Pedestrian and Bicyclist Level of Service on Roadway Segments

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The Danish Road Directorate sponsored a study to develop methods for objectively quantifying pedestrian and bicyclist stated satisfaction with road sections between intersections. The results provide a measure of how well urban and rural roads accommodate pedestrian and bicycle travel. To determine how existing traffic operations, geometric conditions, and other variables affect pedestrians' and bicyclists' satisfaction, 407 randomly selected Danes were shown video clips from 56 roadway segments filmed by a pedestrian walking and a bicyclist riding along the road. Respondents rated the roadway segments on a six-point scale ranging from very dissatisfied to very satisfied. This resulted in 7,724 pedestrian ratings and 7,596 bicyclist ratings. Roadway segments and video clips were described by 150 variables. Pedestrian and bicyclist satisfaction models were developed by cumulative logit regression of the ratings and the variables. The models included variables that related significantly ($p \leq .05$) to the satisfaction ratings. Variables that significantly influenced the level of satisfaction were motorized traffic volume and speed; urban land uses; rural landscapes; the types and widths of pedestrian and bicycle facilities; the numbers and widths of the drive lanes; the volumes of pedestrians, bicyclists, and parked cars; and the presence of median, trees, and bus stops. The models returned the percentage splits of the six levels of satisfaction. These splits were then transformed into a level of service. The models provide traffic planners and others the ability to rate roadways according to pedestrians' and bicyclists' satisfaction and may be used in the process of evaluating existing roads, designing new roads, or redesigning existing roads.

Over the years, the national Danish Road Directorate and local Danish road administrations have occasionally surveyed road users about their perceptions and experiences and have attempted to identify connections between road conditions and user perceptions. However, none of the methodologies developed to describe pedestrian and bicyclist level of service (LOS) or to offset priorities for pedestrian and bicycle facility construction has been widely accepted. The objective of this study was to develop a rigorous methodology that would systematically describe the LOSs that pedestrians and bicyclists experience on roadway segments; that is, road sections between intersections.

Over the past decade, some American studies have been undertaken to develop systematic means of measuring the LOSs that pedestrians and bicyclists experience (*1–6*). Even though these studies have used various study designs, model development techniques, and LOS criteria, each of the models that have been produced has a high degree of validity. These studies provided a solid methodological base for the Danish study.

Because these studies were based on an American context, it was important to develop models by taking Danish conditions into consideration. Some important differences are that Danes walk and cycle more than Americans, pedestrian and bicycle facilities are more commonly present in Denmark, and the designs of some of these facilities are different from those of facilities in the United States. The paper includes a comparison of the Danish and American models.

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STUDY DESIGN

The study basically used a stated preference survey in which each roadway segment was rated based on a fixed scale. The methodology was to have respondents view numerous roadway segments captured on videotape and rate these segments with respect to how satisfied they would be walking and riding a bicycle under the roadway conditions shown on the videos. The video-based methodology has several advantages:

- The number of roadway segments that respondents can rate during a reasonable time frame is high. For example, each respondent rated 44 roadway segments within 56 min in this study.
- One can reach a more diverse group of respondents.
- It is more cost-effective than having respondents on site.
- The exact same roadway and traffic conditions, for example, may be experienced by many respondents; the conditions to be rated can be chosen from several videotapes of the same roadway segment. This form of variable control is impossible when respondents actually walk and ride on the roadway.
- There are no traffic risks to the respondents, which makes it easier to include roadway segments that may include high perceived risks.

Harkey et al. tried to validate a video-based methodology using a stationary camera (*2*). Overall, they concluded that the video-based methodology is a valid technique for obtaining realistic perspectives of bicyclists. However, they did not calibrate their video-based findings to bicyclists riding on roadways. They validated viewpoints only from respondents who were standing still; that is, they did not obtaining realistic perspectives of bicyclists.

Site Selection

With a relatively small number of roadway segments, it is important to maximize the range of conditions included. Before site selection, an orthogonal experimental design was developed. The intent of the design not only was to ensure that the sites selected represented the variety of conditions that pedestrians and bicyclists may encounter, but also that the five factors that prior studies have found to affect pedestrian and bicyclist experienced LOSs were orthogonal; that is, there were no relations between factors across the sites. The five factors and their related categories can be found in Table 1.

A total of 38 urban roadways and 18 rural roadways that matched the orthogonal experimental design were found. All roadways were located within 85 km of Copenhagen, the capital of Denmark, which has a population of approximately 1.5 million. Photos from four of the roadways studied are shown in Figure 1.

The geometric and operational characteristics of the roadway segments that were videotaped varied considerably across the sites and were as follows:

- Average annual daily traffic (AADT) = 500 to 30,000 on urban roads and 1,500 to 13,000 on rural roads;
- Motorized traffic per 40 s = 0 to 31 on urban roads and 1 to 15 on rural roads;
- Average speed of motor vehicles = 27 to 59 km/h on urban roads and 48 to 86 km/h on rural roads;
- Speed limit = 30 to 80 km/h;
- Sidewalk width = 0.8 to 4.5 m;
- Bicycle track width = 1.7 to 2.5 m;
- Bicycle lane width = 1.4 to 1.7 m;
- Paved shoulder width = 0.9 to 1.6 m; and
- Width of outer drive lane = 2.8 to 6.0 m.

