Pedestrian and Bicycle Level of Service at Intersections, Roundabouts and other Crossings

Initial Submission Date: 23 July 2012
Submission Date of Revised Paper: 22 October 2012

Word Count: 5,153 + 4 tables + 5 figures = 7,403 words

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ABSTRACT

The Danish Road Directorate sponsored a study to develop methods for objectively quantifying pedestrian and cyclist stated satisfaction with roundabouts, signalized and non-signalized intersections, mid-block crossings, and pedestrian bridges and tunnels (in short: crossings). The results provide a measure of how well urban and rural crossings accommodate pedestrian and bicycle travel.

In order to determine how existing traffic operations, geometric conditions, and other variables affect pedestrian and cyclist stated satisfaction, 180 randomly selected Danes were shown a total of 158 video clips from 95 crossings filmed by a walking pedestrian and a riding cyclist. Respondents rated crossings on a six-point scale ranging from very dissatisfied to very satisfied. This resulted in 3,023 pedestrian and 3,998 cyclist ratings. Crossings and video clips were described by about 300 variables.

Pedestrian and cyclist 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. Variables such as type, width and height of pedestrian and bicycle facility, length of crossing, size of roundabout, width of roadway, traffic volume, waiting time and speed limit 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 crossings with respect to pedestrian and cyclist satisfaction, and may be used in the processes of evaluating existing, designing new or redesigning existing crossings.

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 the methodologies developed to describe pedestrian and bicycle level of service (LOS) at roundabouts, intersections and other crossings 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 at crossings.

Over the past decade, some studies have been undertaken in order to develop systematic means of measuring pedestrians and cyclists experienced LOS (*1-7*). Even though these studies use various study designs, model development techniques and LOS criteria, the produced models each have a reasonable validity. These studies provided a solid methodological base for the Danish study.

Since these studies were based mostly 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 and the presence of pedestrian and bicycle facilities are more common in Denmark. Furthermore, the design of some of these facilities differs compared to facilities in the USA.

STUDY DESIGN

The study is basically a stated preference survey, where each crossing is rated on a fixed scale. The methodology was to have respondents view numerous crossings captured on videotape by a walking or cycling cameraman and rate these with respect to how satisfied they would be walking or riding a bicycle under the given conditions shown on the videos. The video-based methodology has several advantages:

- The number of crossings that respondents can rate during a reasonable timeframe is high. Each respondent rated 39-40 crossings within 63-68 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 crossing, traffic, etc. conditions may be experienced by many respondents, and the conditions to be rated can be chosen from several videotapes of the same roundabout, intersection or other crossing. This form of variable control is impossible when respondents actually walk or ride on site.
- There are no traffic risks to respondents, which makes it easier to include crossings that may include high risks. The camera man was actually nearly hit by a car at a roundabout.

Harkey et al. (*3*) tried to validate a video-based methodology using a stationary camera. Overall they concluded that the video-based methodology to be a valid technique for obtaining realistic perspectives of cyclists. However, they didn't calibrate their video-based

findings to walking pedestrians or riding cyclists. They only validated viewpoints from still standing respondents, i.e. not obtaining realistic perspectives of pedestrians and cyclists.

Site selection
With a relatively small number of crossings, it is important to maximize the range of conditions included. Orthogonal experimental designs were developed before site selection. The intent of the designs was to ensure that the sites selected not only represented the variety of conditions pedestrians and cyclists may encounter, but also that factors prior studies have found to affect pedestrian and cyclist experienced LOS were orthogonal, i.e. no relations between factors across sites. Factors and their related categories are given in Table 1 and 2.

The video clips were filmed at 46 signalized intersections, 23 roundabouts and 26 non-signalized crossings, which matched the orthogonal experimental design. All crossings were located in Denmark and less than 100 miles from Copenhagen. Photographs from four pedestrian video clips at roundabouts are shown in Figure 1.

FIGURE 1 Photographs from pedestrian video clips at four roundabouts.

TABLE 1 Pedestrian factors and categories in orthogonal design of pedestrian site selection. Numbers in brackets at each category are crossings with the given condition

Site	Factor	Categories
Signalized intersection (32 in total)	Crosswalk and pedestrian signal	- No zebra crossing and no pedestrian signal (8) - Zebra crossing and pedestrian signal present (24)
	Median island	- No median island (16) - Median island present (16)
	Waiting time	- Green at arrival, no waiting time (8) - 5-20 seconds waiting time (8) - 21-40 seconds waiting time (8) - More than 40 seconds waiting time (8)
	Zone	- Urban area (24) - Rural area (8)
	Crossing distance	- Less than 12 meters including median island (8) - 12-28 meters (16) - More than 28 meters (8)
	Motor vehicles on crossing	- 0-2 filmed vehicles (8) - 3 or more filmed vehicles (24)
	Motor vehicles parallel to crossing	- 0-2 filmed vehicles (8) - 3 or more filmed vehicles (24)
Roundabout (18 in total)	Crosswalk and zone	- No zebra crossing, urban area (3) - No zebra crossing, rural area (6) - Zebra crossing present (9)
	Circulating lane(s) and splitter island	- Single-lane, no splitter island (6) - Single-lane, splitter island present (6) - Multilane (6)
	Crossing distance	- Less than 10 meters including splitter island (12) - More than 10 meters (6)
	Circulating motor vehicles and motor vehicles on crossed arm	- 0-2 filmed vehicles (6) - 3-5 filmed vehicles (6) - 6 or more filmed vehicles (6)
Non-signalized crossing (18 in total)	Pedestrian facility	- No zebra crossing, no median island (3) - No zebra crossing, median island present (3) - Zebra crossing present, no median island (3) - Zebra crossing and median island present (3) - Pedestrian bridge or tunnel (6)
	Average speed of motor vehicles on crossed road	- Below 50 km/h (6) - 50-60 km/h (6) - More than 60 km/h (6)
	Crossing distance	- Less than 12 meters including median island (12) - More than 12 meters (6)
	Motor vehicles on crossed road	- 0-2 filmed vehicles (6) - 3-5 filmed vehicles (6) - 6 or more filmed vehicles (6)

