User choices regarding vehicle-driving automation

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Abstract

The introduction of Advanced Driver Assistance Systems (ADAS) in motor vehicles is expected to improve traffic efficiency and safety significantly. These systems support the driver in controlling his vehicle applying advanced sensing, computing and controlling devices. Successful implementation of these systems in the near future will largely depend on the willingness of people to buy and use these systems. As to this willingness, not much is known yet. Therefore, in this paper the willingness of potential ADAS users is explored. Choices for several ADAS have been measured by using the stated choice approach. Both drivers and fleet-owners of cars, trucks and buses have been interrogated about their choices regarding several hypothetical ADAS alternatives. Alternative systems were presented based on their functional features, price levels, and impacts on travel time and fuel consumption. Logit modelling has been applied to estimate how ADAS characteristics affect overall choices. The results show that, drivers and fleet-operators are not that willing to have ADAS in their vehicle(s): on average, in 29% of the cases the respondents are willing to purchase an ADAS alternative. However, this finding needs to be qualified, as user choices fluctuate strongly with specific ADAS characteristics. In particular, ADAS which support the driver in proper distance keeping, lane keeping and lane changing by warnings, at relatively low prices and improve travel time and fuel consumption seems most promising. The probabilities of users for purchasing the ADAS currently available on the market are relatively low.
Keywords: ADAS, user acceptance, stated choices, public policy making.

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1 Introduction

About 43,000 people are killed and 3,500,000 injured every year due to road accidents in the European Union [1]. In addition, if no actions are taken, increased traffic congestion and related environmental stress due to vehicle use is expected in the coming decades [2]. Various electronic in-vehicle devices are currently being developed to improve vehicle-driving performance by automation of basic driving tasks. These systems are known as Advanced Driver Assistance Systems (ADAS). Some ADA systems are already available commercially. Well-known examples involve systems that support the driver in vehicle following , collision avoidance and lane keeping. These ADAS have high potential in terms of improving traffic performance. It has, for instance, been estimated that the large scale implementation of a speed headway controlling device could increase the road capacity up to 25% [3]. Fleets of trucks equipped with collision warning systems have shown rear-end and lane change accident reduction averaging 73% [4]. In general it is estimated that collision avoidance devices could prevent about 45 percent of road fatalities (e.g. [5]).

Given these expectations, public policy makers, among others, are increasingly interested in the implementation possibilities of ADAS. Successful implementation of these systems in the near future will largely depend on the drivers' willingness to buy and use these systems. The current knowledge regarding this willingness is quite limited. Hence, insight into the willingness of potential ADAS users is needed. Such insight is given by exploring the preferences of potential ADAS users regarding system characteristics. Knowledge on these preferences enables system providers to develop systems in such a way that users will adopt these systems.

Different studies have been performed on user preferences regarding ADAS. In general, within these studies, respondents have had to evaluate different attributes (e.g. longitudinal/lateral support, level of intervention, price, and usability) of the system(s) of interest separately. This measurement method is relatively easy to construct and fairly easy for respondents to complete. Moreover, the responses potentially have high reliability. However, the validity of this approach has shown serious limitations in terms of predicting overall preference behaviour [6]. This might be explained by the fact that usually more than one attribute plays a role in the individuals' decision making process and as such individuals make trade-offs between the different attributes of an alternative. These trade-offs are not taken into account by traditional measurement approaches. The trade-offs among attributes are explicitly considered by another measurement approach, the so-called decompositional stated preference approach, also known as conjoint analysis. By this approach individuals have to indicate their overall preferences for hypothetical profiles (as comparable to products), described in terms of a set of levels of pre-specified attributes. Individuals are hereby explicitly forced to make trade-offs among attributes. As profiles are constructed according to the principles of statistical designs, the overall preference can be decomposed into the weights these individuals attach to separate attribute-levels (i.e. the so-called part-worth

