Pedestrian and Bicycle Level of Service on Roadway Segments

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ABSTRACT
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.

In order 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 roadway segments on a six-point scale ranging from very dissatisfied to very satisfied. This resulted in 7,724 pedestrian and 7,596 bicyclist ratings. Roadway segments and video clips were described by 150 variables.

Pedestrian and bicyclist satisfaction models were developed using cumulative logit regression of ratings and variables. The models include variables, which relate significantly ($p \leq 0.05$) to the satisfaction ratings. Motorized traffic volume and speed, urban land uses, rural landscapes, type and width of pedestrian and bicycle facilities, number and width of drive lanes, volumes of pedestrians, bicyclists and parked cars, and also presence of median, trees and bus stops significantly influence the level of satisfaction.

Models return percentage splits of the six levels of satisfaction. These splits are then transformed into a level of service (LOS). The models provide traffic planners and others the capability to rate roadways with respect to pedestrians' and bicyclists' satisfaction, and may be used in the process of evaluating existing roads, designing new roads or redesigning existing roads.

INTRODUCTION

Over the years, the national Road Directorate and local Danish road administrations have occasionally surveyed road users about their perceptions and experiences, and attempted to identify connections between road conditions and user perceptions. However, none of methodologies developed to describe pedestrian and bicycle 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 pedestrians and bicyclists experienced LOS on roadway segments, i.e. road sections between intersections.

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

Since these studies were based on an American context, it was important to develop models taking Danish conditions into consideration. Some important differences are that Danes walk and cycle more than Americans, the presence of pedestrian and bicycle facilities are more common in Denmark, and the design of some of these facilities are different compared to facilities in the United States of America. The paper includes a comparison of the Danish and American models.

STUDY DESIGN

The study is basically a stated preference survey, where each roadway segment is rated 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 timeframe is high. For example, each respondent rated 44 roadway segments within 56 minutes in our study.
- One can reach a more diverse group of respondents.
- It is more cost effective than having respondents on site.
- The exact same roadway, traffic, etc. conditions may be experienced by many respondents, and 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 respondents, which makes it easier to include roadway segments that may include high perceived risks.

Harkey et al. (*2*) tried to validate a video-based methodology using a stationary camara. Overall they concluded that the video-based methodology to be a valid technique for obtaining realistic perspectives of bicyclists. However, they didn't calibrate their video-based findings to bicyclists riding on the roadways. They only validated viewpoints from still standing respondents, i.e. 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 was to ensure that the sites selected not only represented the variety of conditions pedestrians and bicyclists may encounter, but also that five factors that prior studies have found to affect pedestrian and bicyclist experienced LOS were orthogonal, i.e. no relations between factors across the sites. The five factors and their related categories can be found in Table 1.

TABLE 1 Factors and categories in orthogonal design of site selection

Location	Factor	Categories
Urban roadways	Motor vehicles (AADT / vehicles per 40 seconds)	< 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 percent shops in ground floor) Residential Mixed use (< 30 percent shops and < 50 percent housing in ground floor)
Rural roadways	Motor vehicles (AADT / vehicles per 40 seconds)	< 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 total of 38 urban roadways and 18 rural roadways were found and matched the orthogonal experimental design. All roadways were located within 85 kilometers of Copenhagen, the capital of Denmark with approximately 1.5 million people. Photos from four of the studied roadways are shown in Figure 1.

FIGURE 1 Photos from studied roadways. Top left: Shopping street with sidewalks and one-way bicycle tracks. Top right: Residential road with sidewalks and bicycle lanes. Bottom left: Rural road in forest with paved shoulders. Bottom right: Urban road with one-way bicycle tracks – the author is using a Steadycam solution

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

- AADT: 500-30,000 on urban roads, 1,500-13,000 on rural roads
- Motorized traffic per 40 seconds: 0-31 on urban roads and 1-15 on rural roads

- Average speed of motor vehicles: 27-59 km/h on urban roads, 48-86 on rural roads
- Speed limit: 30-80 km/h
- Sidewalk width: 0.8-4.5 meters
- Bicycle track width: 1.7-2.5 meters
- Bicycle lane width: 1.4-1.7 meters
- Paved shoulder width: 0.9-1.6 meters
- Width of outer drive lane: 2.8-6.0 meters

Video production

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

A camera was mounted on each pedestrian and bicyclist using a Steadycam. This enabled control of camera with one hand and avoided shaky pictures. Cameras were approximately 1.5 meters above the ground and angled slightly downwards and to the opposite roadside so 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 high infrequent sounds were excluded.