TABLE 2 Bicycle factors and categories in orthogonal design of bicycle site selection. Numbers in brackets at each category are crossings with the given condition

Site	Factor	Categories
Signalized intersection (36 in total) (crossing one arm at 36 intersections and left-turns made crossing two arms at 16 of these 36 intersections)	Bicycle facility before stop line	- No facility (12) - Narrow cycle lane (4) - Cycle lane (8) - Cycle track (12)
	Bicycle facility inside intersection	- No facility (13) - White cycle crossing (10) - Blue cycle crossing (13)
	Waiting time	- Green at arrival, no waiting time (11) - 5-20 seconds waiting time (8) - 21-40 seconds waiting time (9) - More than 40 seconds waiting time (8)
	Zone	- Urban area (28) - Rural area (8)
	Crossing distance	- Less than 12 meters (10) - 12-28 meters (17) - More than 28 meters (9)
	Motor vehicles on crossing	- 0-2 filmed vehicles (10) - 3 or more filmed vehicles (26)
	Motor vehicles parallel to crossing	- 0-2 filmed vehicles (10) - 3 or more filmed vehicles (26)
Roundabout (20 in total)	Bicycle facility before and at roundabout	- No facility before and at roundabout (4) - No facility before, cycle lane/track next to circulating lane (4) - Cycle lane/track before, no facility at roundabout (4) - Cycle lane/track before, cycle lane next to circulating lane (4) - Cycle track before and next to circulating lane (4)
	Circulating motor vehicles and motor vehicles on crossed arm	- 0-2 filmed vehicles (5) - 3-4 filmed vehicles (5) - 5-6 filmed vehicles (5) - 7 or more filmed vehicles (5)
	Crossing distance	- Less than 10 meters including splitter island (15) - More than 10 meters (5)
	Circulating lane(s)	- Single-lane (15) - Multilane (5)
Non-signalized crossing (18 in total)	Sidewalk across minor road	- Yes, sidewalk across minor road at exit to major road (9) - No, roadway is not interrupted by sidewalk (9)
	Give-way condition	- Yield sign (12) - Stop sign (6)
	Average speed of motor vehicles on crossed road	- Below 50 km/h (6) - 50-60 km/h (6) - More than 60 km/h (6)
	Crossing distance	- Less than 12 meters (12) - More than 12meters (6)
	Motor vehicles on crossed road	- 0-2 filmed vehicles (6) - 3-5 filmed vehicles (6) - 6 or more filmed vehicles (6)

Video production

Video recordings were made in late fall or early spring in daylight hours, no precipitation and no snow on the ground. One set of video recordings were made by a pedestrian walking at normal pace, which is about 5 km/h, for 15 seconds along the first road on the middle of the sidewalk or if no sidewalk on the outer part of a sealed pavement. After these 15 seconds the pedestrian arrived at the crossing making a stop to look for traffic or stop for a red light or continued to cross for a green light or to cross on pedestrian bridge or tunnel. If the pedestrian stopped then the camera were panned left-right-left until crossing were made. After crossing the road the pedestrian walked for 7 seconds along the second 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 second set of video recordings were made by a cyclist riding initially about 20 km/h and riding for 15 seconds along the first road on the bicycle facility or if no facility on the outer drive lane about 50-75 cm from the outer edge. After 15 seconds the cyclist arrived at the stop or give-way line and made a stop if necessary or continued to cross, and after crossing the intersection or roundabout the cyclist rode for 7 seconds along the second road 50-75 cm from the outer edge. The cyclist always rode in the same direction as the nearest vehicles. Overtaking and ride/walk bys were done as a traveler would normally proceed. In total, a video clip included 15 seconds on first road, waiting time, crossing time and 7 seconds on second road. Duration of video clips varies between 28 and 116 seconds.

The camera was mounted on the cameraman using a Steadycam. The cameraman walked or was a passenger on front a 3 wheeled Nihola goods bicycle. The Steadycam device enabled control of camera with one hand and avoided shaky pictures. The camera were held about 1.5 meters above the ground and angled slightly downwards and to the opposite roadside when traveling on the first road so respondents could see both sides the road and the entire intersection, roundabout or other crossing 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 cameraman, weather, sounds other than traffic noise, visible signals, signs and markings, visible objects (e.g. bus shelter, hump, parked bicycle, exhibit goods, etc.) and numbers of parked cars, pedestrians, cyclists, motorized two-wheelers, motor vehicle < 3.5 tons and motor vehicle > 3.5 tons. Traffic was split into traffic streams. Duration of time on first road, waiting time, crossing time and time on second road was also recorded on the basis of the video clips.