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utilities) in creating their overall evaluation of alternatives. As such it is possible to study the relationship between attribute-levels and overall preference behaviour in a more valid way as compared with a measurement approach where attributes are evaluated separately. Therefore, in this study, a conjoint analysis approach was chosen to explore the preferences and choices of potential users regarding ADAS alternatives. Six pre-specified groups involving both drivers and fleet-owners of cars, trucks and buses were questioned about their preferences and choices regarding several alternative ADAS. In previous publications we reported the findings related to the user preferences regarding ADAS [7, 8]. In this paper, we will focus on the user choices regarding ADAS. This paper is organised as follows. In section 2 the research method and survey design for this study is discussed. The response and characteristics of the different groups of interest are presented in section 3. In section 4 the overall estimated choice model is presented and discussed. The probabilities that users will purchase some selected ADAS alternatives are examined in section 5. Finally, conclusions are drawn in section 6.

2 Method

Inspired by the theory of choice behaviour, choice behaviour is assumed to be the result of an individual's cognitive decision-making process [9]. This behaviour is based on the subjective perception and evaluation of choice alternatives in terms of their physical, functional and socio-economic attributes. This then results in an individual preference structure for the various alternatives under consideration. By applying some sort of decision rule, an individual finally chooses an alternative. The following steps are usually followed when applying conjoint experiments [10]:

1. selection of salient attributes;
2. determination of relevant attribute-levels;
3. selection of a method for combining attribute-levels into profiles;
4. choice of a measurement task;
5. choice of a method for estimating preference functions.

For each step, different strategies are possible, which are related to different assumptions, criteria and specific needs of the researcher. A full discussion about the strategies possible and the criteria to choose one particular strategy is beyond the scope of this article. The reader is referred to literature on conjoint modelling [11]. An extensive discussion on the specific choices made within this study is presented in [7]. In this paper, the above-mentioned steps will only be dealt with briefly.

The *selection of salient attributes* underlying preference and choice behaviour of users has been based on the results of previous research. This resulted in an initial list of theoretical system characteristics. This list was next operationalised to clear and measurable attributes, discriminating sufficiently among alternative systems from a user's point of view. The following attributes resulted: distance

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keeping support, lane keeping support and lane changing support, price (purchase costs), impact on travel time, and impact on fuel consumption.
The next step is to *select the relevant attribute-levels* for the attributes selected. The relevant levels in this context refer to levels that are assumed to represent plausible, future alternatives. As for the attributes distance keeping, lane keeping and lane changing, plausible levels have rather straightforwardly been derived from the results of previous research [12]. An overview of the selected attributes and their levels is presented in Table 1.

Table 1: Selected attributes and their levels.

attributes	attribute-levels		
distance keeping	warning	throttle assistance	throttle/brake assistance
lane keeping	none	warning	steering assistance
lane changing	none	warning	steering assistance
price	EUR500	EUR1500	EUR2500
travel time	+10%	equal	-10%
fuel consumption	+5%	equal	-5%

The next step involves *the selection of an appropriate method for combining attribute-levels into profiles* that can be evaluated by the respondents. In order to create profiles, statistical design theory is used. If all possible combinations of attribute-levels would be considered, a so-called full-factorial design would result involving, $3^5 = 243$ profiles. It may be clear that this number of profiles is too high to be adequately evaluated by the respondents. The number of profiles can, however, be reduced by making assumptions on how decision-makers combine part-worth utilities into overall utilities. In this study, no interaction effects between the attributes were assumed, which resulted in a main-effect model. Hence, the overall utility is assumed equal to the sum of the separate part-worth utilities. This model is often used in practice as it minimises the number of profiles and it has proven to predict reasonably well [11]. Several so-called 'main-effect' designs are possible. An important property of main-effect designs is orthogonality, whereby the inter-attribute correlation is zero. Such property allows for a minimum number of profiles to estimate main effects only. The smallest orthogonal fraction by means of which all main effects can be estimated in our study, involved 18 profiles.

As the profiles have been constructed, *a measurement task has to be formulated* by which respondents are invited to indicate their choices regarding the various profiles. Respondents were invited to indicate, for each ADAS alternative, whether they would buy or buy not each ADAS alternative in case of purchasing a new vehicle. An example of a profile as presented in the questionnaire and related question is presented in Figure 1.

