

1 **CAR DRIVERS EXPERIENCED LEVEL OF SERVICE ON FREEWAYS**

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1 **ABSTRACT**

2 The Danish Road Directorate sponsored a study to develop methods for quantifying car
3 drivers experienced level of service on freeways (CLOS). The results provide a measure of
4 how well freeways accommodate car travel.

5 In order to determine how traffic operations, geometric conditions, and other variables
6 affect car drivers' satisfaction, 188 randomly selected respondents were shown 80 video clips
7 of roadway segments filmed from a driving passenger car. Video clips consist of high
8 resolution video filmed through windshield, side windows including exterior mirrors and rear
9 window. Video clips also include a GPS based speedometer.

10 Respondents rated video clips on a six-point scale ranging from very satisfied to very
11 dissatisfied. This resulted in 7,497 useable ratings. 400-450 variables describe respondent
12 answers to six background questions and the video clips i.e. roadway segment geometries,
13 traffic operations, surroundings, weather, etc.

14 Car driver satisfaction models were developed using cumulative logit regression and
15 ordinary generalized linear modeling. The six presented models include 3-10 variables, which
16 relate significantly ($p \leq 0.05$) to satisfaction ratings. These variables are average speed, speed
17 limit, width of hard shoulder, number of entries and other merge areas per mile, number of
18 exits and other diverge areas per mile, flow of long vehicles per lane per hour, direction of
19 sunlight, drivers age, type of driver's license, and drivers yearly mileage. Models return
20 percentage splits of the six levels of satisfaction or average satisfaction. These splits or
21 averages are transformed into a level of service (LOS).

22

1 INTRODUCTION

2 Over the years, many have studied car drivers' perceptions and experiences, and attempted to
3 identify relations to road design, traffic operations, etc. However, none of the methodologies
4 that describe CLOS have been widely accepted. CLOS is not part of Highway Capacity
5 Manual (HCM) (1). This is a problem. CLOS is important in daily communication, and
6 understanding what makes a customer satisfied is core knowledge in any business sector. The
7 HCM includes pedestrian experienced level of service (PLOS) and bicyclist experienced
8 level of service (BLOS), but the resulting LOS scores of using methodologies for PLOS and
9 BLOS are not comparable to LOS for car travel in HCM. That makes it difficult to optimize
10 LOS across transport modes, and across road and intersection types.

11 Studies of freeways indicate that traffic flow, flow of trucks, travel speed, speed
12 variation, traffic density, lane changing, number of drive lanes, width of hard shoulder,
13 quality of road surfacing and presence of road works influence CLOS (2-9). Studies of urban
14 streets indicate that CLOS is affected by travel speed, stops per mile, number and width of
15 drive and parking lanes, median type, pedestrian and bicycle facilities, quality of road
16 surfacing, and presence of trees and left-turn lanes (9-14). Studies of rural highways indicate
17 that CLOS is affected by speed, speed variation, achieved/desired overtaking, flow of trucks,
18 headways, traffic density, forward visibility (sight distances), number of lanes and travel time
19 delay (15-17).

20 A Danish pilot study identified quality of service factors that affect CLOS on urban
21 streets, rural highways and freeways respectively (18). The study involved 20 drivers who
22 drove their own cars 45-60 minutes on predefined routes with various roadway segments.
23 Transcripts and video recordings of the drives identified traffic density, number of drive
24 lanes, road surfacing, density and type of merge areas, surroundings, and incidents such as
25 crashes, road works etc. as core quality of service factors on freeways.

26 Previous research indicates that for quantitative model building of experienced LOS,
27 video surveys are most useful (11). A few studies have shown that satisfaction ratings from
28 respondents watching video from a roadway segment are almost the same as ratings from
29 respondents at or traveling on the same roadway segment. It is important that the video
30 include realistic sound setting and even so it is difficult to sense the actual quality of road
31 surfacing on video due to the lack of vibrations (20-23). The ability to see the quality of road
32 markings and signs depends on the light conditions on the video (23). The studies on
33 experienced LOS indicate that video should be recorded by a traveling road user, in order to
34 produce realistic relations between traveler satisfaction and independent variables. Foster
35 (24) compared satisfaction ratings from an online (internet) survey and from video shows in
36 local ballrooms of the same video clips, and concluded that the online survey resulted in
37 different LOS scores (less satisfied) and larger standard deviations in LOS scores.