A crossing was filmed about 6 times as a pedestrian or as a cyclist. The best video clip the meet the requirements of the orthogonal experimental design were chosen.

Field data collection

Speed measurements of 40 motor vehicles on the main road at non-signalized crossings were made right before or after videotaping, i.e. 20 vehicles in each direction. Measurements were then used for calculating average and 85th-percentile speed.

The layout of the first road at the start of the video clip and at the stop or give way line, layout of the crossing, layout of the entire intersection or roundabout, and layout of the second road at the stop or give way line and at the end of the video clip were measured and recorded. The recordings included e.g. type of crossing, number of arms, traffic control, cross sections including type and size of islands, type and quality of pavements, signal heads and arrows, signs and markings, gradients, speed limits, road lighting, parking regulations, height and number of stairs, buildings, land use and landscape.

Respondents, video shows and questionnaire
Citizens of 18 years of age or older were randomly selected through a register of residents in Lyngby-Taarbaek Municipality in Denmark. 2,400 citizens were invited to participate. 103 men and 77 women participated as respondents in the video shows corresponding to 7.5 per cent of the invited citizens. As compensation for participating the respondents were given a voucher (DKK 199) for a happy day smart box. The compensation was mentioned in the invitation. The videos were shown in a ballroom using a professional video projector on a large screen and a set of stereo loudspeakers. The sound was set so it matched the sound in real traffic. Between 14 and 39 respondents participated in the individual video shows. Each video clip was shown in two video shows and rated by 34-56 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 (*8-9*). 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 things that may occur due to respondent fatigue are that they rate crossings worse as fatigue increases and the rating of a crossing is transferred to the next crossing. Policy-response bias may occur when a respondent consciously tries to affect the survey results due to political conviction.

Basically a respondent attended a 63-68-minute video show including a welcome, presentation of questionnaire, answering seven background questions (sex, age, type of residence, weekly walked kilometers, weekly bicycled kilometers, aids for walking, and ability to bicycle without problems), two learner pedestrian video clips, questions-and-answers, first rating session with 17 pedestrian video clips, 10 minutes break with refreshing soft drinks, second rating session with 18-19 cyclist video clips, third rating session with 4 left-turn cyclist video clips, and 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 8 video shows conducted. The words were as follows: "Welcome to the Road Directorate's survey of pedestrians and cyclists experienced level of service. 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 cyclists are satisfied with

the crossings they experience in the future. This evening you will see video clips showing different crossings that you must rate with respect to how satisfied you are with them."

- Besides the seven 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.

- The rating was kept as simple as possible. The rating was based on a short question: "How satisfied were you as a pedestrian?" If the video clip was made by a bicyclist then "pedestrian" was exchanged with "cyclist" 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 orders the 68 pedestrian video clips, 74 cyclist riding straight ahead video clips and 16 left-turning cyclist video clips were randomized, and rated in both forward and backward order to avoid fatigue bias.

MODEL DEVELOPMENT
The models were developed using the software SAS version 9.2. 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 crossing on a nominal scale, see Table 3. PROC LOGISTIC was used to set up cumulative logit models (CLM) with independent continuous and class variables. The CLM use response ratings on an ordinal scale.

TABLE 3 Response satisfaction ratings of all 158 crossings

Nominal scale	Ordinal scale	No. of responses (per cent of column total)		
		As pedestrian	As cyclist	Total
1	Very satisfied	715 (24 %)	607 (15 %)	1,322 (19 %)
2	Moderately satisfied	736 (24 %)	992 (25 %)	1,728 (25 %)
3	A little satisfied	440 (15 %)	753 (19 %)	1,193 (17 %)
4	A little dissatisfied	331 (11 %)	670 (17 %)	1,001 (14 %)
5	Moderately dissatisfied	355 (12 %)	591 (15 %)	946 (13 %)
6	Very dissatisfied	446 (15 %)	385 (10 %)	831 (12 %)
Total		3,023 (100 %)	3,998 (100 %)	7,021 (100 %)
Average on the nominal scale		3.07	3.20	3.14

The respondents have not used the six different responses on the rating scale to the same degree as they overall seemed more satisfied than dissatisfied. Ratings for individual crossings were very different. The average on the nominal scale varies between 1.39 and 5.89 for the different crossings rated as pedestrian and between 1.64 and 5.87 rated as cyclist.

Eight CLM and eight GLM were chosen as final models. Only CLM, which have slightly smaller residuals compared to GLM, are presented in this paper. Information about crossings and ratings for each of these models are given in Table 4.