Data were collected viewing each video clip. These data include: Placement and direction of camera man, weather, sounds other than traffic noise, visible signs and markings, visible objects (e.g. bus shelter, hump, parked bicycle, exhibit goods, etc.) and numbers of parked cars, pedestrians, bicyclists, motorized two-wheelers, motor vehicle < 3.5 tons and motor vehicle > 3.5 tons.

Each roadway segment was filmed 6-12 times and the best pedestrian and bicycle 40 second video clips meting the requirements of the orthogonal experimental design.

Field data collection

Speed measurements of single motor vehicles on the middle of the roadway segment were made right before or after videotaping. Measurements were then used for calculating average and 85th-percentile speed.

The fixed conditions of roadway segments were measured and described including: Cross section, alignment, type and quality of pavements, signs and markings, speed limit, road lighting, number and design of driveways and minor side roads, buildings, land use 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 of two municipalities were invited to participate. About 13 percent 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) for two cinema tickets. The compensation was mentioned in the invitation. The videos were shown in local ballrooms using professional video projectors on 2.7 x 2.0 meter screens and sets of stereo loudspeakers. The sound was set so 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 rated by 113-161 respondents.

A stated preference survey may particularly in rating surveys like this study result in biased relationships due to e.g. respondent fatigue and policy-response bias (*7-8*). Respondent fatigue can occur due to several reasons. The respondent may not have learnt how to rate the alternative. The respondent is bored or mentally tired, etc. Two typical things that occur due to respondent fatigue are that they rate 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 due to political conviction.

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

- The brief, neutral welcome presentation was made on video in order to be the same in every of the 12 video shows conducted. The words were as follows: "Welcome to the Road Directorate's survey of pedestrians and bicyclists 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. Due to your participation it may follow that more pedestrian and bicyclists are satisfied with the roads 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 for rating each video clip, i.e. there was no guiding text in order to avoid policy-response bias.
- Two video clips served as learner clips before rating sessions. Respondents could pose questions in a short break between leaner clips and the first rating session. Ratings of learner clips were not used for model development. One of the learner clips was repeated on a fixed place in middle of the first rating session.

- The rating was kept as simple as possible. The rating was based on a short question: “How satisfied were you as a pedestrian on the shown road?” If the video clip was made by a bicyclist then “pedestrian” was exchanged with “bicyclist” in the question. The question could be answered by ticking of a six-point scale ranging from very dissatisfied to very satisfied. Respondents had 10 seconds between video clips to make a rating.
- The order of the urban and rural video clips was randomized respectively. Every third video clip was from rural roadway segments and others from urban roadway segments.
- One “repeater” roadway segment was shown at least seven video clips after the same roadway segment in every rating session. This repeater was filmed at exactly the same part of the roadway segment as its original, but with different traffic volumes. Repeaters were used in order to assess the individual respondent ability to detect minor changes and to provide identical answers. Ratings of repeater clips were not used for model development.

MODEL DEVELOPMENT

The models were developed using the software SAS version 8.1. PROC GENMOD was used to set up ordinary generalized linear models (GLM) including independent continuous and class variables. The GLM models use mean ratings for each roadway segment on a nominal scale, see Table 2. PROC LOGISTIC was used to set up cumulative logit models (CLM) and ordinal probit models (OPM) also with independent continuous and class variables. The CLM and OPM models use response ratings on the ordinal scale. The GLM and OPM produces larger residuals than CLM and therefore only the CLM’s are shown in this paper.

TABLE 2 Response satisfaction ratings of the 56 roadway segments

Nominal scale	Ordinal scale	No. of responses (percent of column total)		
		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

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

Some of the original data that were collected viewing the video clips are not relevant to include in final models, because road administrations and others that are to use the models do not have the data in the specific format or data at all. Variables that significantly ($p \leq 0.05$)

relate to the satisfaction ratings and have been filtered out and not included in the final models are:

- *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 as motor vehicle speed increases. On average the difference on the nominal scale is 0.2. The variable is filtered out by setting walking direction to fifty-fifty in urban areas and 85 % in opposite direction - 15 % in same direction in rural areas. The splits in walking direction are typical in Denmark.
- *Sounds other than traffic noise* affect both pedestrian and bicycle satisfaction. Such sounds may be bird chirping, people talking loudly, wind noise, noise from Steadycam, etc. Bird chirping results in a quite high improvement of satisfaction. The difference to no sounds other than traffic noise of bird chirping on the nominal scale is respectively 1.2 and 0.7 for pedestrians and bicyclists. The variable is filtered out by setting it to no sounds other than traffic noise.
- *Weather* also affect both pedestrian and bicycle satisfaction. Danes apparently prefer sunny weather compared to cloudy weather or streets in shade. The variable is filtered out by setting it to sun.
- *Pavement quality* affects bicycle satisfaction. The cycling cameraman has ridden on asphalt on all roadway segments. The number of cracks, debris, etc. seen on video clips affects ratings. The variable is filtered out by setting it to good paved and clean asphalt conditions.

Varaibles that significantly ($p \leq 0.05$) relate to the satisfaction ratings and the original format have been changed and are included in the final models are:

- *Passed motor vehicles* and *passed bicycles*, which are counted viewing a 40 second video clip from a moving pedestrian and bicyclist, is changed into hourly traffic volumes.
- *Passed pedestrians* are changed from a 40 second video clip into hourly passed pedestrians. The reason why this is different from motor vehicle and bicycle traffic is that some of the passed pedestrians are standing still.
- *Passed parked cars* are changed from a 40 second video clip into parked cars per 100 meters of roadway.

Demographics

There are no relationships between satisfaction ratings and demographics at a significance level of $p \leq 0.05$. However there are tendencies. Men seem to be more satisfied than women, see Table 3. Elderly seem more dissatisfied than youth. Urban residents seem more satisfied than rural residents. Respondents walking or bicycling very little or very much seem more dissatisfied than respondents that walk and bicycle some kilometers every week. The number of respondents who needs aids to walk or who are unable to ride a normal two-wheel bicycle was very small, however, these respondents seem more satisfied. There were no significant differences based on which municipality people lived in. These analyses indicate that demographic data would not be relevant to include in the models.

TABLE 3 Response satisfaction rating average on the nominal scale of all roadway segments of various groups of people

Group of respondents	No. of respondents	Rating average on nominal scale
All	407	3.52
Female	223	3.56
Male	184	3.47
12-29 year old	124	3.47
30-49 year old	125	3.49
50-80 year 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)
Can not ride a two-wheeled bike	9	3.63 (bicyclist ratings)

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 $p \leq 0.05$ level. The optimization technique was

Fisher's scoring. The response variable is the six levels of satisfaction, e.g. number of very satisfied responses.

Some variables described more or less the same thing, and one significant variable had to be selected, e.g. choosing the best variable to describe motor vehicle speed, which was represented by average speed, 85th-percentile, speed limit and presence of speed reducing measures. Another situation was to create new variables on the basis of two or more original variables, e.g. instead of having a variable describing the width of a diving 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.

Table 3 shows the utility functions of the CLM found to be best to predict pedestrian satisfaction. 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:

$$SHARE_{\text{very satisfied}} = 1 - 1/(1 + \exp(\text{logit}(p)_{\text{very satisfied}})$$
$$SHARE_{\text{moderately satisfied}} = 1 - SHARE_{\text{very satisfied}} - 1/(1 + \exp(\text{logit}(p)_{\text{moderately satisfied}})$$
$$\ldots$$
$$SHARE_{\text{very dissatisfied}} = 1 - SHARE_{\text{very satisfied}} - SHARE_{\text{moderately satisfied}} - SHARE_{\text{a little satisfied}} - SHARE_{\text{a little dissatisfied}} - SHARE_{\text{moderately dissatisfied}}$$

The CLM model in Table 4 has an R^2-value of 0.55 and a maximum-rescaled R^2-value of 0.57. On average the residual or 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 distance between intercept parameters of the response level of satisfaction in Table 4 are not the same, i.e. the respondents do not value the distance between e.g. "very satisfied" and "moderately satisfied" and the distance between "moderately satisfied" and "a little satisfied" as being the same.

The variables with the largest effect on pedestrian satisfaction are the type and width of walking area and the distance to motor vehicles in 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 increases. Increasing motor vehicle speed makes pedestrians more dissatisfied. Presence of median, four or more drive lanes and trees makes pedestrians more satisfied.