Video Production

All video recordings were made in the fall during daylight hours, with no precipitation and no snow on the ground. Video recordings were made by a pedestrian moving at normal pace, which is about 5 km/h, along the road in the middle of the sidewalk or, if no sidewalk was present, on the outer part of a sealed pavement. Half of the pedestrian video recordings were made while the pedestrian was going in the opposite direction of the nearest vehicles, and the other half were made while the pedestrian was going in the same direction. The other set of video recordings was made by a bicyclist moving at about 20 km/h on the bicycle facility or, if no bicycle facility was present, on the outer drive lane in both instances about 50 to 75 cm from the outer edge. Overtaking and ride-bys or walk-bys were done as a traveler would normally proceed.

A Steadycam camera was mounted on each pedestrian and bicyclist. This enabled the individual to control the camera with one hand and avoid shaky pictures. The cameras were approximately 1.5 m above the ground and were angled slightly downwards and toward the opposite roadside so that the respondents could see both sides of the road and glimpses of the sky. Digital and physical shields were used to filter out wind noise. Recordings were made in stereo. Recordings that had barking dogs, sirens, and other highly infrequent sounds were excluded.

Data were collected by viewing each video clip. These data included the placement and the direction of the individual holding the camera; the weather; sounds other than traffic noise; visible signs and markings; visible objects (e.g., bus shelters, humps, parked bicycles, and exhibited goods); and the numbers of parked cars, pedestrians, bicyclists, motorized two-wheelers, motor vehicles with weights of <3.5 tons, and motor vehicles with weights of >3.5 tons.

Each roadway segment was filmed 6 to 12 times by a pedestrian and bicyclist, and the best 40-s video clips meeting the requirements of the orthogonal experimental design were used.

Field Data Collection

Measurements of the speeds of single motor vehicles in the middle of the roadway segment were made right before or after videotaping.

TABLE 1 Factors and Categories in Orthogonal Design of Site Selection

Location	Factor	Categories
Urban roadways	Motor vehicles (AADT/vehicles per 40 s)	<3,500/0–2 3,500–7,499/3–5 7,500–12,500/6–8 >12,500/9 or more
	Average speed of motor vehicles (km/h)	<45 45–49 50–55 >55
	Type of pedestrian facility	Sidewalk No sidewalk
	Type of bicycle facility	One-way bicycle track (curb or diving verge to drive lane) Bicycle lane (inclusive 30 cm white line to drive lane) Drive lane
	Type of land use/buildings	Shopping (>30% shops in ground floor) Residential Mixed use (<30% shops and <50% housing in ground floor)
Rural roadways	Motor vehicles (AADT/vehicles per 40 s)	<3,500/0–2 3,500–9,500/3–6 >9,500/7 or more
	Average speed of motor vehicles (km/h)	<75 75–83 >83
	Type of pedestrian and bicycle facility	One- or two-way bicycle track (diving verge to drive lane) Paved shoulder (inclusive 20 cm or wider white line to drive lane) Drive lane

(a) (b)

(c) (d)

FIGURE 1 Photos from the roadways studied: (*a*) shopping street with sidewalks and one-way bicycle tracks, (*b*) residential road with sidewalks and bicycle lanes, (*c*) rural road in forest with paved shoulders, and (*d*) urban road with one-way bicycle tracks (author is using Steadycam).

The measurements were then used to calculate the average and the 85th percentile speeds.

The fixed conditions of roadway segments were measured and described. These included the cross section; alignment; the type and the quality of pavements, signs, and markings; the speed limit; road lighting; the numbers and the designs of driveways and minor side roads; buildings; land uses; and landscape.

Respondents, Video Shows, and Questionnaire

Citizens of 12 to 80 years of age were randomly selected through the Central Office of Civil Registration in Denmark. A total of 3,024 citizens in two municipalities were invited to participate. About 13% of the invited citizens, 223 women and 184 men, participated as respondents in the video shows. As compensation for participating, the respondents were given a voucher (DKK 140; DKK 1 = $0.17 in 2006) for two cinema tickets. The compensation was mentioned in the invitation. The videos were shown in local ballrooms by using professional video projectors on screens 2.7 × 2.0 m and sets of stereo loudspeakers. The sound was set so that it matched the sound in real traffic. Between 20 and 43 respondents participated in the individual video shows. Each video clip was shown in four video shows and was rated by 113 to 161 respondents.

In rating surveys like those used in this study, a stated preference survey may particularly result in biased relationships because of, for example, respondent fatigue and policy response bias (*7, 8*). Respondent fatigue can occur for several reasons. The respondent may not have learned how to rate the alternative or the respondent may be bored or mentally tired. Two typical things that occur because of respondent fatigue are that the respondent rates roadway segments worse as fatigue increases and the rating of a roadway segment is transferred to the next segment. Policy response bias occurs when the respondent consciously tries to affect the survey results because of political conviction.