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ADAS profile

distance warning no lane keeping support no lane change support price = EUR500 10% more travel time 5% more fuel consumption

Would you buy this ADAS in case of purchasing a new vehicle?

O yes O no

Figure 1: An example of a profile as presented in the questionnaire.

Once the choices of respondents have been observed, an estimation procedure has to be applied to determine the part-worth utilities or parameters of the multiattribute preference model. Statistical estimation procedures are commonly used in this context. In case data is collected by a choice task, one usually uses maximum likelihood techniques to estimate the parameters of the assumed choice model. In our study it was assumed that an individual's overall utility for an alternative j is composed of a fixed component (V_j) and a random component (e_j), induced by for instance measurement error. As stated above, in this study, the fixed component (V_j) is assumed to be a linear function of separate attributes X_{ij}:

$$V_j := \Sigma_i \beta_i X_{ij},$$

where the β_i's are the parameters to be estimated. If utility-maximizing behaviour is assumed different choice models can be derived. The particular model depends on the assumptions made for the distribution of error. A common assumption in this context is that the errors are identically and independently double exponentially distributed. This leads, in this study, to the binomial logit model for the probability (p_j) that alternative j will be chosen:

$$P_j = \frac{exp\ (V_j)}{1 + exp\ (V_j)} \qquad (1)$$

3 Response rate and profile of respondents

During the end of 1998 and the beginning of 1999, 3350 questionnaires were distributed among drivers and fleet-operators of cars, buses, and trucks. Drivers were randomly approached at different gas stations along Dutch motorways during different days, as the systems questioned in the questionnaire were presented to be for motorway-use only. Truck and bus drivers were approached by mail, as most of these drivers take fuel at their company location. Fleet-operators were selected from the register of the Dutch Chamber of Commerce and from databases of branch organisations, and were approached by mail. A total of 485 questionnaires was returned within a 6-weeks' period, implying an average degree of response of 14.5%. This rate seems reasonable, given the high complexity of the questionnaire in combination with the fact that even 80% of

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the respondents indicated that they were hardly or even not familiar at all with these innovative systems.

The background characteristics of the respondents are presented in Table 2. Statistics at national level for the motorway user population are lacking. Consequently, the representativeness of the sample according to these characteristics could not be tested. For some characteristics, national statistics of the vehicle driving and fleet-operating population in general are available. If so, these figures have been used to make it likely that the respondent group belongs to the motorway user population. It is unlikely that the distribution of gender, age and education of bus- and truck drivers as well as car-, bus- and truck fleet-operators will differ among motorway user population and the general road user population. As for car drivers, this is more likely as a relatively high part of the motorway usage involves commuting and business motives. The average Dutch business driver is a man, about 40 years old, well educated and drives many kilometres on motorways (Korver [13]). Furthermore, the fact that almost half of the car-driving respondents indicated to be business drivers, likely influenced the bias of the profile of the car driving respondents towards the profile of a business driver.

Table 2: Background characteristics of respondents.

group characteristic		sample (n=485)	drivers (n=320)	fleet-operators (n=165)
gender:	male	90.2%	-	-
	female	9.8%	-	-
age:	mean	40.1	-	-
	(std)	(10)	-	-
education:	less than sec. school	38.2%	-	-
	sec. school	19.2%	-	-
	bachelor or higher	42.6%	-	-
ownership[a]:	private	-	54%	-
	business	-	46%	-
driven km. per week[b]:	mean	-	1223	1903
	(std)	-	1130	925
transport area[c]:	regional	-	-	35.8%
	national	-	-	61.8%
	international	-	-	64.2%
fleet size:	less than 10 vehicles	-	-	8.1%
	10 to 50 vehicles	-	-	18.9%
	more than 50 vehicles	-	-	73.0%
familiarity:	not familiar	23.8%	-	-
	moderately familiar	55.9%	-	-
	quite familiar	20.3%	-	-

[a] only asked to car drivers; [b] for drivers these figures apply to motorway driven kilometres only; [c] respondents could indicate more than one option.