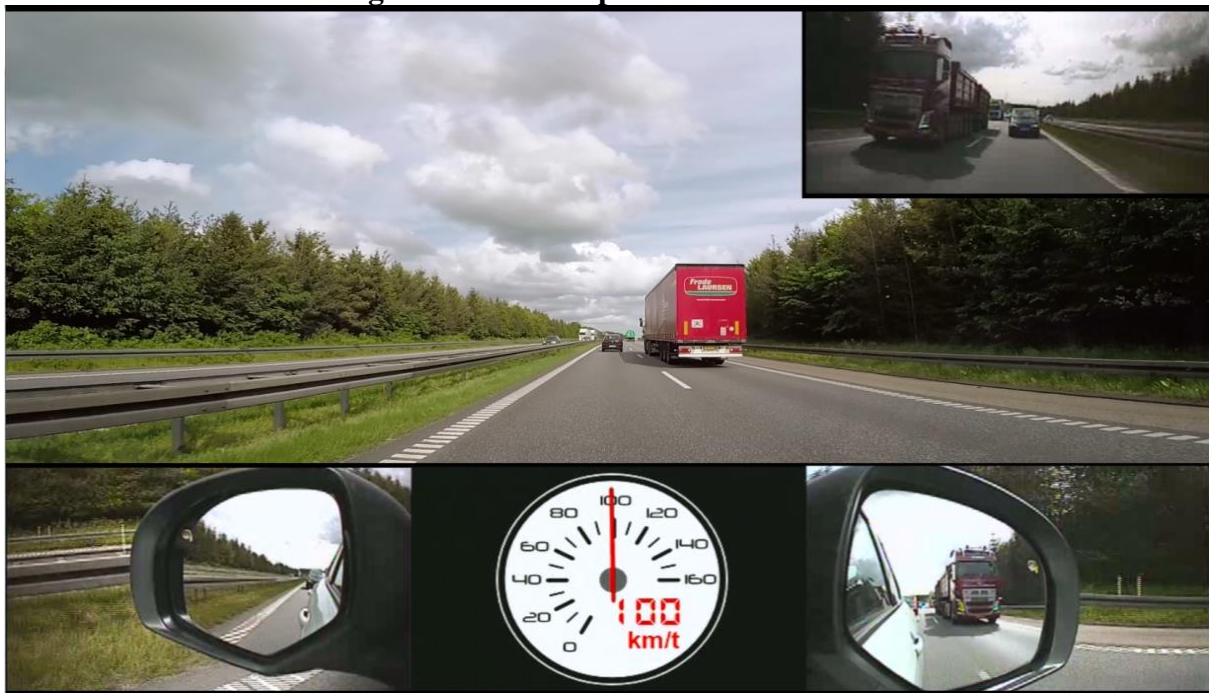
38 The objective of this study was to develop a rigorous methodology that systematically
39 can describe CLOS on roadway segments. This study focuses on freeways. A later study will
40 focus on rural highways and urban streets. Previous Danish studies have developed
41 methodologies for PLOS and BLOS (20-21). Another objective of this study is that LOS
42 scores for the three modes should be comparable, i.e. similar methodology as in previous
43 studies is preferred. The studies on CLOS on freeways, rural highways and urban streets and
44 the Danish pilot study provided a solid base for setting up a study, which is able to quantify
45 the impacts of quality of service factors.

1 **STUDY DESIGN**

2 The study is a stated perception (satisfaction) survey, where each roadway segment is rated
3 on a fixed satisfaction scale. The methodology was to have respondents view numerous
4 roadway segments captured on video and rate these segments with respect to how satisfied
5 they would be driving a car under the roadway conditions shown on video.

6 Two basic elements in a video survey have to be addressed; duration and design of
7 video clips. From previous studies we know that respondents want to rate a video clip after
8 about 30-40 seconds and starts to lose interest in a video clip after about 2-3 minutes (4, 21).
9 In order to find the most appropriate duration and design of video clips a second pilot study
10 was undertaken (23). This study included a panel of respondents testing size, shape and
11 presence of five elements in a video clip; view out of windshield, rear window, the two side
12 windows including exterior mirrors and a speedometer. Different types of separation and
13 frames between these elements were also tested. The panel preferred the design shown in
14 Figure 1. This design provided them the opportunity to quickly perceive road design, traffic
15 operations, etc.

16
17 **FIGURE 1 Preferred Design of a Video Clip**



18
19

20 Different ways of recording and presenting sounds was also tested in the pilot study.
21 Recordings of sound from two microphones located close to the driver's ears were found to
22 be best (23). Different ways of introducing a video clip was also tested. Besides a video clip
23 number that respondents use to find the right spot to make a satisfaction rating on a scoring
24 card, the panel found it important that the introduction informs about the type of road and the
25 speed limit.