Basically, a respondent attended a 56-min video show that included a welcome, presentation of the questionnaire, the provision of answers to eight background questions (age, sex, rural or urban residence, type of residence, number of kilometers walked weekly, number of kilometers bicycled weekly, the aids used for walking, and whether the respondent was able to bicycle without problems), two learner video clips, a time for questions and answers, the first rating session with 21 video clips, a 10-min break with refreshing soft drinks, a second rating session with 21 video clips, and a closure. If the learner clips and the first rating session included the pedestrian video clips, then the second session was the bicycle video clips, and vice versa. Half of the video shows were with pedestrian video clips in the first rating session. A video show included several measures to avoid biased relationships:

- The brief, neutral welcome presentation was made on video so that it was the same in each of the 12 video shows conducted. The text of the presentation was as follows:

> Welcome to the Road Directorate's survey of pedestrian- and bicyclist-experienced level of service. The survey is made in collaboration with the municipalities of Roskilde and Naestved. The survey's objective is to develop a tool that can improve the planning for pedestrian and bicycle traffic. Because of your participation, it may follow that more pedestrian and bicyclists are satisfied with the roads that they experience in the future. This evening you will see a set of video clips showing different roads that you must rate with respect to how satisfied you are with them.

- Besides the eight background questions, the questionnaire only included space to provide a rating of each video clip; that is, there was no guiding text to avoid a policy response bias.
- Two video clips served as learner clips before the rating sessions began. The respondents could pose questions in a short break between the leaner clips and the first rating session. The ratings for the learner clips were not used for model development. One of the learner clips was repeated at a fixed place in the middle of the first rating session.
- The rating was kept as simple as possible and was based on a short question: "How satisfied were you as a pedestrian on the road shown?" If the video clip was made by a bicyclist, then "pedestrian" was replaced by "bicyclist" in the question. The question could be answered by ticking off a six-point scale, ranging from very dissatisfied to very satisfied. The respondents had 10 s between video clips to make a rating.
- The order of the urban and the rural video clips was randomized. Every third video clip was from rural roadway segments and the others were from urban roadway segments.
- In every rating session, one "repeater" roadway segment was shown at least seven video clips after the same roadway segment had been shown previously. This repeater was filmed at exactly the same part of the roadway segment as its original, but with different traffic volumes. Repeaters were used to assess the individual respondent's ability to detect minor changes and to provide identical answers. The ratings of repeater clips were not used for model development.

MODEL DEVELOPMENT

The models were developed by using SAS (version 8.1) software. The PROC GENMOD calculation procedure in the SAS software was used to set up ordinary generalized linear models (GLMs), which included independent continuous and class variables. The GLMs use the mean ratings for each roadway segment on a nominal scale (Table 2). The PROC LOGISTIC calculation procedure in the SAS software was used to set up cumulative logit models (CLMs) and ordinal probit models (OPMs), which also included independent continuous and class variables. The CLM and OPM models use response ratings on an ordinal scale. The GLMs and OPMs produce larger residuals than the CLMs, and therefore, only the CLMs are presented in this paper.

The respondents used the six different responses on the rating scale almost to the same degree. The ratings for individual roadway segments were very different. The average on the nominal scale varied between 1.52 and 5.70 for the different roadway segments rated as pedestrian and between 1.30 and 5.66 for the different roadway segments rated as bicyclist.

Some of the original data that were collected from the viewing of the video clips are not relevant for inclusion in the final models because road administrations and others that are to use the models do not have the data in the specific format or do not have any data at all. The variables that significantly ($p \leq .05$) related to the satisfaction ratings and that were filtered out and not included in the final models are as follows:

- Walking direction. Walking direction influences pedestrian satisfaction. Pedestrians walking in the opposite direction of vehicular traffic nearby are more satisfied than pedestrians walking in the same direction as traveling vehicles. The difference becomes greater

TABLE 2 Response Satisfaction Ratings of the 56 Roadway Segments

		Responses (percent of column total)		
Nominal Scale	Ordinal Scale	As Pedestrian	As Bicyclist	Total
1	Very satisfied	1,419 (18)	924 (12)	2,343 (15)
2	Moderately satisfied	1,708 (22)	1,425 (19)	3,133 (20)
3	A little satisfied	1,276 (17)	1,259 (17)	2,535 (17)
4	A little dissatisfied	858 (11)	1,012 (13)	1,870 (12)
5	Moderately dissatisfied	1,016 (13)	1,348 (18)	2,364 (15)
6	Very dissatisfied	1,447 (19)	1,628 (21)	3,075 (20)
Total		7,724 (100)	7,596 (100)	15,320 (100)
Average on the nominal scale		3.35	3.70	3.52

as motor vehicle speeds increase. On average, the difference on the nominal scale was 0.2. The variable was filtered out by setting the walking direction to 50% in the opposite direction and 50% in the same direction in urban areas and to 85% in the opposite direction and 15% in the same direction in rural areas. The splits in walking direction are typical in Denmark.