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As fleet-operators probably could not indicate the amount of kilometres their fleet vehicles drove on motorways only, which the drivers were requested to estimate, we also asked them in addition to the average total amount of kilometres driven per vehicle, to indicate the geographical area(s) in which their vehicles mostly operate. Considering all fleets together, the vehicles were mostly used at national and international scale, indicating that most kilometres were driven on motorways. On average, both driver- and fleet-operator groups indicated substantially higher amounts of driven kilometres as compared to national statistics (CBS [14]). This indicates that the respondents are frequent users of motorways. The size of fleets varied considerably within each group of fleet-operators. In the Netherlands there are relatively few companies with large fleets as compared to the number of companies with small fleets (CBS [14]). Hence, a relatively low response rates among fleet-operators in this survey reported earlier, still imply coping with a substantial part of the total vehicle fleet. Finally, the respondents were asked to what degree they were familiar with the systems in the questionnaire. The large majority of the respondents indicated that they were hardly or not at all familiar with these systems.

Summarising, it seems plausible that the responding groups belong to the 'motorway user' population. Furthermore, it is clear that each group of interest in this study is represented by a reasonable number of respondents.

4 Overall preferences

The overall estimated preference model for all respondents is presented in Table 3. The estimated part-worth utilities, i.e. the utility that respondents derive from a certain attribute-level, are shown in the first column. These can be interpreted as deviations from the average profile rating (intercept). The second column shows the *t*-values, which are used to test whether the estimated part-worth utilities contribute significantly to the overall utility. As only n-1 indicator variables are estimated for n attribute-levels, only n-1 *t*-values are presented for each attribute. Except for the levels throttle assistance, no lane changing, a price of EUR1500 and an equal travel time, all attribute-levels significantly influence the overall profile utility at a 0.05 level. The third column indicates the relative importance of the attribute in relation to the overall utility. Importance is derived by calculating first the range of each attribute, which involves the absolute difference between the highest and lowest part-worth utility of the levels of an attribute. Then these ranges are summed across all attributes. Finally, the range of an attribute is divided by the sum of ranges and the result is expressed in percentages. An indicator for the performance of the model is given by the Rho-squares, which express the extent to which the estimated model fits the observed data. The model is estimated from aggregate profile choices, the Rho-square is 0.90, indicating a good fit. This is not surprising as all individual differences are already sorted out by aggregating the data before model estimation.

The intercept of the estimated model is –0.89, which implies that, on average, the respondents value the adoption of selected ADAS lower then no ADAS. In particular, filling in this average utility into the binomial logit model (1) shows

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that, on average, in 29% of the cases the respondents are willing to purchase an ADAS alternative. Now the derived part-worth utilities will be discussed in more detail, focussing on the contribution to the overall attractiveness of the systems of each attribute-level, and assuming that all other attribute-levels remain unchanged.

Table 3: Estimated model.

attribute	part-worth utility	t-value[1]	relative attribute importance (in %)
distance keeping			10.2% (5)
warning	0.21	4.195	
throttle assistance	-0.03	-.575	
throttle & brake assistance	-0.18		
lane keeping			8.4% (6)
none	-0.11	-2.263	
warning	0.21	5.440	
steering assistance	-0.10		
lane changing			16.7% (4)
none	-0.08	1.559	
warning	0.36	7.552	
steering assistance	-0.28		
price			25.6% (1)
EUR500	0.50	10.541	
EUR1500	-0.02	-.498	
EUR2500	-0.48		
travel time			20.4% (2)
+10%	-0.42	-7.989	
equal	0.06	1.255	
-10%	0.36		
fuel consumption			18.8% (3)
+5%	-0.42	-7.998	
equal	0.12	2.342	
-5%	0.30		
regression intercept	-0.89	-24.745	
McFadden's RhoSq	0.90		
n	485		

[1]*As only n-1 parameters are estimated for each of the n attribute-levels, only n-1 t-values are given.*

With respect to the attribute *distance keeping,* warning systems (.21) are clearly more preferred to actual assistance systems, either throttle assistance (-.03) or brake assistance (-.18). The estimated part-worth utilities indicate a nearly perfect linear relationship, considering that the part-worth of the middle level (throttle assistance) is not significant. The difference in part-worth utilities of the warning and throttle and brake assistance is two times the difference of the

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part-worth utilities between the warning and throttle assistance. This implies that users, with respect to distance keeping, are rather indifferent regarding throttle assistance but dislike more serious interventions by braking.