26 The duration and "content" of a video clip was tested in several ways. In one test the
27 panel rated their satisfaction as a car driver as fast as possible still feeling confident about

1 their rating. The average view time needed to make a rating was 12-15 seconds. Fastest rating
2 was after 3 seconds and slowest rating after 35 seconds. Overall 22 % of the fast ratings were
3 different compared to ratings made after the end of the video clip. It was concluded that video
4 clips with simple driving conditions should be 20 seconds or longer for respondents to rate
5 their satisfaction reliably, while video clips with complex driving conditions should be about
6 30 seconds or longer.

7 Another test was performed in order to possibly identify *The Peak-End rule* (25). This
8 rule states that the rating value of a representative moment is a simple average of the most
9 extreme affect (Peak) experienced during the episode and the affect experienced near its end
10 (End). For this test a few long video clips of 80-90 seconds were used. The video clips had
11 different endings and “peaks” even though peaks were not extreme. Video clips were shown
12 in their entire length and in bits of 20-30 seconds and the panel had to rate their satisfaction
13 with each bit and also the entire video clips. Satisfaction ratings of the entire video clip were
14 the same as the average of all bits of the same video clip. So peaks and ends were not more
15 important to ratings than other parts of the video clips. Perhaps changes in road design and
16 traffic conditions when driving are not “fast enough” for *The Peak-End rule* to actually
17 materialize within 80-90 seconds. We therefore concluded that for video clips up to at least
18 90 seconds of duration, the stimuli, i.e. shown road design, traffic conditions, etc., during the
19 entire video clip would be reflected in satisfaction ratings. As mentioned earlier some
20 experiences with rating of video clips show that respondents get bored after 2-3 minutes of
21 viewing a video clip. Boredom/fatigue will result in ratings becoming more negative, which
22 have been seen in many studies (25). Therefore a video clip should preferably not be longer
23 than 150 seconds. If longer, ratings would have a negative bias and ratings may perhaps only
24 be related to parts of the video clip.

25 The idea was then to include 30-90 seconds long video clips (maybe very few video
26 clips of 90-150 seconds if needed). This means that on freeways with a 90-130 km/h speed
27 limit, the recorded segments could be up to 2.2-3.2 km long, and should at least be about a
28 third of this length. Similarly, recorded rural highway segments could be up to 1.5-2.2 km
29 and urban street segments up to 0.7-1.5 km. The roadway segments should have similar good
30 quality regarding road surface, markings and signs, because the quality of these elements
31 would be difficult for respondents to include in their satisfaction ratings. Video clips should
32 be presented as shown in Figure 1 in local ball rooms with proper sound.

34 **Site selection**

35 Based on experience with quantitative model building from previous studies it was decided
36 that the video-based study of CLOS should include 36 freeway segments, 36 rural highway
37 segments and 36 urban street segments. A third of the roadway segments (randomly chosen)
38 should be represented by not only one video clip but two. The extra video clip (repeater-clip)
39 should show very different traffic conditions, i.e. the volume-to-capacity-ratio in the driven
40 direction should be at least two categories higher or lower than in the ‘original’ video clip,
41 see categories in Table 1. On average, the original and repeater video clip has a difference in
42 flow of 814 passenger car units per lane per hour, which corresponds to about 35 % of the
43 capacity. Repeater-clips were to be included for two reasons; 1) better capturing of
44 satisfaction ratings in free-flow situations, and 2) better quantification of traffic conditions
45 impact on satisfaction.

1 With a relatively small number of roadway segments, it is important to maximize the
 2 range of conditions included. Three orthogonal experimental designs were developed before
 3 site selection (23). The intent of the design was to ensure that the sites selected not only
 4 represented the variety of conditions drivers may encounter, but also that important quality of
 5 service factors that prior studies have found to affect CLOS were orthogonal, i.e. no relations
 6 between factors across sites. Table 1 shows the quality of service factors chosen to set up the
 7 orthogonal experimental design for freeways.
 8

9 **TABLE 1 Quality of Service Factors and Related Categories in Orthogonal Design of**
 10 **the Selection of Freeway Segments**

Quality of Service Factors	Categories	Number of Freeway Segments
Volume-to-capacity-ratio in the driven direction	0.00-0.22	6
	0.22-0.43	6
	0.43-0.65	6
	0.65-0.83	6
	0.83-0.93	6
	0.93-	6
Number of drive lanes and presence of wide hard shoulder in the driven direction	2 and no hard shoulder	6
	2 and wide hard shoulder	15
	3 and wide hard shoulder	9
	4-5 and wide hard shoulder	6
Number of entries in the driven direction	0	16
	1	12
	2 or more	8
Type of segment driven on	Only freeway segment	18
	Start on entrance lane	5
	End on exit lane	5
	With merge of two freeways	4
	With diverge into two freeways	4
Surroundings	Changing environment	11
	Fields (open)	9
	Forest (at least to one side)	7
	Urban	9