- Sounds other than traffic noise. Sounds other than traffic noise affect both pedestrian and bicyclist satisfaction. Such sounds may be birds chirping, people talking loudly, wind noise, noise from the Steadycam, and so forth. Bird chirping results in an improvement with the level of satisfaction that is quite high. The differences between no sounds other than traffic noise and bird chirping on the nominal scale were 1.2 and 0.7 for pedestrians and bicyclists, respectively. The variable was filtered out by setting it to no sounds other than traffic noise.
- Weather. Weather also affected both pedestrian and bicyclist satisfaction. Danes apparently prefer sunny weather over cloudy weather or streets in shade. The variable was filtered out by setting it to sun.
- Pavement quality. Pavement quality affected bicyclist satisfaction. The cycling cameraman rode on asphalt on all roadway segments. The number of cracks, debris, and so forth seen on the video clips affected the ratings. The variable was filtered out by setting it to good paved and clean asphalt conditions.

The variables that significantly ($p \leq .05$) related to the satisfaction ratings and the original format have been changed and are included in the final models are as follows:

- Passed motor vehicles and passed bicycles. The numbers of passed motor vehicles and passed bicycles, which were counted during the viewing of a 40-s video clip from a moving pedestrian and bicyclist, were changed into hourly traffic volumes.
- Passed pedestrians. The number of passed pedestrians was changed from the number observed in a 40-s video clip to the number observed in an hour. The reason why this is different from motor vehicle and bicycle traffic is that some of the passed pedestrians were standing still.
- Passed parked cars. The number of passed parked cars was changed from the number observed in a 40-s video clip to the number observed per 100 m of roadway.

Demographics

There were no relationships between satisfaction ratings and demographics at a significance level (p-value) of $\leq .05$. However, there were tendencies. Men seemed to be more satisfied than women (Table 3). Elderly people seemed to be more dissatisfied than youth.

TABLE 3 Average Response Satisfaction Ratings on the Nominal Scale for All Roadway Segments by Various Groups of People

Group of Respondents	Respondents	Rating Average on Nominal Scale
All	407	3.52
Female	223	3.56
Male	184	3.47
12–29 years old	124	3.47
30–49 years old	125	3.49
50–80 years old	157	3.59
Urban resident	386	3.53
Rural resident	20	3.35
Living in detached house	220	3.54
Living in terraced house	63	3.55
Living in flat	96	3.53
Living in farmhouse	6	3.36
Living in student hostel	7	3.31
Living in other housing	15	3.29
0–1 km walking per week	11	3.65 (pedestrian ratings)
2–3 km walking per week	85	3.31 (pedestrian ratings)
4–6 km walking per week	128	3.30 (pedestrian ratings)
7–10 km walking per week	95	3.32 (pedestrian ratings)
11+ km walking per week	88	3.43 (pedestrian ratings)
0–5 km bicycling per week	114	3.70 (bicyclist ratings)
6–10 km bicycling per week	72	3.77 (bicyclist ratings)
11–20 km bicycling per week	81	3.61 (bicyclist ratings)
21–40 km bicycling per week	76	3.64 (bicyclist ratings)
41+ km bicycling per week	61	3.81 (bicyclist ratings)
Do not use walking aids	404	3.35 (pedestrian ratings)
Use walking aids	2	2.68 (pedestrian ratings)
Can ride a two-wheeled bike	397	3.70 (bicyclist ratings)
Cannot ride a two-wheeled bike	9	3.63 (bicyclist ratings)

Urban residents seemed to be more satisfied than rural residents. Respondents who walk or bicycle very infrequently or very often seemed more to be dissatisfied than respondents who walk and bicycle some kilometers every week. The number of respondents who need aids to walk or who are unable to ride a normal two-wheel bicycle was very small; however, these respondents seemed to be more satisfied. There were no significant differences on the basis of which municipality people lived in. These analyses indicate that demographic data would not be relevant for inclusion in the models.

Pedestrian Model

Determining the key independent variables that influence pedestrian satisfaction was the primary objective of the data analysis. The approach was to use CLM stepwise regression to determine all main effects, search for significant square and interaction terms, and eliminate all variables that were not significant at a p level of ≤.05. Fisher's scoring optimization technique was used. The response variable is the six levels of satisfaction, for example, the number of very satisfied responses.

Some variables described more or less the same thing, and one significant variable had to be selected. For example, the best variable that described motor vehicle speed had to be chosen; and so motor vehicle speed was represented by the average speed, the 85th percentile speed, the speed limit, and the presence of speed-reducing measures. Another situation was to create new variables on the basis of two or more original variables. For example, instead of having a variable describing the width of a driving verge and another describing the width of a parking lane, it was better having one variable describing the width of a buffer area between the nearest drive lane and the pedestrian or bicycle facility.