That pedestrian become more dissatisfied as the number of parked motor vehicles increases contradicts the findings of Landis et al. (*5*) who found the opposite, i.e. more parked cars result in more satisfied pedestrians. This discrepancy may to some degree be explained by varying definitions of variables. The variable BUF in Table 4 includes the width of marked or curbed on-street parking, but also a 2 meter wide "parking lane" if there is 3 or more parked cars per 100 meter roadside with no marking/curbing for parking. The reason for this definition is that this relatively low number of parked cars will actually generate a buffer between the sidewalk and driving cars. The Danish findings are that as the buffer between the sidewalk and driving cars become wider, e.g. due to parked cars, bicycle facilities, dividing verges, etc., pedestrians becomes more satisfied, whereas more parked cars result in more dissatisfied pedestrians.

TABLE 4 Pedestrian model and variable definitions

$$logit(p) = \alpha \begin{bmatrix} very\,satisfied = -2.8526 \\ moderately\,satisfied = -1.2477 \\ a\,little\,satisfied = -0.0646 \\ a\,little\,dissatisfied = 0.8758 \\ moderately\,dissatisfied = 2.2543 \end{bmatrix} + WA \begin{bmatrix} sidewalk - concrete\ flags = 3.5486 \\ sidewalk - asphalt = 1.9149 \\ bicycle\ path/track = 1.0124 \\ bikelane/paved\ shoulder = -2.8293 \\ driving\ lane = -3.6464 \end{bmatrix} +$$

$$AREA \begin{bmatrix} residential = 0.4871 \\ shopping = 0.5385 \\ mixed = -1.6349 \\ rural\ fields = 1.2380 \\ rural\ forest = 0.5122 \end{bmatrix} - 0.002476 \cdot MOT + 0.0000003364 \cdot MOT^2 -$$

$$0.0303 \cdot SPEED + 0.00002211 \cdot SPEED \cdot MOT - 0.005432 \cdot PED +$$

$$0.000005062 \cdot PED^2 - 0.003772 \cdot BIKE + 0.000003111 \cdot BIKE^2 + 0.4408 \cdot BUF -$$

$$0.0365 \cdot BUF^2 - 0.05286 \cdot PARK + 1.0180 \cdot MED + 0.2938 \cdot SB + 0.6277 \cdot BL +$$

$$0.7380 \cdot LANE + 0.3311 \cdot TREE$$

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 (*meters*),
PARK	=	parked motor vehicle on road per 100 meters,
MED	=	median dummy, no median = 0, median = 1,
SB	=	width of walking area, if this is a sidewalk or bicycle path / track (*meters*)
BL	=	total width of walking area and nearest drive lane, if walking area is a bicycle lane, paved shoulder or drive lane (*meters*),
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 meters = 1, otherwise 0.

Bicycle model

The data analysis and regression in order to find the bicycle model was performed in the same manner as for the pedestrian model. Table 5 shows the utility functions of the CLM found to be best to predict bicyclist satisfaction.

TABLE 5 Bicycle model and variable definitions

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

$$0.0005585 \cdot MOT - 2.3895 \cdot LBUF + 0.0004691 \cdot MOT \cdot LBUF - 0.0958 \cdot SPEED +$$
$$0.000421 \cdot SPEED^2 - 0.000002913 \cdot MOT \cdot SPEED + 0.0402 \cdot LBUF \cdot SPEED +$$
$$0.000002446 \cdot MOT \cdot LBUF \cdot SPEED - 0.001623 \cdot PED + 0.0000008309 \cdot PED^2 -$$
$$0.09416 \cdot PARK + 1.7782 \cdot PATH + 1.3938 \cdot ULAN + 2.5196 \cdot RSHO +$$
$$0.2413 \cdot DBL - 0.2593 \cdot RBUF + 1.2694 \cdot SW - 0.6988 \cdot BUS + 0.6821 \cdot LANE$$

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 (*meters*),
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 meters,
PATH	=	width of bicycle path / track on nearest roadside (*meters*),
ULAN	=	width of bicycle lane / paved shoulder (at least 0.9 meters wide) on nearest roadside in urban areas (*meters*),
RSHO	=	width of bicycle lane / paved shoulder (at least 0.9 meters wide) on nearest roadside in rural areas (*meters*),
DBL	=	width of nearest drive lane including bicycle lane / paved shoulder of less than 0.9 meters width (*meters*),
RBUF	=	width of buffer area between sidewalk and bicycle facility/drive lane (*meters*),
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.

The bicycle model includes 14 main effects, two squares and four interaction terms. The CLM model in Table 5 has an R^2-value of 0.52 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 better to responses than the bicycle model.