11 All 108 roadway segments were found in Denmark. The presented study includes 80
 12 video clips – 48 from freeway segments, 16 rural highway segments and 16 urban street
 13 segments. Segments of rural highways and urban streets are part of the study in order to get
 14 comparable CLOS across road types. A roadway segment had to fulfill a number of other
 15 things than just the quality of service factors described in Table 1. The recording car may not
 16 have a yield line, stop line, formal pedestrian crossing, level crossing (rail), etc., where the
 17 car may have to brake or stop on the segment. Video clips should not start before the car had
 18 accelerated away from e.g. an intersection, and should end before decelerating towards e.g. a
 19 roundabout. For freeway and rural highway segments, the video clip should end at least 100
 20 meters before a yield or stop line. Also a 10 and a 5 seconds rule apply stating that the video
 21 clip should start at least 10 seconds before a lane change or major change in cross section
 22 (including transition area), and should end at least 5 seconds after a lane change and major
 23

1 cross section change. The reason for these rules is that respondents do not understand these
2 changes unless they have time to experience a state before and after.

3 4 **Video production**

5 Video recordings were made in fall, spring and summer 2014-2015 in daylight hours, no
6 precipitation and no snow on the ground. Video recordings were made from a passenger car
7 using a GoPro for view out of windshield and a VBOX system with synchronized cameras
8 through side and rear window and GPS based speedometer. If possible, the car travelled 0-5
9 km/h below the speed limit, in the right-hand lane, in center of the drive lane, and with a time
10 distance of 2 seconds or more to a vehicle in front and in the same drive lane. Turn signals
11 were always used when performing lane changes. There were no radio, music, talk or fiddling
12 with stuffs inside the recording car. All recordings that had aggressive or unusual behavior
13 were deselected e.g. near-crashes, extreme speeds, wrecked vehicles, hunks, barking dogs,
14 sirens, etc.

15 Each roadway segment was filmed 3-6 times in order to get a video clip that met the
16 requirements of the orthogonal experimental designs. Segments with repeater-clips were
17 filmed 6-12 times in total. Selected video clips were edited into 60 minutes long video films
18 using Adobe Premiere Elements 12. Video clips were on average 45 seconds long and varied
19 between 30 and 140 seconds. Two video clips were longer than 90 seconds.

20 21 **Data collection**

22 Fixed conditions were measured in the field and using aerial photos and road databases. Data
23 on fixed conditions include e.g. cross section, alignment, road surfacing, planting within road
24 area, markings, types of separation, signs and regulation, road lighting and barriers and other
25 equipment, exits, entries, side roads and driveways, speed reducing measures, bus stops,
26 medians, turn lanes, visible landscape and buildings within 100 meters from road, etc.

27 A synchronized stationary camera placed on the last half of the roadway segment
28 recorded traffic in both directions during recording of video clips and with known position of
29 the recording car. Traffic in the driven direction was counted per lane in length categories and
30 10 seconds intervals for one minute with the recording car in the middle. Traffic in the
31 opposite direction seen on the video clip was counted per lane in length categories and 10
32 seconds intervals. Video clips and stationary camera were used to estimate motor vehicle
33 speed in the opposite direction.

34 Data from the video clips include information about e.g. weather, sunlight, speed of
35 the recording car every second, passed road users in opposite and same direction respectively
36 including over takings, passed parked vehicles, passed yielding road users, and estimated
37 speed of other motor vehicles in the driven direction.

38 39 **Respondents, video shows and questionnaire**

40 A total of 1,542 randomly selected citizens 18 years of age or older from Herning (town of
41 30,000 inhabitants) and Lyngby-Taarbæk (Greater Copenhagen 1.5 million inhabitants)
42 municipalities were invited to participate, but only 193 participated in eight video shows,
43 corresponding to 13 percent. Videos were shown in local ballrooms using professional video
44 projectors on 3.5 x 2.0 meter screens and sets of stereo loudspeakers. Between 13 and 43
45 participated in the individual video shows. Responses from five participants were discarded

1 for different reasons. Each video clip was shown in four video shows and rated by 81-107
2 respondents. Respondents were car drivers.