Equation Box 1 shows the utility functions of the CLMs that were found to predict pedestrian satisfaction the best. This model includes 13 main effects, three squares, and one interaction term. The predicted six shares of level of satisfaction may be calculated on the basis of the utility function in the following manner:

$$
\begin{aligned}
\text{SHARE}_{\text{very satisfied}} &= 1 - 1/(1 + \exp(\text{logit}(p)_{\text{very satisfied}})) \\
\text{SHARE}_{\text{moderately satisfied}} &= 1 - \text{SHARE}_{\text{very satisfied}} \\
&\quad - 1/(1 + \exp(\text{logit}(p)_{\text{moderately satisfied}})) \\
&\ldots \\
\text{SHARE}_{\text{very dissatisfied}} &= 1 - \text{SHARE}_{\text{very satisfied}} \\
&\quad - \text{SHARE}_{\text{moderately satisfied}} \\
&\quad - \text{SHARE}_{\text{a little satisfied}} \\
&\quad - \text{SHARE}_{\text{a little dissatisfied}} \\
&\quad - \text{SHARE}_{\text{moderately dissatisfied}}
\end{aligned}
$$

The CLM model in Equation Box 1 has an R^2 value of .55 and a maximum rescaled R^2 value of .57. On average, the residual or the difference between response satisfaction and predicted satisfaction for roadway segments is 0.09 on the nominal scale for the pedestrian model. The reader may notice that the mathematical distances between intercept parameters of the response level of satisfaction in Equation Box 1 are not the same; that is, the respondents do not value the distance between, for example, "very satisfied" and "moderately

EQUATION BOX 1

$$
\text{logit}(p) = \alpha \begin{bmatrix} \text{very satisfied} = -2.8526 \\ \text{moderately satisfied} = -1.2477 \\ \text{a little satisfied} = -0.0646 \\ \text{a little dissatisfied} = 0.8758 \\ \text{moderately dissatisfied} = 2.2543 \end{bmatrix} + \text{WA} \begin{bmatrix} \text{sidewalk-concrete flags} = 3.5486 \\ \text{sidewalk-asphalt} = 1.9149 \\ \text{bicycle path/track} = 1.0124 \\ \text{bike lane/paved shoulder} = -2.8293 \\ \text{driving lane} = -3.6464 \end{bmatrix} + \text{AREA} \begin{bmatrix} \text{residential} = 0.4871 \\ \text{shopping} = 0.5385 \\ \text{mixed} = -1.6349 \\ \text{rural fields} = 1.2380 \\ \text{rural forest} = 0.5122 \end{bmatrix}
$$

$$
\begin{aligned}
&-0.002476 \bullet \text{MOT} + 0.0000003364 \bullet \text{MOT}^2 - 0.0303 \bullet \text{SPEED} + 0.00002211 \bullet \text{SPEED} \bullet \text{MOT} - 0.005432 \bullet \text{PED} \\
&+ 0.000005062 \bullet \text{PED}^2 - 0.003772 \bullet \text{BIKE} + 0.000003111 \bullet \text{BIKE}^2 + 0.4408 \bullet \text{BUF} - 0.0365 \bullet \text{BUF}^2 - 0.05286 \bullet \text{PARK} \\
&+ 1.0180 \bullet \text{MED} + 0.2938 \bullet \text{SB} + 0.6277 \bullet \text{BL} + 0.7380 \bullet \text{LANE} + 0.3311 \bullet \text{TREE}
\end{aligned}
$$

where

logit(p) = utility function of the cumulative logit model,
α = intercept parameter of the response level of satisfaction,
WA = type of walking area,
AREA = type of roadside development or landscape,
MOT = motor vehicles per hour in both directions,
SPEED = average motor vehicle speed (km/h),
PED = passed pedestrians per hour on nearest roadside at 5 km/h walking speed,
BIKE = bicycles and mopeds per hour in both directions,
BUF = width of buffer area between walking area and drive lane (m),
PARK = parked motor vehicle on road per 100 m,
MED = median dummy, no median = 0, median = 1,
SB = width of walking area, if this is a sidewalk or bicycle path/track (m),
BL = total width of walking area and nearest drive lane, if walking area is a bicycle lane, paved shoulder or drive lane (m),
LANE = drive lane dummy, four or more drive lanes = 1, one to three lanes = 0,
TREE = tree dummy, one tree or more on road per 50 m = 1, otherwise 0.

satisfied" and the distance between "moderately satisfied" and "a little satisfied" the same.

The variables with the greatest effects on pedestrian satisfaction are the type and the width of the walking area and the distance to the motor vehicles in the nearest drive lane (WA, BUF, SB, and BL). As pedestrians become more separated from motor vehicles and bicycles, they become more satisfied. Pedestrians become more dissatisfied as the volumes of motor vehicles, bicycles, and pedestrians and also the number of parked motor vehicles increase. Increasing motor vehicle speed makes pedestrians more dissatisfied. The presence of a median, four or more drive lanes, and trees makes pedestrians more satisfied.

That pedestrians become more dissatisfied as the number of parked motor vehicles increases contradicts the findings of Landis et al. (5), who found the opposite; that is, the presence of more parked cars results in more satisfied pedestrians. This discrepancy may be explained to some degree by the various definitions of the variables. The variable BUF in Equation Box 1 includes the width of marked or curbed on-street parking, but also includes a 2-m-wide "parking lane" if there are three or more parked cars per 100 m of roadside with no marking or curbing for parking. The reason for this definition is that the relatively low number of parked cars will actually generate a buffer between the sidewalk and driving cars. The findings for the Danish population are that as the buffer between the sidewalk and driving cars become wider—for example, because of parked cars, bicycle facilities, and dividing verges—pedestrians become more satisfied, whereas the presence of more parked cars results in more dissatisfied pedestrians.