The variables with the largest effect on bicyclist satisfaction are the type and width of the bicycle facility / drive lane and the distance to both motor vehicles in 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 increases. Increasing motor vehicle speed makes bicyclists more dissatisfied. Presence of four or more drive lanes and sidewalks make bicyclists more satisfied, whereas presence of bus stops makes them more dissatisfied.

The relationship, where 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. Pedestrians influence on bicyclist satisfaction is complex. Pedestrians going to or from 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 further away from pedestrians and bicyclists as the number of drive lanes increases.

Biases

The respondents rated the learner video clip that was repeated ten video clips late almost the same. 263 out of 404 respondent, or 65 percent of ratings were exactly the same. 89 percent of ratings of learner and the repeated video clips was not more than one response level of satisfaction from each other. There were no significant differences in average ratings and standard deviation of ratings between learner and 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 do not affect the rating of a roadway segment done by all respondents together, because almost the same number of respondents started with too satisfied ratings as the number of respondents starting with too dissatisfied ratings. Due to the simplicity of the rating system and the lack of influence from learner rating problems it may 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, using intercept interviews would require a greater number of respondents.

The video clips were only randomized once. Pedestrian and bicycle video clips were then respectively divided into three portions. The 21 video clips in a rating session was shown in four ways, i.e. first rating session, first rating session in reversed order, second rating session and second rating session in reversed order. By doing so it was possible to detect respondent fatigue. There was a weak tendency to respondents rating becoming more dissatisfied during rating sessions, however, the average rating only worsened by 0.05 on the nominal scale from the first to the twenty-first video clip.

The use of repeater roadway segment video clips enabled comparisons of response and modeled satisfaction due to changes in traffic conditions on the same roadway. In total there were twelve of these repeaters. The direction of the change in satisfaction due to changing traffic is the same for eleven of twelve repeaters when comparing response and modeled satisfaction. The difference in satisfaction of repeater with different traffic volumes and original video clip is in magnitude almost the same comparing response and modeled satisfaction. The average on the nominal scale of the 12 original video clips is respectively 3.92 and 3.85 for response and modeled satisfaction, whereas the average of the repeaters is respectively 3.79 and 3.77. This indicates that the models may very slightly underestimate the influence traffic volumes have on pedestrian and bicycle satisfaction.

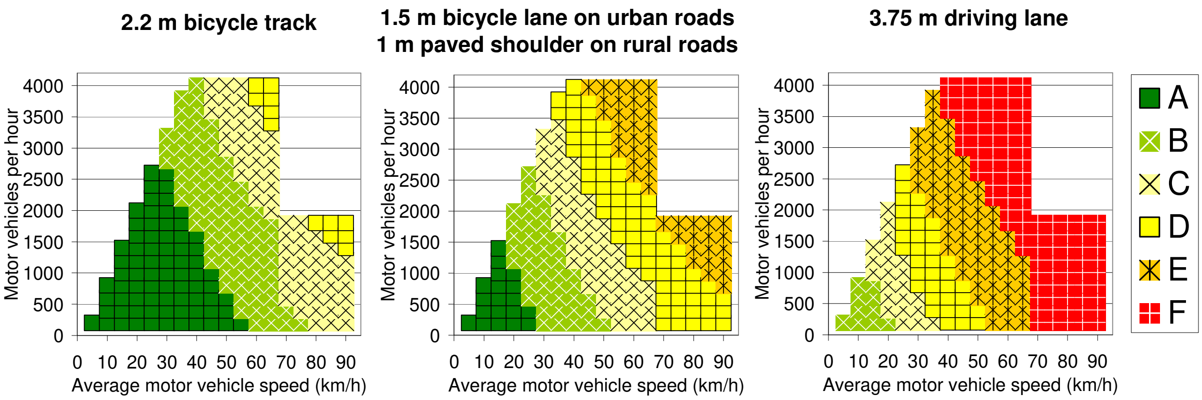
Overall we may conclude that the possible biases that may arise due to study design are small and may be neglected.

LEVEL OF SERVICE 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 (A through F) were defined as follows. A "democratic" definition is used, meaning that if 50 percent or more are very satisfied then LOS is designated A. LOS is designated B if 50 percent or more are very or moderately satisfied and less than 50 percent are very satisfied. And so forth, ending up with a LOS F if 50 percent or more are very dissatisfied.