TABLE 4 Response satisfaction ratings of crossings for various models

Nominal and ordinal scale		No. of responses							
		Pedestrian models				Cyclist models			
		Signalized intersections (crossing 1 arm)	Roundabouts (crossing 1 arm)	Non-signalized intersections (crossing 1 road)	Pedestrian bridges and tunnels (crossing 1 road)	Signalized intersections straight ahead (crossing 1 arm)	Signalized intersections left-turn (crossing 2 arms)	Roundabouts (crossing 1 arm)	Non-signalized intersections (crossing 1 road)
1	Very satisfied	435	131	70	79	317	77	146	67
2	Moderately satisfied	378	178	133	47	448	174	214	156
3	A little satisfied	166	125	115	34	275	157	153	168
4	A little dissatisfied	109	100	90	32	245	117	147	161
5	Moderately dissatisfied	93	130	85	47	173	124	131	163
6	Very dissatisfied	229	125	67	25	87	63	110	125
Total		1,410	789	560	264	1,545	712	901	840
Average, best crossing		1.39	1.75	2.36	1.82	1.64	2.20	1.66	2.08
Average, all crossings		2.81	3.37	3.34	2.98	2.85	3.32	3.26	3.68
Average, worst crossing		5.68	5.89	5.08	3.73	5.09	4.92	5.20	5.87
Number of video clips		32	18	12	6	36	16	20	18

Some of the original data that were collected are not relevant to include 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 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:

- *Number of rating session* was found statistically significant in pedestrian models for signalized intersections, roundabouts and non-signalized intersections and cyclist models for roundabouts and non-signalized intersections. The eight video shows were held over two weeks. In the second week many university students attended the shows. Pedestrian video clips were in the first rating session in the first week but third rating session in the second week. The positive students affected the average rating. The number of rating session was filtered out by setting it to the number for the first week, because respondents in this week represented the general public well.
- *Sound other than traffic noise* was found statistically significant in the pedestrian model for signalized intersections. Positive sounds such as bird chirping and people talking made respondents more satisfied, whereas negative sounds like people shouting, machine noise and horns made them more dissatisfied. The difference between positive and no sounds on the nominal scale is 0.40. The difference between negative and no sounds is only 0.02. The variable is filtered out by setting it to no sounds other than traffic noise.

- *Weather* was found statistically significant in pedestrian models for signalized and non-signalized intersections and the cyclist model for non-signalized intersections. Danes most often prefer streets in shade compared to cloudy weather. The variable is filtered out by setting it to sunshine, which was rated between crossings in shade and in cloudy weather.

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. Men's average rating on the nominal scale is 3.10 whereas women's average rating is 3.21. Elderly seem more dissatisfied than youth. The average rating of 18-24 year olds is 2.96, whereas 25-54 year olds rated 3.18 and 55-85 year olds rated 3.37 on average. Type of residence, amount of weekly walking and cycling, and walking aids and ability to cycle do not seem to affect the satisfaction ratings to any larger extent. The analyses indicate that demographic data would not be relevant to include in the models when the aforementioned variable *number of rating session* is included.

Pedestrian models

Determining the key independent variables that influence pedestrian satisfaction was the prime objective of the data analyses. 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 or combining variables to describe pedestrian facilities, which was represented by several variables such as presence of sidewalk, width of sidewalk, presence of zebra crossing, width of zebra crossing, length of zebra crossing, etc.

Figure 2 shows the utility functions of the four CLMs found best to predict pedestrian satisfaction. The models include three, three, three and two main effects respectively. The predicted six shares of level of satisfaction may be calculated on the basis of the utility function in the following manner:

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

The CLM for signalized intersections, roundabouts, non-signalized intersections and pedestrian bridges and tunnels have average residuals, i.e. difference between response and predicted satisfaction, of 0.15, 0.23, 0.16 and 0.16 respectively on the nominal scale.

FIGURE 2 Pedestrian models (CLM) and variable definitions.

Signalized intersections – crossing one arm:

$$\text{logit(p)} = a \begin{bmatrix} vs = -2.9034 \\ ms = -1.2479 \\ ls = -0.1937 \\ ld = 0.8803 \\ md = 2.0046 \end{bmatrix} + \text{WA} \begin{bmatrix} sidewalk, zebra = 2.8411 \\ sidewalk, roadway = -2.1178 \\ no\ sidewalk, zebra = 1.8121 \\ no\ sidewalk, roadway = -2.5354 \end{bmatrix} - 0.0908 * \text{TIME} + 1.0572 * \text{TRAF},$$

where logit(p) = utility function of CLM, a = intercept parameter (vs=very satisfied, ms=moderately satisfied, ls=a little satisfied, ld=a little dissatisfied, md= moderately dissatisfied), WA = type of walking area before intersection and when crossing, TIME = crossing time in seconds, TRAF = vehicles per second on the crossed arm.

Roundabouts – crossing one arm:

$$\text{logit(p)} = a \begin{bmatrix} vs = -3.0555 \\ ms = -1.3880 \\ ls = -0.2888 \\ ld = 0.6445 \\ md = 2.1564 \end{bmatrix} + \text{CA} \begin{bmatrix} zebra = 1.4974 \\ roadway = -1.4974 \end{bmatrix} + \text{PA} \begin{bmatrix} sidewalk = 0.9687 \\ cycle\ track\ /\ path = 0.7155 \\ roadway = -1.6842 \end{bmatrix} - 5.5993 * \text{TRAFFIC},$$

where CA = type of crossing area, PA = type of pedestrian area on road before roundabout, TRAFFIC = circulating vehicles in roundabout per second before crossed arm.

