

Making automated driving support – Method for Driver-Vehicle task allocation

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Abstract

For partly automated driving, allocation of (sub)tasks between driver and vehicle is often considered from a technological or legal point-of-view. However, partial automation often leads to reduced operability after transitions to manually driving. Therefore, this paper presents a concise method for a more distinct task-allocation whilst accounting for various aspects influencing out-of-the-loop performance problems, among which: system complexity, avoidance of errors, ability to correct and comfort. To investigate how the method should account for these aspects, the impact of different levels of automation on task performance in general and recovery tasks in particular was considered. Next, we considered how required attention and effort influences avoidance of errors and satisfaction. After presenting the method, exemplary assessment of task allocation for an automated-parking system, showed how the provided method helps to develop new systems for partly automated driving.

1 Introduction

The driving task is a complex task. It does not only demand visual-motoric skills, but is also cognitively demanding: It requires decision making within complex and various traffic situations. Therefore, car manufacturers put a lot of effort in solutions to assist the driver: making driving safer and more comfortable. Driver assistance also has the potential to reduce mobility problems, by increasing traffic flow (Van Arem, 2006). An advanced form of driver assistance is *automated driving*, which' technical feasibility is shown in projects like Stadtpilot (Heitmüller, 2010). Nevertheless, due to the diversity of driving tasks it seems unlikely that automation will be applicable for all traffic situations (Van den Beukel, 2010). As a consequence, systems for automated driving should account for *partial* automation; i.e. supporting both automated and manually driving. However, partial automation causes new concerns, while placing the driver (operator) remote from the control loop reduces the operator's awareness of the situation or system's status. Especially when system errors, malfunction or

breakdowns occur, this results in slower reaction times (Wickens, 1992) and misunderstanding what corrective actions need to be taken (Kaber & Endsley, 1997). When accidents occur, this in turn also causes reliability issues.

In view of the potential benefits of automated driving and the identified concerns, this paper advocates deployment of a method for a more distinct allocation of (sub)tasks to either man or machine. Knowing that the feasibility and acceptance of a partly automated system relate to various aspects (among which: complexity, avoidance of errors, ability to correct, comfort and trust), this paper investigates how a method for task allocation could account for these aspects. First, knowledge will be retrieved how operability and task performance is –in general– influenced by dividing (sub)tasks between man or machine. Next, desired steps that should be considered for allocation will be explained. An example of task allocation for semi-automated parallel parking will be given, before the paper concludes to what extend the provided method for task allocation helps developing systems for semi-automated driving, whilst avoiding before mentioned problems.

2 Influence of degrees of automation on performance

Different definitions with degrees of automation exist. Many definitions refer to technical feasibility, some refer to legal implications (see example in table 1), but most definitions do not refer to what humans are in need for (Hollnagel, 2006).

“High Automation: The system takes over longitudinal *and* lateral control; the driver must no longer *permanently monitor* the system. In case of a take-over request, the driver must *take-over* control within a *certain time buffer*.”

Table 1: Exemplary definition of a degree of automation called ‘high automation’, referring to obligatory consequences for transitions of control. Example adapted from German federal institute for road research (Bast).

For our desired method of tasks allocation we prefer to use a definition from Endsley and Kaber (1999), called Levels of Automation (LOA). The reason is that the LOAs have been tested for task performance also after automation terminated. Hence, the results provide insight in how different degrees of automation relate to the ability to recover and will therefore be an important contribution to the avoidance of out-of-the-loop (OOTL) performance problems. The defined LOAs and results from the test will now be explained.

2.1 Levels of Automation

Endsley and Kaber refer with their defined Levels of Automation (LOA) to the complete control-loop to perform tasks: The levels contain human and/or computer allocation of the following (sub)tasks: (a) *Monitoring*: Perceiving information regarding system status and/or the ability to perform tasks, (b) *Generating*: Formulating options or strategies to achieve tasks, (c) *Selecting*: Deciding on a particular option or strategy, and (d) *Implementing*: Carrying out the chosen option. From 10 theoretically possible LOAs (Endsley & Kaber, 1999),

we acknowledge 5 levels relevant for automated driving, which are indicated and explained in table 2. Because it is difficult for either the human or machine to perform any task without directly monitoring either the state of the system or inputs from the other, functions are sometimes allocated to both human and computer.

Levels of Automation:	Mon. ¹	Gen. ²	Sel. ³	Imp. ⁴	Examples:
<i>Advising^a</i>	<i>H/C</i>	<i>H/C</i>	<i>H</i>	<i>H/C</i>	<i>Lane change assist</i>
<i>Intervention^b</i>	<i>H/C</i>	<i>H/C</i>	<i>C</i>	<i>C</i>	<i>Cruise control</i>
<i>Action Support</i>	<i>H/C</i>	<i>H</i>	<i>H</i>	<i>H/C</i>	<i>Automated gear box</i>
<i>Supervisory Control</i>	<i>H/C</i>	<i>C</i>	<i>C</i>	<i>C</i>	<i>Highly automated driving</i>
<i>Full Automation</i>	<i>C</i>	<i>C</i>	<i>C</i>	<i>C</i>	

Table 2: Levels of automation and their allocation to tasks within a control-loop. Adapted from Endsley & Kaber (1999). Meaning of abbreviation: ¹) Monitoring; ²) Generating; ³) Selecting; ⁴) Implementation of options. Remarks: ^a)Originally called: Shared Control. ^b)Originally called: Automated Decision Making.

