CAR DRIVERS EXPERIENCED LEVEL OF SERVICE ON FREEWAYS

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ABSTRACT

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

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

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

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

INTRODUCTION

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

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

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

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

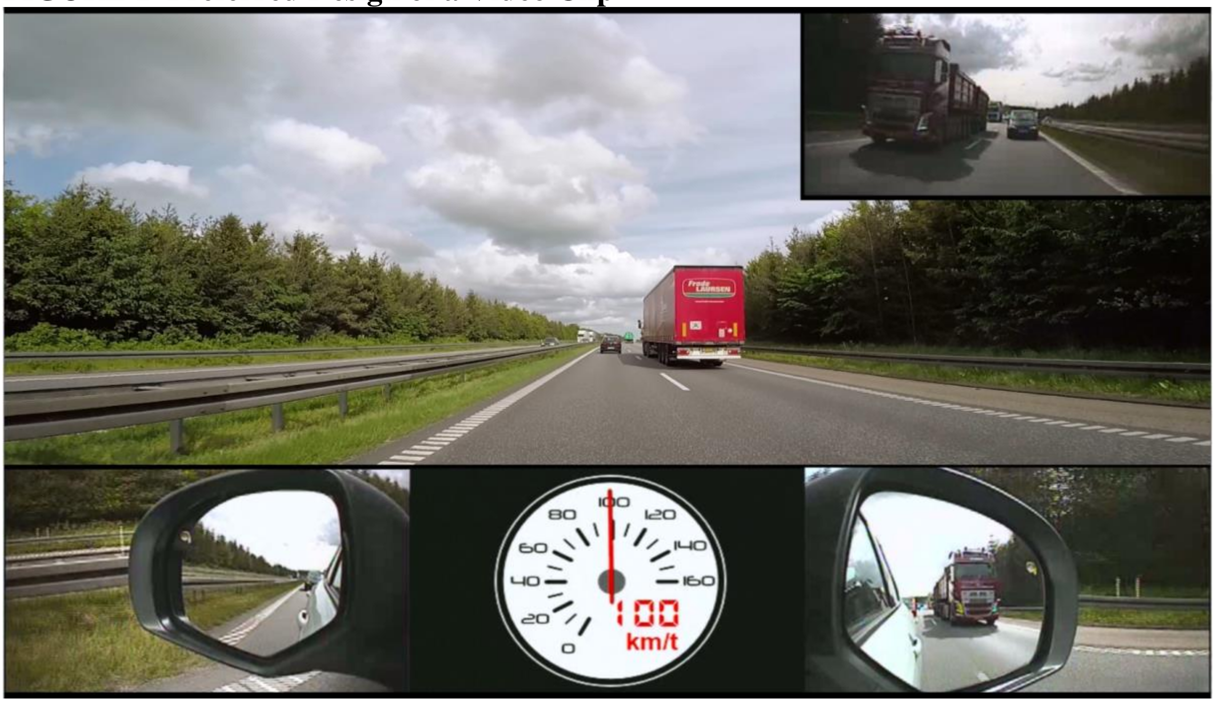
The objective of this study was to develop a rigorous methodology that systematically can describe CLOS on roadway segments. This study focuses on freeways. A later study will focus on rural highways and urban streets. Previous Danish studies have developed methodologies for PLOS and BLOS (*20-21*).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

STUDY DESIGN

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

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

FIGURE 1 Preferred Design of a Video Clip



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

The duration and "content" of a video clip was tested in several ways. In one test the panel rated their satisfaction as a car driver as fast as possible still feeling confident about their rating. The average view time needed to make a rating was 12-15 seconds. Fastest rating was after 3 seconds and slowest rating after 35 seconds. Overall 22 % of the fast ratings were different compared to ratings made after the end of the video clip. It was concluded that video clips with simple driving conditions should be 20 seconds or longer for respondents to rate their satisfaction reliably, while video clips with complex driving conditions should be about 30 seconds or longer.

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

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

Site selection

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

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

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

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

Video production

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

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

Data collection

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

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

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

Respondents, video shows and questionnaire

A total of 1,542 randomly selected citizens 18 years of age or older from Herning (town of 30,000 inhabitants) and Lyngby-Taarbaek (Greater Copenhagen 1.5 million inhabitants) municipalities were invited to participate, but only 193 participated in eight video shows, corresponding to 13 percent. Videos were shown in local ballrooms using professional video projectors on 3.5 x 2.0 meter screens and sets of stereo loudspeakers. Between 13 and 43 participated in the individual video shows. Responses from five participants were discarded for different reasons. Each video clip was shown in four video shows and rated by 81-107 respondents. Respondents were car drivers.

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

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

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

MODEL DEVELOPMENT

Car driver satisfaction models for freeways were developed using the software SAS version 9.4. PROC GENMOD was used to set up ordinary generalized linear models (GLM). GLM models use average ratings for each freeway segment on the nominal scale, see Table 2. PROC LOGISTIC was used to set up cumulative logit models (CLM). CLM models use response ratings on the ordinal scale. Determining the key independent variables that influence respondents (car drivers) satisfaction was the primary objective of data analyses. The approach was to use CLM stepwise regression to determine all main effects, search for significant square and interaction terms, and eliminate spurious variables and variables not significant at a $p \leq 0.05$ level. Optimization technique was Fisher's scoring. Increasing the number of variables had to result in a reasonable reduction in Akaike Information Criterion (AIC). After the development of CLM models, the same variables were then used in GLM models except for variables describing respondents.