As for the attributes *lane keeping* and *lane changing* support, a warning device is preferred to no support or steering assistance. Hence, it may be concluded that people on average like the idea of systems that warn them in case of danger with respect to lane keeping and lane changing. However, they dislike the idea of systems actually taking over steering tasks.

The part-worth utilities of the attributes *price*, *travel time* and *fuel consumption* each show, as expected, decreasing tendencies: an increase in price, travel time or fuel consumption decreases the overall utility contribution. As for the attributes price and travel time, the estimated part-worth utilities indicate a nearly perfect linear relationship, considering that the part-worths of the middle levels (EUR1500 respectively equal travel time) is not significant. This is not the case for the attribute fuel consumption. Reducing fuel consumption from +5% to the current value (level 'equal) increases the overall utility three times as much than a further reduction of fuel consumption from the current value to a saving of 5%. This tendency indicates that systems that increase fuel consumption, are strongly disfavoured as compared to systems which do not have that effect. Furthermore, this implies that systems that reduce fuel consumption, are only slightly more preferred than systems that maintain fuel consumption at equal levels.

Comparing the attribute importance of the variables, it turns out that *price* is the most important attribute, followed by *travel time* and *fuel consumption.* Hence, these cost and performance related attributes are considered more important than the other, functional attributes. Of the functional attributes, *lane changing* is considered much more important than *distance keeping* respectively *lane keeping*. However, this measure of attribute importance has to be interpreted carefully, because this could be related to the range of attribute-levels chosen. If, for instance, a smaller range of attribute-levels had been chosen, say EUR1000, EUR1500 and EUR2000, the range of the part-worth utilities would likely become smaller too, with lower importance as a result. Consequently, conclusions based on attribute importance can only be drawn within the range of attribute-levels specified in this study.

5 Predicting ADAS choices

After the specification of the model, it is now possible to simulate choices for all possible combinations of ADAS attribute-levels. First, the overall utility for each profile of interest is calculated by filling in the related part-worth utilities into the estimated model. Note that for continuous attributes, part-worth utilities of intermediate attribute-levels can be derived by interpolation. This allows the simulation of utilities for all profiles, which can be constructed within the range of (continuous) attribute-levels. Finally, choice behaviour can be computed by filling in the estimated profile utility into the binomial logit model as presented by (*1*).

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Table 4: Choice probabilities for selected ADAS.

ADAS-low	ADAS-high
distance throttle & brake assistance	distance warning
no lane keeping support	lane keeping warning
lane change steering assistance	lane change warning
price = EUR2500	price = EUR 500
10% more travel time	10% less travel time
5% more fuel consumption	5% less fuel consumption
Purchase prob.: 0.06	*Purchase prob.: 0.74*

ACC	CWS	Autocruise
distance throttle assistance	distance warning	distance throttle & brake assistance
no lane keeping support	no lane keeping support	lane keeping steering assistance
no lane change support	lane change warning	no lane change support
price = EUR 2500	price = EUR 2500	price = EUR 2500
equal travel time	equal travel time	equal travel time
equal fuel consumption	equal fuel consumption	5% less fuel consumption
Purchase prob: 0.20	*Purchase prob.: 0.33*	*Purchase prob.: 0.20*

In Table 4 the probabilities whether some selected ADAS would be bought in case of purchasing a new vehicle are given. Each column represents a specific ADAS profile, together with its probability of purchasing in the last row. The first two columns represent the least respectively the most popular ADAS of all

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ADAS which can be constructed out of the predefined attribute-levels. These are obtained by adding, for each attribute, the minimal respectively the maximal part-worth utilities and fill these in into the binomial logit model. The last three columns represent ADAS alternatives that are currently coming into market: Adaptive Cruise Control (ACC), Collision Warning System (CWS) and Autocruise.