Non-signalized intersections – crossing main road:

$$\text{logit(p)} = a \begin{bmatrix} vs = -1.8957 \\ ms = -0.2380 \\ ls = 0.9503 \\ ld = 2.0246 \\ md = 3.4307 \end{bmatrix} + \text{WALK} \begin{bmatrix} separate\ path = 1.2059 \\ sidewalk = 0.8540 \\ roadway = -2.0599 \end{bmatrix} - 5.1583 * \text{TRA} + \text{CF} \begin{bmatrix} zebra = 0.3957 \\ roadway = -0.3957 \end{bmatrix},$$

where WALK = pedestrian facility at give way line, TRA = vehicles per second on crossed road, CF = type of crossing facility.

Pedestrian bridges and tunnels – crossing main road:

$$\text{logit(p)} = a \begin{bmatrix} vs = 2.0217 \\ ms = 2.8788 \\ ls = 3.4662 \\ ld = 4.0847 \\ md = 5.4463 \end{bmatrix} + \text{TC} \begin{bmatrix} bridge = 1.4165 \\ tunnel = -1.4165 \end{bmatrix} - 0.6441 * \text{HEIGHT},$$

where TC = type of crossing – pedestrian bridge or tunnel, HEIGHT = height in meters between top and bottom of stairs.

The reader may notice that the mathematical distance between intercept parameters of the response level of satisfaction in Figure 2 are not the same. This means 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.

At signalized intersections the most important variable to pedestrian satisfaction is the presence of a zebra crossing. In Denmark a zebra crossing may only be present if there also is a pedestrian signal present and vice versa. Marking zebra crossings at signalized intersections improve pedestrian satisfaction by 3-4 levels, e.g. going from very dissatisfied to a little or moderately satisfied. A sidewalk before the signalized intersection also improves pedestrian satisfaction however only slightly by 0.5-1 level. The time a pedestrian spend crossing the intersection arm also influences the level of satisfaction. Shorter crossing times are more satisfying than longer. Pedestrians often walk faster as the crossing becomes longer, and the walking cameraman did also walk faster at longer crossings. When this is taken into account, a 10 meter long crossing (walking speed is 1.3 meters per second) is about one level more satisfying than a 40 meter long crossing (1.6 m/sec). More vehicular traffic on the crossed signalized intersection arm makes the pedestrian more satisfied. The level of satisfaction improves one level when the amount of traffic increases about 7,000 vehicles per hour. This is maybe because the intersection is viewed as more efficient as more traffic passes and hence viewed more positive even though more traffic may also be viewed as a risk factor and a nuisance.

At roundabouts the most important variable is also the presence of a zebra crossing. A zebra crossing here improves pedestrian satisfaction by 2-3 levels. The pedestrian prefer to walk on a sidewalk or cycle path before crossing the arm at the roundabout compared to walking on the roadway, i.e. outer part of a drive lane, cycle lane or shoulder. Walking on a sidewalk compared to walking on the roadway improved pedestrian satisfaction by about one level. Circulating vehicular traffic also influences pedestrian satisfaction at roundabouts. As traffic volumes increase the pedestrian becomes more dissatisfied. Circulating traffic have been found to be a better predictor in statistically terms for both pedestrian and cyclist LOS than traffic on the crossed arm at the roundabout. The pedestrian satisfaction decreases by one level when an increase of about 700 circulating vehicles per hour occurs.

At non-signalized intersections, the presence of a zebra crossing does influence pedestrian satisfaction but only by about half a level. The reason for this may be that only a small proportion of the vehicles stop to let pedestrians cross at non-signalized zebra crossings when this cross the main road. The type of facility that a pedestrian walks on before reaching the crossing has much greater influence on pedestrian satisfaction. Satisfaction improves by 2-4 levels when walking on a separate path or sidewalk compared to walking on the roadway. Traffic volumes have more or less the same influence at non-signalized intersections as at roundabout. The pedestrian satisfaction decreases by one level when an increase of about 700 vehicles per hour on the main road occurs.

When pedestrians cross the main road using a pedestrian bridge or tunnel it seems that only the type of crossing and height between the top and bottom of the stairs influence the level of pedestrian satisfaction. Variables such as traffic volume are not significant, however,