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

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

$$SHARE_{\text{very satisfied}} = 1 - 1/(1 + \exp(\text{logit}(p)_{\text{very satisfied}})$$

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

…

$$SHARE_{\text{very dissatisfied}} = 1 - SHARE_{\text{very satisfied}} - SHARE_{\text{moderately satisfied}} - SHARE_{\text{a little satisfied}} - SHARE_{\text{a little dissatisfied}} - SHARE_{\text{moderately dissatisfied}}$$

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

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

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

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

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

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

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

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

$$logit(p) = a^{xx} \cdot \begin{bmatrix} vs = -6.0587 \\ ms = -4.4451 \\ ls = -3.4536 \\ ld = -2.4012 \\ md = -1.0588 \end{bmatrix} + 0.0380 \cdot AvgSpeed^{xx} + 0.4015 \cdot HardSh^{xx} - 0.0103 \cdot SpeedLimit^{x}$$
$$-0.4973 \cdot Entry^{xx} + 0.1920 \cdot Exit^{x} - 0.0034 \cdot Truck^{xx} + Sunlight^{xx} \cdot \begin{bmatrix} Front = -0.2258 \\ Right = -0.1614 \\ Left = -0.0744 \\ Behind = 0.6067 \\ No = 0.0000 \end{bmatrix}$$
$$+1.3158 \cdot \log(Age^{xx}) + License^{xx} \cdot \begin{bmatrix} Yes = 0.3221 \\ No = 0.0000 \end{bmatrix} + Mileage^{x} \cdot \begin{bmatrix} 1 - 999\ km = -0.2768 \\ 1{,}000 - 4{,}999\ km = 0.1438 \\ 5{,}000 - 9{,}999\ km = 0.0978 \\ 10{,}000 - 20{,}000\ km = -0.1058 \\ Over\ 20{,}000\ km = 0.0000 \end{bmatrix}$$

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.

^{xx} is a p-value of <0.001, ^{x} is a p-value of <0.05.

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

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

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

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

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

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

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

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

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

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.

$^{\times\times}$ is a p-value of <0.001, $^{\times}$ is a p-value of <0.05.

Biases

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

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

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

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

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

LEVEL OF SERVICE CRITERIA

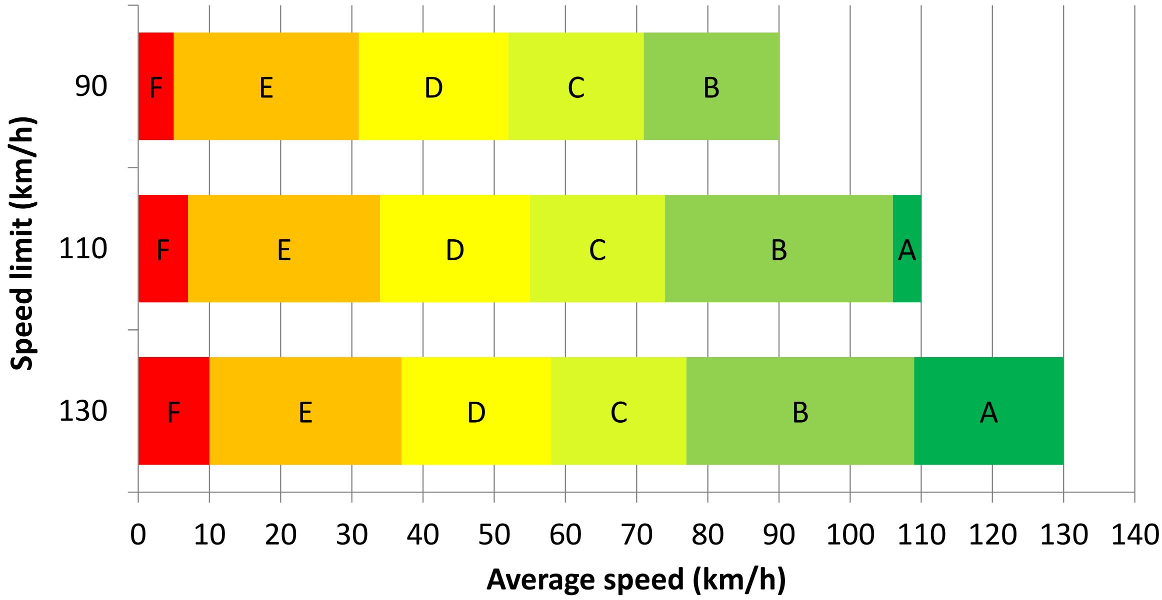
The LOS criteria are based on the split of the response levels of satisfaction. To remain consistent with the Highway Capacity Manual (*1*), six CLOS designations (A through F) were defined as follows. A "democratic" definition is used, meaning that if 50 percent or more are very satisfied then LOS is 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 CLOS, average speed and speed limit. The figure shows as a rule of thumb that the experienced level of service on freeways deteriorates by one level when the average speed is reduced by 20-30 km/h. Freeways with a speed limit of 90 km/h may not get a LOS A unless the average speed is above 102 km/h.

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

Vehicles longer than 12.5 meters have some influence on CLOS. Long vehicles are calculated as 2.5 passenger car units in traffic flow models. However, the impact on CLOS of one long vehicle is about the same as 6-7 passenger cars. This is why there is a Truck variable in the models in Figure 2 and 3. CLOS worsen about a third of a level when the share of vehicles that are trucks increase from 0 to 10 percent.

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



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

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

CONCLUSIONS

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

The car driver satisfaction models and the subsequent LOS designations provide traffic planners and others the capability to rate freeways with respect to road users satisfaction. Models can rate existing freeways in real-time and retrospective, and provide road users, navigation systems and road administrations with valuable information to choices before and during journeys and to optimize budgets for freeway improvements. Models may also be used in the process of designing new freeways or redesigning existing freeways.

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

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