The least popular ADAS involves a device which cost EUR 2500 and supports the driver by controlling distance keeping and lane changing manoeuvres, gives no support on lane keeping and increases travel time and fuel consumption. The probability that this ADAS will be purchased is only 0.06. On the other hand, the buying probability is the highest (0.76) for an ADAS which warns the driver in case of following too close, improper lane keeping and a vehicle in the blind spot during lane changes, which is offered at a price of EUR 500 and reduces travel time and fuel consumption. These findings suggest that it has to be tried, if one is aiming at maximising the number of people which should buy ADAS, to implement systems that have a warning functionality, at low prices and that do reduce travel time and fuel consumption.

Looking at the ADAS alternatives currently available, the probabilities of purchasing such an alternative are still relatively low. The CWS has the highest probability of being purchased by users as compared to the ACC and the Autocruise. Note that today's costs of these alternatives might still be higher then EUR 2500 [15], and are strongly related with specific operating characteristics. As such the stated choices should be handle with care as the real world probabilities are likely to be lower then presented here, implying even less market opportunities. However, it is generally expected that prices will decrease within the next years due to economies of scale [7]. As such, the probabilities that people will purchase these alternatives will, according to this model, increase in the future.

6 Conclusion and discussion

In this paper, the stated choices of potential ADAS users were examined by applying conjoint analysis. Utility functions were estimated based on the respondents' choices for hypothetical profiles, each varying in functional, cost and performance related attributes. The estimated utility functions described the part-worth utility contribution of each attribute-level to the overall utilities of possible systems. Assuming utility-maximising behaviour, a binomial logit model has been estimated, expressing the probability that an ADAS alternative will be purchased by a user.

The estimated utilities indicate that the cost-benefit attributes are more important than the functional attributes. Price is the most important attribute, which indicates that price drops can have a considerable effect on choices for systems. The results regarding travel time and fuel consumption clearly indicate that one should make an effort to implement systems that do, at least, not increase travel time and fuel consumption. With respect to the functional attributes, the utility function indicates that lane changing support is preferred to

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distance keeping and lane keeping. This is interesting given the high level of attention within research and development on distance keeping and lane keeping systems. For all three functional attributes, the warning level is more preferred than the other levels. In particular for lane keeping and lane changing, warning support is preferred to both no support and steering assistance. Apparently there is some user need for support of lane keeping and lane changing.

The analysis further pointed out that the ADAS alternatives currently available have relative low probabilities of being purchased. Lower prices, less intervening devices (warning instead of control) and improved performance on travel time and fuel consumption could increase these probabilities. Hence, in order to achieve large scale implementation of ADAS these latter operating characteristics should be applied as much as possible. This can be done in different ways. Apart from future ADAS cost developments, policymakers might speed up implementation by providing financial incentives to ADAS purchasers (e.g. government subsidies). Next, ADAS requirements might be specified by policymakers, which discourage the development of ADAS that increase fuel consumption and travel times. The stimulation of ADAS warning functionality instead of intervening functionality by policymakers is more difficult as these decisions primarily are taken by the automotive industry. Furthermore, from a transport policy point of view, intervening devices seem more effective in reducing negative externalities as compared to warning devices. As such, policymakers might educate potential users on this improved effectiveness by ADAS that do take over driving tasks. Results from the past show for instance that people are more positive about intervening devices as soon as they have experienced the enhanced functionality.

It is often assumed that users will not accept ADAS. In this study we found that, on average, on average, in 29% of the cases the respondents are willing to purchase an ADAS alternative. As such there appears to be more basis for implementing these systems on a larger scale than is often thought. Hence, this result may change the minds of many policymakers who are of the opinion that user acceptance of driver support services is totally lacking. Furthermore, this study shows how choices for purchasing ADAS alternatives change by varying the specific system operating characteristics. This provides policymakers with some guidelines to stimulate the implementation of systems that maximise these choice probabilities and discourage the implementation of systems that are unlikely to be chosen.

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