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

FIGURE 2 Bicycle LOS of three types of bicycle facilities depending on motor vehicle speed and hourly motor vehicle volume. Base conditions: Nearest drive lane is 3.75 m wide, urban residential road with sidewalks at speeds of 0-65 km/h, rural road with fields and no sidewalks at speeds of 70-90 km/h. Models are not valid in white areas



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 one sixteenths of a LOS designation. An increase of 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 eights and one fourth of a LOS designation respectively. Increasing bicycle lane width by 0.1 meter results in an improvement of bicycle satisfaction of about 0.1, and a 0.2 meter 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, e.g. average widths to the nearest 0.1 or 0.2 meters should be used, in order to estimate satisfaction and LOS by using the models. Other continuous variables like traffic volumes, 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, e.g. hourly motor vehicle traffic rounded to nearest hundred is sufficient.

COMPARING AMERICAN AND DANISH MODELS

The Danish models have been compared to four American models. All American models make use of average ratings on the nominal scale of the same kind as in Table 2. The estimates based on the CLM Danish models have been changed into average ratings on the nominal scale in order to be compared to the American models.

The pedestrian model was relevant to compare to an American model described by Landis et al. (*5*). In order to have an optimal comparison the following base condition is used: Road with two 3.6 meters wide drive lanes, no bicycle facility, 1.8 meters wide sidewalks of asphalt, 500 motor vehicles per hour, average motor vehicle speed of 60 km/h, no parking, no bicycle and pedestrian traffic, no trees and rural fields in the area. This base condition gives a pedestrian rating of 2.62 using the Danish model and 2.79 using the American. If the sidewalk is removed then the pedestrian rating is worsened, i.e. more dissatisfied pedestrians, by 2.64 using the Danish model and 1.36 using the American. An increase in motor vehicles per hour from 500 to 1,000 results in a worsened pedestrian rating of 0.23 using the Danish model and 0.18 using the American. If average speed increases from 60 to 70 km/h, then pedestrian rating is worsened by 0.14 using the Danish model and 0.23 using the American.

The bicycle model was relevant to compare to three American models (*2-4*). The following base condition is used: Road with two 5.1 meters wide drive lanes, no bicycle facility, 1.8 meters wide sidewalks, 500 motor vehicles per hour with 5 percent heavy vehicles, average and 85th-percentile motor vehicle speed of 60 and 65 km/h respectively, no parking, no bicycle and pedestrian traffic, good even asphalt road, no bus stops and rural fields in the area. This base condition gives a bicyclist rating of 4.03 using the Danish model and 2.72-4.29 using the American models. If 1.5 meters wide bicycle lanes are marked and the drive lanes are consequently reduced to a 3.6 meters width the bicyclist rating is improved, i.e. more satisfied bicyclists, by 1.28 using the Danish model and 0.66-0.98 using American models. An increase in motor vehicles per hour from 500 to 1,000 results in a worsened bicyclist rating of 0.27 using the Danish model and 0.20-0.50 using American models. If average speed increases from 60 to 70 km/h, then bicyclist rating is worsened by 0.32 using the Danish model and 0.00-0.22 using American models.

Overall, the Danish and American models evaluate pedestrian and bicycle LOS similarly. However, the presence of pedestrian and bicycle facilities is of greater importance in the Danish models than in the American models. This might be because pedestrian and bicycle facilities are more common in Denmark, and Danes therefore to a greater extent expect these facilities to be present. Another 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 have been used in the Danish study, whereas the American studies are based on respondents that have signed up for participation.

CONCLUSIONS

Overall the models show that many variables influence pedestrian and bicyclist satisfaction and LOS on roadway segments, however, the presence and 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, in order to estimate satisfaction and LOS by using the models. Other continuous variables like traffic volumes, motor vehicle speed and number of parked motor vehicles are less important to pedestrian and bicyclist satisfaction and LOS on roadway segments, and hence reasonable rounded figures for these variables are sufficient. Dummy variables, e.g. presence of trees, bus stops and median, can in combination affect pedestrian and bicyclist satisfaction and LOS considerably.

The pedestrian and bicycle satisfaction models and the subsequent LOS designations provide traffic planners and others the capability to rate roadways with respect to road users satisfaction. 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 for evaluating existing roads in order to find the roadway segments that are the most dissatisfying to pedestrians and bicyclists or to find roadways that will improve pedestrian and bicycle LOS considerably by using specific measures. The models may also be used in the design process of designing new roads or redesigning existing roads.

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