3 A video survey may result in biased relationships due to e.g. respondent fatigue and
4 policy-response bias. Learner video clips were used to avoid bias from beginner rating
5 problems. One learner video clip was repeated later in the video show in order to identify
6 possible beginner problems. Video clips were shown in random order in a video show and
7 then turned in backward order in another show in order to avoid respondent fatigue bias.
8 Policy-response biases were hopefully at a minimum by having a brief, neutral welcome
9 presentation on video and a short neutral instruction to satisfaction rating also on video. The
10 rating was kept as simple as possible. The rating was based on a short question: "How
11 satisfied were you as a car driver on the shown road?" The question could be answered by
12 ticking of a six-point scale ranging from very satisfied to very dissatisfied. An overview of
13 satisfaction ratings is given in Table 2. Respondents had 10 seconds between video clips to
14 make a rating.
15

16 **TABLE 2 Satisfaction Ratings of Roadway Segments**

Nominal and ordinal scale		Number of responses (percent of column total)			
		Freeways	Rural highways	Urban streets	Total
1	Very satisfied	1,851 (41 %)	452 (30 %)	241 (16 %)	2,544 (34 %)
2	Moderately satisfied	1,418 (32 %)	451 (30 %)	401 (27 %)	2,270 (30 %)
3	A little satisfied	586 (13 %)	278 (19 %)	283 (19 %)	1,147 (15 %)
4	A little dissatisfied	353 (8 %)	186 (12 %)	225 (15 %)	764 (10 %)
5	Moderately dissatisfied	198 (4 %)	100 (7 %)	232 (15 %)	530 (7 %)
6	Very dissatisfied	92 (2 %)	33 (2 %)	117 (8 %)	242 (3 %)
Total		4,498 (100 %)	1,500 (100 %)	1,499 (100 %)	7,497 (100 %)
Average (nominal)		2.09	2.42	3.10	2.36
Average, best roadway segment		1.31	1.49	1.69	1.31
Average, worst roadway segment		4.42	3.85	4.77	4.77

17 Respondents attended a 60-minutes video show with a welcome, presentation of
18 questionnaire, answering six background questions (age, sex, type of residence, type of driver
19 license, years with driver license, yearly driver mileage), two learner video clips, questions-
20 and-answers, first rating session with 20 video clips, 10 minutes break with refreshing soft
21 drinks and chocolate, second rating session with 20 video clips, closure. So a video show
22 included a total of 40 different video clips in random order.
23
24

25 MODEL DEVELOPMENT

26 Car driver satisfaction models for freeways were developed using the software SAS version
27 9.4. PROC GENMOD was used to set up ordinary generalized linear models (GLM). GLM
28 models use average ratings for each freeway segment on the nominal scale, see Table 2.
29 PROC LOGISTIC was used to set up cumulative logit models (CLM). CLM models use
30 response ratings on the ordinal scale. Determining the key independent variables that
31 influence respondents (car drivers) satisfaction was the primary objective of data analyses.
32 The approach was to use CLM stepwise regression to determine all main effects, search for

1 significant square and interaction terms, and eliminate spurious variables and variables not
 2 significant at a $p \leq 0.05$ level. Optimization technique was Fisher's scoring. Increasing the
 3 number of variables had to result in a reasonable reduction in Akaike Information Criterion
 4 (AIC). After the development of CLM models, the same variables were then used in GLM
 5 models except for variables describing respondents.

6 The variable that has the strongest relation to satisfaction ratings is *average speed of*
 7 *the recording car and surrounding vehicles* (overtaking, being overtaken, in front and back of
 8 recording car) *in the driven direction* during the video clip. This average speed relates more
 9 to ratings than average speed of the recording car, which means overtaking is included in
 10 respondent perception and their satisfaction rating. Speed of cars in the opposite driving
 11 direction has no influence on ratings. If average speed is excluded from a model then traffic
 12 density described as passenger car units per lane per km becomes the most important variable
 13 and relates most to satisfaction ratings. Again it is the traffic density for all lanes in the driven
 14 direction that relates most to ratings, not traffic density in the driven lane, and traffic density
 15 in the opposite driving direction does not relate to ratings. If both average speed and traffic
 16 density are excluded from a model then traffic flow described as passenger car units per lane
 17 per hour in the driven direction becomes the variable that relates most to the satisfaction
 18 ratings. However, such traffic flow model improves significantly when a dummy variable
 19 describing traffic breakdown (yes/no) is added. When average speed is in the model then
 20 neither traffic density nor traffic flow is significant, however, the flow of long vehicles in the
 21 driven direction is significant. Models with traffic density or traffic flow are not shown in this
 22 paper as they produce much larger residuals than models with average speed.

23 Three CLM models of increasing complexity (more and more variables) have been
 24 developed, see utility functions in Figure 2. The predicted six shares of level of satisfaction
 25 may be calculated on the basis of the utility function in the following manner:

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

32
 33 The CLM models in Figure 2 have on average a residual of 0.20-0.25 on the nominal
 34 scale. (For comparison: Models with traffic flow and traffic breakdown variables have
 35 average residuals of 0.33-0.53.) Adding more variables than average speed does not improve
 36 models and lower average residual considerably.