the pedestrian flow volumes were not high on the shown video clips. Pedestrians prefer bridges compared to tunnels. As the height of stairs become higher pedestrians become more dissatisfied. This height is typically 3-4 meters at tunnels and 5-8 meters at bridges.
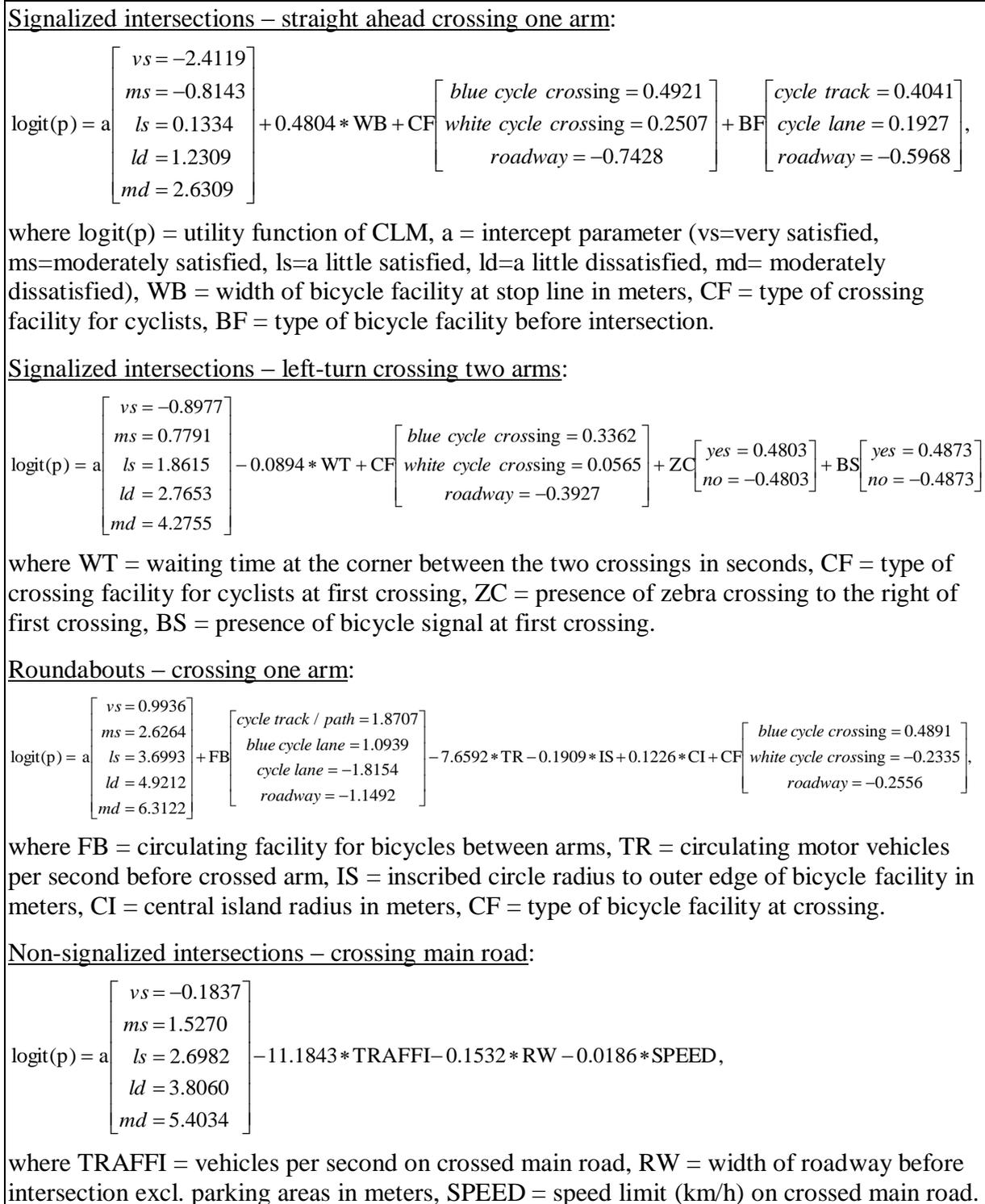
Bicycle models
The data analyses and regressions in order to estimate final bicycle models were performed in the same manner as for pedestrian models. Figure 3 shows the utility functions of the four CLMs found best to predict cyclist satisfaction. The models for cyclists at signalized intersections riding straight ahead and making left-turn, for roundabouts and non-signalized intersections include three, four, five and three main effects respectively. The predicted six shares of level of cyclist satisfaction may be calculated on the basis of the utility function in the same manner as for pedestrian satisfaction. The CLM for cyclists at signalized intersections riding straight ahead and making left-turn, for roundabouts and non-signalized intersections have average residuals of 0.40, 0.29, 0.26 and 0.23 respectively on the nominal scale. This means that models are generally better to predict pedestrian satisfaction than cyclist satisfaction.

At signalized intersections it is apparently only the width and type of bicycle facilities that influence cyclist satisfaction when they ride straight ahead crossing one intersection arm. As the bicycle facility becomes about 2.5 meters wider at the stop line the cyclists become one level more satisfied. No bicycle facility equals a width of zero. A blue cycle crossing inside the intersection makes cyclists about one level more satisfied compared to riding on the roadway. A white cycle crossing is a design consisting of white lines and bicycle symbols. There is no legal difference between blue, white and no cycle crossing in Denmark. The type of bicycle facility before the intersection is also important (it is the type before an eventual right-turn lane). Riding on a cycle track before the intersection makes cyclists about one level more satisfied compared to riding on the roadway.

Cyclists turn left at signalized intersections in a special way in Denmark. They first cross one arm and then wait at the corner for green light in the other direction and when green is signaled then they cross the second arm. The duration of the waiting time influences cyclist satisfaction, e.g. if waiting time increase by 30 seconds then cyclists become approximately 2 levels more dissatisfied. Presence of cycle crossings inside the intersection has a little less influence on left-turning cyclists satisfaction compared to straight ahead riding cyclists. The presence of a zebra crossing or a bicycle signal may improve left-turning cyclist satisfaction about one level. Presence of zebra crossings makes more room for the waiting left-turning cyclist on the corner and brings him or her further away from moving vehicles.

FIGURE 3 Bicycle models (CLM) and variable definitions.

