PAVEMENT FACTOR VALUES

1.	Cracking	0.50
2.	Patching	0.25
3.	Weathering	0.25
4.	Potholes	0.75
5.	Rough Edge	0.75
6.	Curb & Gutter	0.25
7.	Rough RR Crossing	0.50
8.	Drainage Grates	0.75
	PF =	SUM

LOCATION FACTOR VALUES

1.	TYPICAL SECTION	
	A. Angle Parking	0.75
	B. Parallel Parking	0.50
	C. Right Turn Lanes	0.25
	D. Physical Median	(-) 0.25
	E. Center Turn Lane	(-) 0.25
	F. Paved Shoulder	(-) 0.75
2.	ALIGNMENT	
	A. Grades, Severe	0.50
	B. Grades, Moderate	0.25
	C. Horiz. Curves, Frequent	0.25
	D. Restricted Sight Dist.	0.50
3.	ENVIRONMENT	
	A. Numerous Drives	0.50
	B. Industrial Land Use	0.50
	C. Commercial Land Use	0.25
	LF =	SUM

FIGURE 1 Davis roadway segment formula (*3*).

and SCI models. The IHS model was developed primarily because the aforementioned models lack complete consideration of the exposure variables, and they incorporated substantial subjectivity in their methodology in estimating the values of some variables. Although the first shortcoming is significant, the second is devastating: if the same data collection personnel are not employed year after year to provide their assessment of roadway conditions, considerable distortion in the outputs of the aforementioned models can occur, severely limiting priority ranking and other annual or repetitive applications. Accordingly, the IHS model was developed to avoid these shortcomings.

Modeling Factors

In order to effectively simulate the potential hazards to a bicyclist sharing the roadway with motor vehicles, a model must consider two components. They are longitudinal and transverse interaction components of the on-road bicycling environment.

In the longitudinal roadway environment, several interactions are present and thus affect the bicyclist's perception of hazard. First there are the volume, speed, and characteristics (*5*) of the motor vehicles using the shared right-of-way and their perceived effect on the bicyclist. As the volume, speed, and size of motor vehicles increase, so does the bicyclist's perception of interaction hazard. Second is the proximity of the bicyclist to these motor vehicles. As width of the outermost roadway lane decreases, forcing together the bicyclist's and the motor vehicle's travel paths, the perceived hazard increases. Finally is the pavement condition or hazards affecting the travel line of the bicyclist. As pavement condition deteriorates, the bicyclist is required to pay more attention to the immediate travel line; thus, the perceived hazard increases.

In the transverse environment, uncontrolled vehicular movement (i.e., roadway access and on-street parking) presents a hazard to the bicyclist using a shared right-of-way. Representative roadway features include driveways and parallel or on-street parking.

These transverse features represent a similar "turbulence" or hazard to the bicyclist as to motor vehicle operators, which has been acknowledged in recent highway access management policy development (*6*). Accordingly, as the number of driveways or on-street parking increases, a corresponding increase in the perceived hazard to the on-road bicyclist is expected. Affecting this perception of hazard is the driveway traffic frequency and the rate of turnover in on-street parking.

Model Terms

On the basis of the aforementioned bicyclist interaction factors and incorporating some terms from the Epperson-Davis version of the RCI model (*4*), the IHS model has been developed with the following general form:

$$IHS = \left\{ \frac{(ADT)}{L} \times \left(\frac{14}{W}\right)^2 \times \left[a_1 \frac{S}{30} \times (1 + \%HV)^2 + a_2 PF \right] + a_3 LU \times CCF \right\} \times \frac{1}{10} \qquad (1)$$

where

ADT = average daily traffic,
L = total number of through lanes,
W = usable width of outside through lane (includes width of any bike lanes; measured from pavement edge, or gutter pan, to center of road, yellow stripe, or lane line, whichever is less),
LU = land use (intensity) adjoining the road segment (commercial value = 15, noncommercial value = 1),
CCF = curb cut (or on-street parking) frequency, a measure of uncontrolled access (i.e., turbulence per unit of distance),
PF = pavement factor [the reciprocal of FHWA Highway Performance Monitoring System (HPMS) PAVECON factor (*7*)],
S = speed limit,
HV = presence of heavy vehicles (e.g., trucks) expressed as decimal, and
a_1–a_3 = calibration coefficients initially equal to unity.

One of the strengths of the IHS model is its data format. The data needed for the model are collected objectively and economically. As shown in Table 1, the field data collection is standardized, requiring a minimum of subjective evaluation and technical skills.