37 The variables Sunlight, Age, License and Mileage may be replaced by a constant of
 38 +2.2681 in the Model Speed Logit 3 in Figure 2, when the "average" respondent and sunlight
 39 conditions are being used. The average residual increases to 0.25, when the four variables are
 40 replaced by the constant.

1 **FIGURE 2 CLM Models for Car Driver Experienced Level of Satisfaction on Freeways**
 2 **(Based on Ratings of 48 Video Clips from Freeways Including Repeater Video Clips)**

CLM Model Speed 1 (AIC=11,813, Average residual=0.25)

$$\text{logit}(p) = a^{**} \cdot \begin{bmatrix} vs = -5.3651 \\ ms = -3.8228 \\ ls = -2.8732 \\ ld = -1.8615 \\ md = -0.5575 \end{bmatrix} + 0.0488 \cdot \text{AvgSpeed}^{**} + 0.3058 \cdot \text{HardSh}^{**} - 0.00675 \cdot \text{SpeedLimit}^*$$

CLM Model Speed 2 (AIC=11,740, Average residual=0.24)

$$\text{logit}(p) = a^{**} \cdot \begin{bmatrix} vs = -4.2926 \\ ms = -2.7356 \\ ls = -1.7670 \\ ld = -0.7287 \\ md = 0.6080 \end{bmatrix} + 0.0433 \cdot \text{AvgSpeed}^{**} + 0.3366 \cdot \text{HardSh}^{**} - 0.0109 \cdot \text{SpeedLimit}^{**} - 0.3988 \cdot \text{Entry}^{**} + 0.2200 \cdot \text{Exit}^{**}$$

CLM Model Speed 3 (AIC=11,568, Average residual=0.20)

$$\text{logit}(p) = a^{**} \cdot \begin{bmatrix} vs = -6.0587 \\ ms = -4.4451 \\ ls = -3.4536 \\ ld = -2.4012 \\ md = -1.0588 \end{bmatrix} + 0.0380 \cdot \text{AvgSpeed}^{**} + 0.4015 \cdot \text{HardSh}^{**} - 0.0103 \cdot \text{SpeedLimit}^*$$

$$-0.4973 \cdot \text{Entry}^{**} + 0.1920 \cdot \text{Exit}^* - 0.0034 \cdot \text{Truck}^{**} + \text{Sunlight}^{**} \cdot \begin{bmatrix} \text{Front} = -0.2258 \\ \text{Right} = -0.1614 \\ \text{Left} = -0.0744 \\ \text{Behind} = 0.6067 \\ \text{No} = 0.0000 \end{bmatrix}$$

$$+ 1.3158 \cdot \log(\text{Age}^{**}) + \text{License}^{**} \cdot \begin{bmatrix} \text{Yes} = 0.3221 \\ \text{No} = 0.0000 \end{bmatrix} + \text{Mileage}^* \cdot \begin{bmatrix} 1 - 999 \text{ km} = -0.2768 \\ 1,000 - 4,999 \text{ km} = 0.1438 \\ 5,000 - 9,999 \text{ km} = 0.0978 \\ 10,000 - 20,000 \text{ km} = -0.1058 \\ \text{Over } 20,000 \text{ km} = 0.0000 \end{bmatrix}$$

- 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),
 AvgSpeed = average speed (km/h) in driven direction,
 HardSh = width of hard shoulder including edge line (meters),
 SpeedLimit = speed limit (km/h),
 Entry = number of entries/merge areas per km in driven direction,
 Exit = number of exits/diverge areas per km in driven direction,
 Truck = vehicles > 12.5 meters per lane per hour in driven direction,
 Sunlight = direction from where sunlight “hits” driver,
 Age = age of respondent,
 License = Yes, if respondent holds license to large truck, and
 Mileage = yearly driving.

** is a p-value of <0.001, * is a p-value of <0.05.

1 Also three GLM models of increasing complexity have been developed, see the
 2 satisfaction functions in Figure 3. The GLM models have on average a residual for freeway
 3 segments of 0.19-0.25 on the nominal scale, which is almost the same as for the CLM
 4 models.

5
 6 **FIGURE 3 GLM Models for Car Driver Experienced Satisfaction on Freeways (Based**
 7 **on Ratings of 48 Video Clips from Freeways Including Repeater Video Clips)**

GLM Model Speed 1 (AIC=39.2, Average residual=0.25)

$$AvgSatis = 13.5704^{**} - 5.7037 \cdot \log(AvgSpeed^{**}) - 0.2082 \cdot HardSh^{**} + 0.0037 \cdot SpeedLimit$$

GLM Model Speed 2 (AIC=34.8, Average residual=0.22)

$$AvgSatis = 11.8828^{**} - 4.9984 \cdot \log(AvgSpeed^{**}) - 0.2219 \cdot HardSh^{**} + 0.0057 \cdot SpeedLimit \\ + 0.2234 \cdot Entry^* - 0.1138 \cdot Exit$$