Signalized intersections – straight ahead crossing one arm:

$$\text{logit}(p) = a \begin{bmatrix} vs = -2.4119 \\ ms = -0.8143 \\ ls = 0.1334 \\ ld = 1.2309 \\ md = 2.6309 \end{bmatrix} + 0.4804 * WB + CF \begin{bmatrix} blue\ cycle\ crossing = 0.4921 \\ white\ cycle\ crossing = 0.2507 \\ roadway = -0.7428 \end{bmatrix} + BF \begin{bmatrix} cycle\ track = 0.4041 \\ cycle\ lane = 0.1927 \\ roadway = -0.5968 \end{bmatrix},$$

where logit(p) = utility function of CLM, a = intercept parameter (vs=very satisfied, ms=moderately satisfied, ls=a little satisfied, ld=a little dissatisfied, md= moderately dissatisfied), WB = width of bicycle facility at stop line in meters, CF = type of crossing facility for cyclists, BF = type of bicycle facility before intersection.

Signalized intersections – left-turn crossing two arms:

$$\text{logit}(p) = a \begin{bmatrix} vs = -0.8977 \\ ms = 0.7791 \\ ls = 1.8615 \\ ld = 2.7653 \\ md = 4.2755 \end{bmatrix} - 0.0894 * WT + CF \begin{bmatrix} blue\ cycle\ crossing = 0.3362 \\ white\ cycle\ crossing = 0.0565 \\ roadway = -0.3927 \end{bmatrix} + ZC \begin{bmatrix} yes = 0.4803 \\ no = -0.4803 \end{bmatrix} + BS \begin{bmatrix} yes = 0.4873 \\ no = -0.4873 \end{bmatrix},$$

where WT = waiting time at the corner between the two crossings in seconds, CF = type of crossing facility for cyclists at first crossing, ZC = presence of zebra crossing to the right of first crossing, BS = presence of bicycle signal at first crossing.

Roundabouts – crossing one arm:

$$\text{logit}(p) = a \begin{bmatrix} vs = 0.9936 \\ ms = 2.6264 \\ ls = 3.6993 \\ ld = 4.9212 \\ md = 6.3122 \end{bmatrix} + FB \begin{bmatrix} cycle\ track\ /\ path = 1.8707 \\ blue\ cycle\ lane = 1.0939 \\ cycle\ lane = -1.8154 \\ roadway = -1.1492 \end{bmatrix} - 7.6592 * TR - 0.1909 * IS + 0.1226 * CI + CF \begin{bmatrix} blue\ cycle\ crossing = 0.4891 \\ white\ cycle\ crossing = -0.2335 \\ roadway = -0.2556 \end{bmatrix},$$

where FB = circulating facility for bicycles between arms, TR = circulating motor vehicles per second before crossed arm, IS = inscribed circle radius to outer edge of bicycle facility in meters, CI = central island radius in meters, CF = type of bicycle facility at crossing.

Non-signalized intersections – crossing main road:

$$\text{logit}(p) = a \begin{bmatrix} vs = -0.1837 \\ ms = 1.5270 \\ ls = 2.6982 \\ ld = 3.8060 \\ md = 5.4034 \end{bmatrix} - 11.1843 * TRAFFI - 0.1532 * RW - 0.0186 * SPEED,$$

where TRAFFI = vehicles per second on crossed main road, RW = width of roadway before intersection excl. parking areas in meters, SPEED = speed limit (km/h) on crossed main road.

The type of bicycle facility between arms influences cyclist satisfaction very much at roundabouts. Satisfaction improves 2-3 levels when cyclists ride on a cycle path, cycle track or colored cycle lane (blue or red) compared to riding on a cycle lane or the roadway, i.e. circulating lane. A blue cycle crossing across the arm improves satisfaction about half a level. The volume of circulating traffic has a slightly larger influence on cyclist satisfaction compared to pedestrian satisfaction. Cyclist satisfaction decreases by one level when an increase of about 600 circulating motor vehicles per hour occurs. The size of the roundabout matters. The cyclist detour becomes longer the further away from the center of the roundabout that the cyclist rides, and this result in more dissatisfied cyclists. Cyclists seem to prefer large central islands over small and cyclists prefer narrow circulating lane(s) over wide maybe because of the relations to motor vehicle speed. Overall, cyclists become less satisfied as the size of the roundabout increase.

At non-signalized intersections cyclist satisfaction worsen rapidly as traffic volume on the main road to be crossed increases. Cyclist satisfaction improves about one level when the volume of vehicles per hour decreases 400. The total width of drive lanes on the road that the cyclist travels along before reaching the intersection also matters. A width increase of about 8 meters results in a worsening of one level in cyclist satisfaction. If the cyclist rides on a separate path before reaching the intersection, i.e. no road, then the width is zero. The speed limit on the main road that the cyclist crosses influences cyclist satisfaction only a little bit.

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 4 presents the relations between pedestrian LOS at signalized intersections and pedestrian facilities, traffic volumes and crossing distance.

Figure 4 gives the clear impression that the type of pedestrian facility has great influence on pedestrian satisfaction at signalized intersections, whereas the influences from traffic volume and crossing distance are much smaller. With a zebra crossing it is possible to have a LOS A-D, but without zebra crossing LOS is only E or F.