TABLE 1 Data Inventory Guidelines

W=	Useable width of outside through lane [includes width of any bike lanes; measured from pavement edge, or gutter pan, to center of road, yellow stripe or lane line, whichever is less]
Bike Lane=	(Y or N) Only indicate "Yes" if there is a bona fide bike lane OR if the paved shoulder is 1.2 meters (4 feet) wide or greater
Comm. Land Use =	Indicate "Yes" only if there is at least thirty (30) percent of commercial uses adjoining the road segment. For the purposes of a windshield survey and this data's use in the Interaction Hazard scoring, "Commercial" land use is defined as any land uses other than single family residential (or agricultural).
Total Curb Cuts =	Record the number of non-controlled access points and on-street parking spaces of each segment
PAVECON =	Evaluate the pavement condition according to the FDOT's Roadway characteristics Inventory Feature 230 - Surface Description). If a bike lane is present, record that surface condition, not that of the auto lane. 5.0 Very good - Only new or nearly new pavements are likely to be smooth enough and free of cracks and patches to qualify for this category. 4.0 Good - Pavement, although not as smooth as those described above, gives a first class ride and exhibits signs of surface deterioration. 3.0 Fair - Riding qualities are noticeably inferior to those above, may be barely tolerable for high speed traffic. Defects may include rutting, map cracking, and extensive patching. 2.0 Poor - Pavements have deteriorated to such an extent that they affect the speed of the free-flow traffic. Flexible pavement has distress over 50 percent or more of the surface. Rigid pavement distress includes joint spalling, patching, etc. 1.0 Very Poor - Pavements that are in an extremely deteriorated condition. Distress occurs over 75 percent or more of the surface.

TABLE 2 IHS Model Sensitivity

$$IHS = \{(\frac{ADT}{L}) \times (\frac{14}{W})^2 \times [a_1 \frac{S}{30} \times (1+\%HV)^2 + a_2PF] + a_3LUxCCF\} \times \frac{1}{10} \quad (2)$$

Baseline Inputs:

ADT = 15,000 vpd	% HV = 0
L = 2 lanes	PF= 0.25 (good condition pavement)
W = 12 ft	LU = 15 (commercial area)
S = 45 mph	CCF = 42 per mile

and calibration coefficients $a_1 = a_2 = a_3 = 0.01$, 0.01, and 0.024 respectively

		IHS	% Change
Baseline Interaction Hazard Score (IHS)		19.3	N/A
Lane Width Modifications to Segment			
W = 11	(substandard)	22.7	18% increment
W = 12	(standard)	19.3	no change
W = 14	(wide outside lane)	14.5	24% reduction
W = 16	(dedicated bike lane)	11.5	40% reduction
Speed Control Measures			
S = 55		22.7	18% increase
S = 45	(baseline value)	19.3	no change
S = 40		17.6	9% reduction
S = 30		14.2	26% reduction
Traffic Volume Reduction Measures			
20,000		25.3	31% increase
15,000	(typical LOS D volume)	19.3	no change
10,000		13.4	31% decrease
5,000		7.5	61% decrease
1,000	(typical collector threshold)	3.8	80% decrease
Pavement Surface Conditions			
PF = 1.0	(PAVECON*= 1.0 very poor)	27.0	40% increase
PF = 0.5	(PAVECON = 2.0 poor)	21.9	13% increase
PF = 0.33	(PAVECON = 3.0 fair condition)	20.1	5% increase
PF = 0.25	(PAVECON = 4.0 good condition)	19.3	no change
PF = 0.20	(PAVECON = 5.0 new)	18.8	3% decrease
* The FDOT/HPMS Pavement Condition rating (see description in Table 1)			
Access (curb cut or on-street parking) Management			
CCF = 220	(Continuous Parallel Parking)	25.7	33% increase
CCF = 100	(Typical CBD Condition)	21.3	11% increase
CCF = 42	(Spacing = 125 ft)	19.3	no change
CCF = 22	(Spacing = 245 ft)	18.6	4% decrease
CCF = 12	(Spacing = 440 ft)	18.2	5% decrease
CCF = 8	(Spacing = 660 ft)	18.1	6% decrease
CCF = 4	(Spacing =1320 ft)	17.9	7% decrease
Truck Route Control			
%HV = 20%	(truck route-extremely high)	26.1	35% increase
%HV = 15%	(truck route-high)	24.3	26% increase
%HV = 10%	(truck route-typical)	22.6	17% increase
%HV = 5%	(typical of arterial)	21.0	9% increase
%HV = 2%	(typical of collector)	20.0	4% increase
%HV = 0%	(typical of local road)	19.3	no change