Bicycle Model

The data analysis and regression used to find the bicycle model were performed in the same manner used for the pedestrian model. Equation Box 2 shows the utility functions of the CLMs found to predict bicyclist satisfaction the best.

The bicycle model includes 14 main effects, two squares, and four interaction terms. The CLM model in Equation Box 2 has an R^2 value of .52 and a maximum rescaled R^2 value of 0.53. The average residual for roadway segments is 0.19 on the nominal scale for the bicycle model. Hence, the pedestrian model fits the responses better than the bicycle model does.

The variables with the greatest effects on bicyclist satisfaction are the type and the width of the bicycle facility or drive lane and the distance to both motor vehicles in the nearest drive lane and pedestrians (LBUF, PATH, ULAN, RSHO, DBL, RBUF, and SW). As bicyclists become more separated from motor vehicles and pedestrians, they become more satisfied. Bicyclists become more dissatisfied as the volumes of motor vehicles and pedestrians and also the number of parked motor vehicles increase. Increasing motor vehicle speed makes bicyclists more dissatisfied. The presence of four or more drive lanes and sidewalks makes bicyclists more satisfied, whereas the presence of bus stops makes them more dissatisfied.

The relationship in which bicyclists become more dissatisfied as the volume of pedestrians increases also applies to shared-use paths (*9*). However, this Danish study is the first to show that the relationship applies to roadway environments. The influence of pedestrians on bicyclist satisfaction is complex. Pedestrians going to or from

EQUATION BOX 2

$$\operatorname{logit}(p) = \alpha \begin{bmatrix} \text{very satisfied} = -1.3652 \\ \text{moderately satisfied} = 0.3741 \\ \text{a little satisfied} = 1.5512 \\ \text{a little dissatisfied} = 2.4805 \\ \text{moderately dissatisfied} = 3.8449 \end{bmatrix} + \text{AREA} \begin{bmatrix} \text{residential} = 0.0557 \\ \text{shopping} = -0.3400 \\ \text{mixed} = -0.0334 \\ \text{rural fields} = -0.0196 \\ \text{rural forest} = 0.3369 \end{bmatrix} - 0.0005585 \bullet \text{MOT} - 2.3895 \bullet \text{LBUF} + 0.0004691$$

$$\bullet \text{MOT} \bullet \text{LBUF} - 0.0958 \bullet \text{SPEED} + 0.000421 \bullet \text{SPEED}^2 - 0.000002913 \bullet \text{MOT} \bullet \text{SPEED} + 0.0402 \bullet \text{LBUF} \bullet \text{SPEED}$$

$$+ 0.000002446 \bullet \text{MOT} \bullet \text{LBUF} \bullet \text{SPEED} - 0.001623 \bullet \text{PED} + 0.0000008309 \bullet \text{PED}^2 - 0.09416 \bullet \text{PARK} + 1.7782 \bullet \text{PATH}$$

$$+ 1.3938 \bullet \text{ULAN} + 2.5196 \bullet \text{RSHO} + 0.2413 \bullet \text{DBL} - 0.2593 \bullet \text{RBUF} + 1.2694 \bullet \text{SW} - 0.6988 \bullet \text{BUS} + 0.6821 \bullet \text{LANE}$$

where

logit(p) = utility function of the cumulative logit model,
α = intercept parameter of the response level of satisfaction,
AREA = type of roadside development or landscape,
MOT = motor vehicles per hour in both directions,
LBUF = width of buffer area between bicycle facility and drive lane on the nearest roadside (m),
SPEED = average motor vehicle speed (km/h),
PED = passed pedestrians per hour on nearest roadside at 20 km/h riding speed,
PARK = parked motor vehicle on nearest roadside per 100 m,
PATH = width of bicycle path/track on nearest roadside (m),
ULAN = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in urban areas (m),
RSHO = width of bicycle lane/paved shoulder (at least 0.9 m wide) on nearest roadside in rural areas (m),
DBL = width of nearest drive lane including bicycle lane/paved shoulder of less than 0.9 m width (m),
RBUF = width of buffer area between sidewalk and bicycle facility/drive lane (m),
SW = sidewalk dummy, sidewalk on nearest roadside = 1, no sidewalk = 0,
BUS = bus stop dummy, bus stop on roadway = 1, no bus stop = 0,
LANE = drive lane dummy, four or more drive lanes = 1, one to three lanes = 0.

buses and parked vehicles may result in some sort of interaction with bicyclists, which they perceive negatively. Bicyclists have fewer interactions per pedestrian when they walk on sidewalks.

Both pedestrians and bicyclists become more satisfied as the number of drive lanes increases, given the same volume of motor vehicle traffic. The logical reason for this is that the average motor vehicle drives farther away from pedestrians and bicyclists as the number of drive lanes increases.