GLM Model Speed 3 (AIC=31.8, Average residual=0.19)

$$AvgSatis = 10.5268^{**} - 4.2813 \cdot \log(AvgSpeed^{**}) - 0.2529 \cdot HardSh^{**} + 0.0051 \cdot SpeedLimit$$

$$+ 0.2931 \cdot Entry^{**} - 0.1015 \cdot Exit - 0.0022 \cdot Truck^* + Sunlight^* \cdot \begin{bmatrix} Front = 0.0490 \\ Right = -0.0201 \\ Left = -0.0747 \\ Behind = -0.4412 \\ No = 0.0000 \end{bmatrix}$$

where AvgSatis = average satisfaction on the nominal scale,
 AvgSpeed = average speed (km/h) in driven direction,
 HardSh = width of hard shoulder including edge line (meters),
 SpeedLimit = speed limit (km/h),
 Entry = number of entries/merge areas per km in driven direction,
 Exit = number of exits/diverge areas per km in driven direction,
 Truck = vehicles > 12.5 meters per lane per hour in driven direction,
 Sunlight = direction from where sunlight "hits" driver,
 Age = age of respondent,
 License = Yes, if respondent holds license to large truck, and
 Mileage = yearly driving.

** is a p-value of <0.001, * is a p-value of <0.05.

8
 9

10 **Biases**

11 The respondents rated learner video clips that were repeated in the second rating session.
 12 Only 46 percent of ratings of the first learner video clip were exactly the same as ratings in
 13 the second rating session, but for the second learner video clip 58 percent were exactly the
 14 same. The average rating on the nominal scale for the first learner video clips was 2.42, but
 15 when the same video clips were shown in the second rating session the average rating was

1 3.13, a difference of 0.71. For the second learner video clip this difference was only 0.02.
2 This means that some respondents actually had rating problems with the first learner video
3 clip, but respondents seem to have overcome these beginner problems when rating the second
4 learner video clip. Therefore it is concluded that results and models are not biased due to bias
5 related to beginner problems.

6 The order of video clips was randomized once. However, video clips were shown in
7 this randomized order and in reversed randomized order. By doing so it was possible to detect
8 how respondent fatigue influenced satisfaction ratings. Analyses show that there was no
9 tendency to respondents rating becoming more dissatisfied or satisfied during rating sessions,
10 the average rating only worsened by 0.004 on the nominal scale from the first to the twentieth
11 video clip in a session. The respondents had the exact same level of satisfaction in the first
12 and second rating session, so the break between the two sessions had no influence. It is
13 therefore concluded that results and models are not biased due to bias related to respondent
14 fatigue.

15 Repeater video clips had some influence on model development. When models were
16 developed without ratings of repeater video clips, i.e. only ratings of 36 video clips were
17 included, then the variable for speed limit was not significant. The speed limit variable works
18 as a proxy for the free-flow condition. By using ratings of repeater video clips, a bias related
19 to lack of varying satisfaction for different free-flow conditions has been avoided.

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

22

23 **LEVEL OF SERVICE CRITERIA**

24 The LOS criteria are based on the split of the response levels of satisfaction. To remain
25 consistent with the Highway Capacity Manual (*J*), six CLOS designations (A through F)
26 were defined as follows. A “democratic” definition is used, meaning that if 50 percent or
27 more are very satisfied then LOS is designated A. LOS is designated B if 50 percent or more
28 are very or moderately satisfied and less than 50 percent are very satisfied. And so forth,
29 ending up with a LOS F if 50 percent or more are very dissatisfied.