1 Km = 0.6 mi
1 m = 3.28 ft

Equation Adjustment and Sensitivity Analysis

Two nonstatistical adjustments were performed during the initial development of the IHS model: an inter-term and an overall equation. The inter-term adjustment was conducted first. Using the baseline inputs (representing a typical two-lane minor arterial) as shown in Table 2, the calibration coefficients a_1, a_2, and a_3 were adjusted to 0.01, 0.01, and 0.02, respectively. The final speed, pavement condition, and transverse terms compose 79, 13, and 8 percent of the equation's value, respectively. The first two terms, after mathematical distribution, are magnified by common volume, laneage, and lane width factors. On the basis of both consensus group meetings and interviews with bicyclists representing design cyclist Groups A, B, and C (*8*) (see definitions in Table 3), these percentages represent a consensus on the terms' reflection of bicyclists' perceptions.

Second, a total sensitivity analysis was conducted to adjust the equation with respect to changes in the variables. Table 2 also shows the corresponding IHS model values and their percentage change for various traffic and roadway conditions. Again, the consensus group and interview technique confirmed the appropriateness of the values of the constants a_1, a_2, and a_3 of this prestatistically adjusted version of the model.

SUGGESTED STATISTICAL CALIBRATION AND VALIDATION METHODOLOGY

Although research funding requests for statistical calibration of the IHS model are currently being made, the model is being used in several metropolitan areas with the initially adjusted calibration coefficients. Already, it has been well received by bicycle planners, who have expressed interest in its statistical calibration for transferability to other metropolitan areas.

The proposed calibration and validation methodology of the IHS model includes the use of a policy-capturing study (or Lens model). The following is the suggested design:

1. Randomly select 30 (the number of calibration coefficients multiplied by 10) road segments with inventoried geometric, traffic, and environmental conditions.
2. Obtain 90 volunteer bicyclists [at least 30 from each rider group (*8*)] and schedule the riding of the test road segments during common traffic periods.
3. Have the volunteers complete questionnaires designed to quantify their perception of the riding hazard of each segment, resulting in the availability of 2,700 observations for regression analysis.
4. Use the following statistical technique: (*a*) Multiple regression analysis will be made. (*b*) If the perceptions are statistically significant, separate model forms (calibration coefficients) will be established. (*c*) Otherwise, a single model form establishing the values of the calibration coefficients a_1, a_2, and a_3 will be adequate. (*d*) Determination of whether there is a statistical difference among the perceptions of the rider groups will be made.
5. Videotape a rider's view of all road segments. The same volunteers participating in Steps 2 and 3 will complete questionnaires to assist in the determination of whether correlation is strong between actual riding perception versus video-viewing per-

TABLE 3 Design Cyclist Groups

- Group A - Advanced Bicyclists: Experienced riders who can operate under most traffic conditions, they comprise the majority of the current users of collector and arterial streets and are best served by the following:
    - Direct access to destinations usually via the existing street and highway system.
    - The opportunity to operate at maximum speed with minimum delays.
    - Sufficient operating space on the roadway or shoulder to reduce the need for either the bicyclist or the motor vehicle operator to change position when passing.
- Group B - Basic Bicyclists: These are casual or new adult and teenage riders who are less confident of their ability to operate in traffic without special provisions for bicycles. Some will develop greater skills and progress to the advanced level, but there will always be many millions of basic bicyclists. They prefer:
    - Comfortable access to destinations, preferably by a direct route; either low-speed, low traffic-volume streets or designated bicycle facilities.
    - Well-defined separation of bicycles and motor vehicles on arterial and collector streets (bike lanes or shoulders), or on separate bike paths.

Group C - Children: Pre-teen riders whose roadway use is initially monitored by parents, eventually they are accorded independent access to the system. They and their parents prefer the following:

- Access to key destinations surrounding residential areas, including schools, recreation facilities, shopping, or other residential areas.
- Residential streets with low motor vehicle speed limits and volumes.
- Well-defined separation of bicycles and motor vehicles on arterial and collector streets, or on separate bike paths.

ception. If the correlation is strong, then the video-based approach in other geographic areas will provide for relatively inexpensive validation studies for model transferability.

6. Finalize the IHS model equation and publish the report.

Comments from reviewers and attendees at the 73rd Annual Meeting of the Transportation Research Board suggest that (*a*) the denominator in the speed term should be 10 mph instead of 30 mph to reflect the AASHTO design for bicyclists and (*b*) research indicates that pavement condition does not affect the bicyclist's perception of hazard. During the statistical calibration of the model, these issues should be investigated.

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