Biases

The respondents rated the learner video clip that was repeated 10 video clips later almost the same. A total of 263 of 404 responses, or 65% of the ratings, were exactly the same. Eighty-nine percent of the ratings of the learner and the repeated video clips were not more than one response level of satisfaction from each other. There were no significant differences in the average ratings and the standard deviations of the ratings between the learner and the repeated video clips. This means that some respondents actually did have rating problems at the beginning or throughout the entire rating session. However, these problems did not affect the rating of a roadway segment done by all respondents together, because the number of respondents who started with a too satisfied rating was almost the same as the number of respondents who started with a too dissatisfied rating. Because of the simplicity of the rating system and the lack of influence from learner rating problems, it would be possible to use intercept interviews of road users instead of test participants, if one wishes, to rate roadway segments, intersections, and so forth in the field. However, the use of intercept interviews would require a greater number of respondents.

The video clips were randomized only once. The pedestrian and bicycle video clips were each then divided into three portions. The 21 video clips in a rating session were shown in four ways, that is, the first rating session, the first rating session in reversed order, the second rating session, and the second rating session in reversed order. By doing so it was possible to detect respondent fatigue. There was a weak tendency for the respondent ratings to become more dissatisfied during the rating sessions; however, the average rating worsened by only 0.05 on the nominal scale from video clips 1 to 21.

The use of repeater roadway segment video clips enabled comparisons of response and modeled satisfaction because of changes in the traffic conditions on the same roadway. In total, there were 12 of these repeaters. The direction of the change in satisfaction because of a change in traffic was the same for 11 of the 12 repeaters when the responses and the modeled satisfaction were compared. The magnitude of the difference in satisfaction for the repeater video clip with different traffic volumes and the original video clip was almost the same as that when the response and the modeled satisfaction were compared. The averages on the nominal scale of the 12 original video clips were 3.92 and 3.85 for response and modeled satisfaction, respectively, whereas the averages for the repeater video clips were 3.79 and 3.77, respectively. This indicates that the models may very slightly underestimate the influence that traffic volumes have on pedestrian and bicyclist satisfaction.

Overall, it may be concluded that the possible biases that may arise because of the study design are small and may be neglected.

LOS CRITERIA

The LOS criteria are based on the split of the response levels of satisfaction. To remain consistent with the *Highway Capacity Manual* (*10*), six LOS designations (LOSs A through F) were defined as follows. A "democratic" definition of LOS is used. This means that LOS is designated A if 50% or more of the respondents are very satisfied, LOS is designated B if 50% or more are very or moderately satisfied and less than 50% are very satisfied, and so forth, ending up with an LOS of F if 50% or more are very dissatisfied.

These definitions make it much easier to grasp road user satisfaction and to present the models relationships. Figure 2 presents the relations between bicycle LOS and the type of bicycle facility and motor vehicle volume and speed.

Increasing the number of hourly motor vehicles by 100 results in a worsening of approximately 0.05 on the nominal scale of both pedestrian and bicyclist satisfaction, which is about the same as $\frac{1}{16}$ of an LOS designation. An increase in the average motor vehicle speed by 5 km/h results in a worsening of approximately 0.1 of pedestrian satisfaction and 0.2 of bicyclist satisfaction; i.e., about one-eighth and one-fourth of an LOS designation, respectively. Increasing the bicycle lane width by 0.1 m results in an improvement of bicyclist satisfaction of about 0.1, and a 0.2-m widening of the sidewalk results in an improvement of pedestrian satisfaction of about 0.04.

It is important to have precise information about existing pedestrian and bicycle facilities; for example, average widths to the nearest 0.1 or 0.2 m should be used to estimate satisfaction and LOS by using the models. Other continuous variables like traffic volumes,

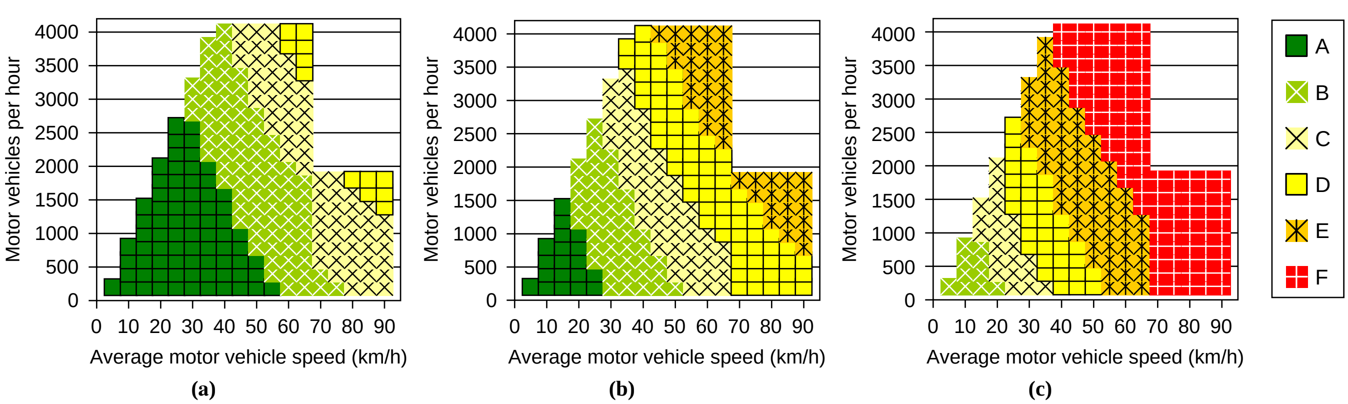

FIGURE 2 Bicycle LOSs of three types of bicycle facilities, depending on motor vehicle speed and hourly motor vehicle volume. Baseline conditions were as follows: (*a*) the nearest drive lane is 3.75 m wide; (*b*) the urban residential road had sidewalks and speeds of 0 to 65 km/h; and (*c*) the rural road has fields, no sidewalks, and speeds of 70 to 90 km/h. The models are not valid in the white areas.