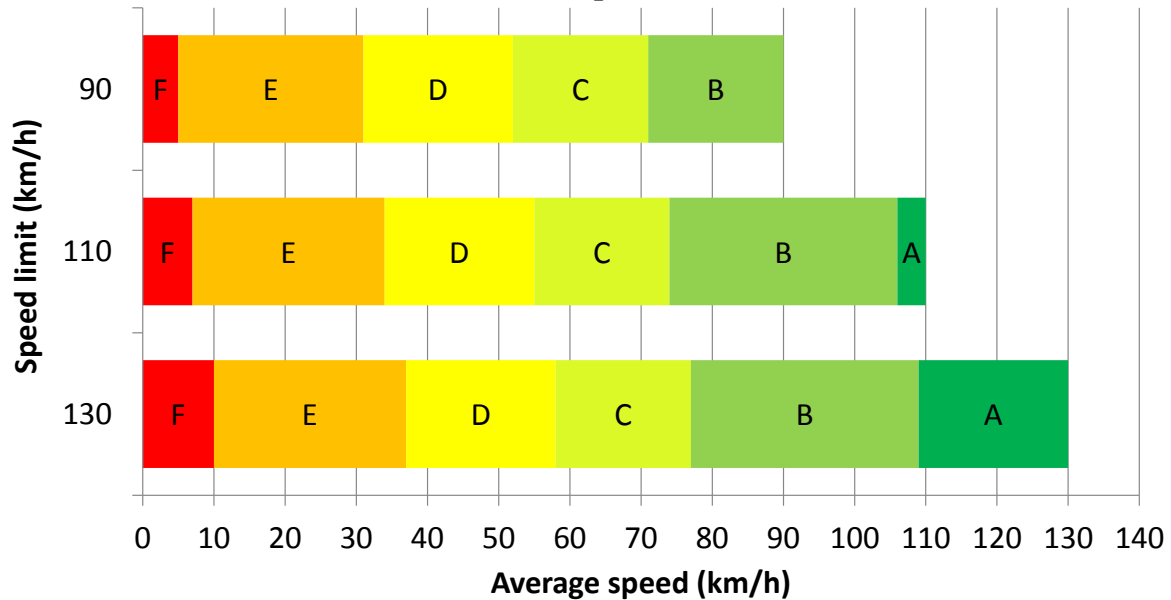
30 Having these definitions makes it much easier to grasp road user satisfaction and to
31 present the models relationships. Figure 4 presents the relations between CLOS, average
32 speed and speed limit. The figure shows as a rule of thumb that the experienced level of
33 service on freeways deteriorates by one level when the average speed is reduced by 20-30
34 km/h. Freeways with a speed limit of 90 km/h may not get a LOS A unless the average speed
35 is above 102 km/h.

36 The width of the hard shoulder is measured from the inner edge of the edge line to the
37 edge of the asphalt. This width varies from 0.3 to 4.0 meters on Danish freeways. CLOS is
38 improved by a quarter of a level when this width is increased by 1 meter. There is about a
39 quarter of a level in CLOS difference between having 1 and 10 entries per 10 km. Similarly
40 there is about an eighth level of service difference between 1 and 10 exits per 10 km of
41 freeway. Closely spaced entries may worsen CLOS rather much.

42 Vehicles longer than 12.5 meters have some influence on CLOS. Long vehicles are
43 calculated as 2.5 passenger car units in traffic flow models. However, the impact on CLOS of
44 one long vehicle is about the same as 6-7 passenger cars. This is why there is a Truck

1 variable in the models in Figure 2 and 3. CLOS worsen about a third of a level when the
 2 share of vehicles that are trucks increase from 0 to 10 percent.

3
 4 **FIGURE 4 Relations between CLOS, Average Speed and Speed Limit. Hard Shoulder**
 5 **width is 3.0 meters (Based on CLM Model Speed 1)**



6
 7

8 Sunlight coming in the car through the windshield annoys the driver and he/she is
 9 then less satisfied compared to no sunlight. But sunlight coming from behind makes drivers
 10 more satisfied.

11 It was also found that respondent age, type of driver license and yearly mileage
 12 impacted satisfaction rating on freeways. Older drivers are more satisfied than younger.
 13 People with large truck driver license are more satisfied than those without such a license.
 14 Those driving less than a 1,000 km a year are more dissatisfied than people driving more.
 15 There were no difference in ratings from Herning and Lyngby-Taarbaek, which means that
 16 respondents from minor towns and metropolitan areas rate freeways the same way.

17

18 CONCLUSIONS

19 Overall models show that car drivers experienced level of service on freeways heavily
 20 depend on average speed of vehicles in the driven direction. Speed is much stronger related to
 21 CLOS than traffic flow or traffic density. When flow reaches capacity of a freeway then
 22 speed drops significantly and drivers go from being satisfied to being dissatisfied in most
 23 cases. How dissatisfied drivers are after a traffic breakdown depends on the speed in this
 24 flow. Models that do not include average speed as an independent variable but include traffic
 25 flow have strong relations between flow and CLOS before a traffic breakdown but describe
 26 CLOS poorly after a breakdown.

27 The car driver satisfaction models and the subsequent LOS designations provide
 28 traffic planners and others the capability to rate freeways with respect to road users
 29 satisfaction. Models can rate existing freeways in real-time and retrospective, and provide
 30 road users, navigation systems and road administrations with valuable information to choices

1 before and during journeys and to optimize budgets for freeway improvements. Models may
2 also be used in the process of designing new freeways or redesigning existing freeways.

3 Models are not biased due to respondent fatigue, beginner rating problems or lack of
4 satisfaction ratings of free-flow conditions. Models enable practitioners to calculate the
5 experienced utility that car drivers perceive on freeways.

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