FIGURE 4 Pedestrian LOS at signalized intersections with four types of pedestrian facilities depending on vehicle volume on crossed arm and crossing distance. Walking speed increases from 1.3 m/sec at a 10 m crossing to 1.6 m/sec at a 40 m crossing.
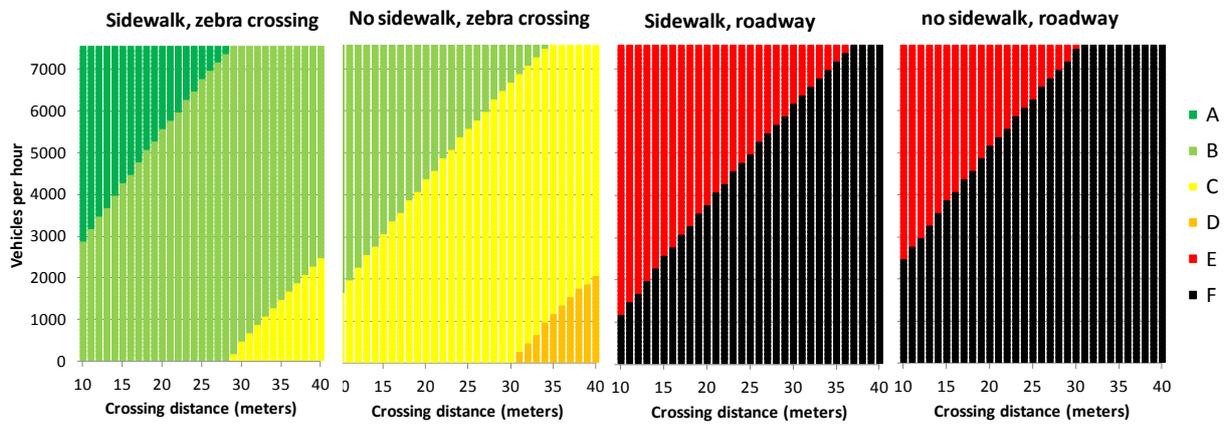
Figure 5 shows the relations between cyclist LOS at roundabouts and cyclist facilities, circulating traffic volumes and size of the central island. The central island do not include truck apron meaning that mini-roundabouts, where you may drive over the entire island at the center, have a central island radius of zero meters. Figure 5 clearly shows a big difference in cyclist LOS between riding on a colored cycle lane and cycle lane in white, and between riding on a cycle path or track and the roadway. It also shows that circulating traffic volume and size of the roundabout have some influence on cyclist LOS.

FIGURE 5 Cyclist LOS at roundabouts with four types of bicycle facilities depending on circulating motor vehicle volume before crossed arm and central island radius. The width of circulating area between central island and outer edge of bicycle area is 10 m.
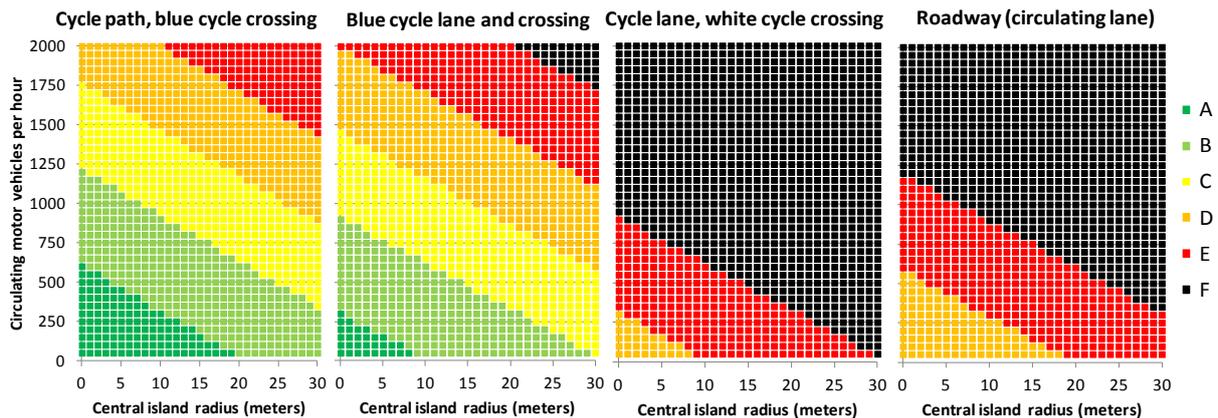
CONCLUSIONS

Overall the models show that many variables influence pedestrian and cyclist satisfaction and LOS at intersections, roundabouts and other crossings. The presence and type of pedestrian and bicycle facilities are the most important variables. Vehicle traffic volumes also influence LOS in many of the models. In a few models, the length of crossing or size of roundabout influence LOS. Waiting time and motor vehicle speed apparently only play minor roles in pedestrian and cyclist LOS at crossings.

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 variables like traffic volumes, speed limit and relevant distances are also necessary to calculate pedestrian and cyclist LOS at different type of crossings.

The pedestrian and bicycle satisfaction models and the subsequent LOS designations provide traffic planners and others the capability to rate intersections, roundabouts and other crossings with respect to road user 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 crossings in order to find those that are the most dissatisfying to pedestrians and bicyclists or to find crossings that will improve pedestrian and bicycle LOS considerably by using specific measures. The models may also be used in the process of designing new or redesigning intersections, roundabout and other crossings.

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