motor vehicle speed, and number of parked motor vehicles are less important to pedestrian and bicyclist satisfaction and LOS on roadway segments. Precise information about these other continuous variables is not necessary; for example, rounding of the hourly motor vehicle traffic to the nearest 100 is sufficient.

COMPARING AMERICAN AND DANISH MODELS

The Danish models were compared with four American models. All American models make use of average ratings on the nominal scale of the same kind as those in Table 2. The estimates based on the Danish CLMs have been changed into average ratings on the nominal scale for comparison with the American models.

The pedestrian model was relevant for comparison with the American model described by Landis et al. (*5*). For an optimal comparison, the following baseline conditions were used: the road had two 3.6-m-wide drive lanes, no bicycle facility, 1.8-m-wide sidewalks of asphalt, 500 motor vehicles per hour, an average motor vehicle speed of 60 km/h, no parking, no bicycle and pedestrian traffic, no trees, and rural fields in the area. This baseline condition gives a pedestrian rating of 2.62 by use of the Danish model and a pedestrian rating of 2.79 by use of the American model. If the sidewalk is removed, the pedestrian rating is worsened; that is, pedestrians are more dissatisfied; by 2.64 by use of the Danish model and 1.36 by use of the American model. An increase in the number of motor vehicles per hour from 500 to 1,000 results in a worsening pedestrian rating; by 0.23 by use of the Danish model and by 0.18 by use of the American model. If the average speed increases from 60 to 70 km/h, the pedestrian rating is worsened by 0.14 by use of the Danish model and by 0.23 by use of the American model.

The bicycle model was relevant for comparison with three American models, which have been described elsewhere (*2–4*). The following baseline conditions are used: a road with two 5.1-m-wide drive lanes; no bicycle facility; 1.8-m-wide sidewalks; 500 motor vehicles per hour with 5% heavy vehicles; average and 85th percentile motor vehicle speeds of 60 and 65 km/h, respectively; no parking; no bicycle or pedestrian traffic; a good, even asphalt road; no bus stops; and rural fields in the area. This baseline condition gives a bicyclist rating of 4.03 by use of the Danish model and ratings of 2.72 to 4.29 by use of the American models. If 1.5-m-wide bicycle lanes are marked and the widths of the drive lanes are consequently reduced to 3.6 m, the bicyclist rating is improved (i.e., the bicyclists are more satisfied) by 1.28 by use of the Danish model and by 0.66 to 0.98 by use of the American models. An increase in the number of motor vehicles per hour from 500 to 1,000 results in bicyclist ratings that worsen by 0.27 by use of the Danish model and by 0.20 to 0.50 by use of the American models. If the average speed increases from 60 to 70 km/h, the bicyclist ratings are worsened by 0.32 by use of the Danish model and by 0.00 to 0.22 by use of the American models.

Overall, the Danish and American models evaluate pedestrian and bicycle LOSs similarly. However, the presence of pedestrian and bicycle facilities is of greater importance in the Danish models than in the American models. First, this might be because pedestrian and bicycle facilities are more common in Denmark and Danes therefore expect these facilities to be present to a greater extent. A second reason may be that Danes walk and ride bicycles more, and therefore, these facilities are more important to them in their daily transport. A third reason could be that randomly selected respondents were used in the Danish study, whereas the American studies were based on respondents who signed up for participation.

CONCLUSIONS

Overall, the models show that many variables influence pedestrian and bicyclist satisfaction and LOSs on roadway segments; however, the presence and the width of pedestrian and bicycle facilities are by far the most important variables. It is important to have precise information about existing pedestrian and bicycle facilities to estimate satisfaction and LOS by using the models. Other continuous variables, like traffic volumes, motor vehicle speed, and the number of parked motor vehicles, are less important to pedestrian and bicyclist satisfaction and LOSs on roadway segments; and hence, the use of reasonable rounded figures for these variables is sufficient. Dummy variables, for example, the presence of trees, bus stops, and medians, in combination can affect pedestrian and bicyclist satisfaction and LOSs considerably.

The pedestrian and bicyclist satisfaction models and the subsequent LOS designations provide traffic planners and others the ability to rate roadways with respect to the satisfaction of road users. The models allow practitioners to better plan and design for pedestrian and bicycle traffic and to optimize budgets for improvements. The models can be used to evaluate existing roads to find the roadway segments that are the most dissatisfying to pedestrians and bicyclists or to find roadways that will improve pedestrian and bicyclist LOSs considerably by using specific measures. The models may also be used in the process of designing new roads or redesigning existing roads.

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