As mentioned, Endsley and Kaber tested LOAs for task performance, also after automation terminated. Their test consisted of a visual-motoric computer based task, requiring information retrieval, information processing, decision making and acting. Test subjects saw on a computer screen objects travelling (with different sizes and different speeds) from an outer circle to the centre. The objective was to eliminate as much as possible objects by clicking ‘on’ them, using a mouse pointer. Performance was measured by counting scores for eliminating the objects. These scores depended on size and speed of the objects, evoking different strategies for a participant to optimize performance. Automation levels varied between e.g. advising on a strategy, imposing a strategy or automatically executing a (humanly defined) strategy. The avoidance of out-of-the-loop (OOTL) performance problems was assessed by deliberately (but unannounced) stopping the automation. Then performance was measured after automation failure and compared between different LOAs.

2.2 Effects of LOA on human/system performance

The results of testing LOAs (Endsley & Kaber, 1999) showed the following effects on human and/or system performance: Overall operator/system performance proved to be best for LOAs involving partial automation of the implementation aspect of a task, as is the case with *Action Support*. With regard to option-generation, purely human generation of options (*Action Support*) and purely computer generation of options (*Supervisory Control* and *Full Automation*), performed far better than joint human-computer generation of options (like with *Advising* and *Intervention*). This low performance can be explained by distraction and doubts that humans encounter during joint human-computer selection of options and is in agreement with previous research (Selcon, 1990). The results advocate that option-generation should be performed by either the human or the machine. With respect to performance after automation failure, recovery was lowest (i.e. ‘fastest’) for *Action Support*. This result indicates that the ability to recover from automation failures improves with partly automation requiring some operator interaction in the implementation role.

2.3 Influence of human attention and effort on performance

Knowledge how task performance relates to required human attention and effort, is also important for the allocation of tasks. Rasmussen (1982) provides a generally accepted hierarchy of levels for human task performance and distinguishes: skill-based, rule-based and knowledge-based performance. Now, we will consider how human performance on each of these levels influences overall performance and the avoidance of errors.

Skill-based performance involves tasks that are highly trained and occur as an almost ‘automatically’ reaction on sensory input. Skill-based performance has therefore the advantage of fast responses and requires very little attention. However, the presentation of information that triggers automatic responses can be so strong, that other information could be ignored. Mistakes typically occur during exceptional situations when drivers fail to identify changed information, causing the execution of a false routine (Martens, 2007). *Rule-based* performance involves tasks that are characterized by a strong top-down control: A situation triggers choice of a particular schemata and then actions are applied according to this scheme. Therefore, misinterpretation-errors, causing operators to apply the wrong rule, are the main risk for deteriorated performance at this level. Problems may as well occur if people lack knowledge about the rule that should be applied. *Knowledge-based* performance involves tasks that require a high level of cognitive attention to interpret new information and to acquire solutions. Errors on this level are mainly caused by inaccurate knowledge, inadequate analysis-skills or task overload as knowledge-based tasks are demanding. Furthermore, the task is impaired by adding another (sub)task (Patten et.al., 2004).

3 Allocation of tasks between driver and vehicle

The previous chapter explained how division of automation over (sub)tasks and required human effort, generally influence the aspects: (a) overall task performance, (b) the ability to correct and (c) the avoidance of errors. Although feasibility and acceptance of a partly automated system relate to more aspects, these aspects are among the most important, as they all three counter-influence both feasibility and acceptance. After an introductory remark, the next section will therefore present a concise plan with 6 steps to allocate tasks whilst considering all aspects mentioned in the Introduction.

Before applying the steps below, it first should be investigated what subtasks are involved in the overall task that is under consideration for (partial) automation. The reason is that for some steps it is necessary to know how the subtasks are divided over the control-loop (i.e. concerning either sensing of information, processing information or acting) and with what performance level the subtasks are generally executed. Now we will explain the steps:

1. Obligatory allocation

The first step considers allocation based on an obligatory selection between human or computer task performance, i.e. due to legislation and/or liability. An example is select-

ing human performance for operating the steering wheel within a system for lane change assist, allowing the human to take full responsibility for this task.

2. Consider feasibility

Within the second step, it should be considered whether computer or machine-based allocation is both technically possible and efficient. Technology develops continuously and the technical possibility for automated driving is shown in practise. However, it should also be considered whether computer-based performance of a (sub)task is efficient in terms of required energy, costs, reaction times and avoidance of negative side-effects.

3. Consider safety potential (avoidance of errors)

It is important for task allocation to be aware of a system's safety potential. Although precise assessment of safety potential is complex and time-consuming, the previous chapter allows us to generally recommend for the avoidance of errors to elude joint human-computer generation of options. Furthermore, one should consider the potential benefits that task allocation has for remaining (sub)tasks. Referring to section 2.3, automating skill- or rule-based tasks is beneficial because of either achieving higher accuracy, or freeing up cognitive resources (which helps avoiding errors for knowledge-based tasks). Knowledge-based tasks could be automated when the involved sensory input and algorithms are precisely known. Then, automation could be advantageous because of higher accuracy, better reaction-times and avoiding fatigue. Nevertheless, humans are generally better in improvisation in unfamiliar environments (Martens, 2007).

4. Consider recovery (ability to correct)

Although the ability to correct is depended on system's complexity and relates to the interface which allows operators to recover, based on section 2.2, the general consideration is to enable the human to remain involved in the implementation part of a task to avoid decrease in operator performance after take-over.

5. Consider acceptance

This step considers emotional aspects due to task allocation. For a new system to be successful, it is important that users accept it. Acceptance is influenced by feelings of security and trust. Other important aspects are: satisfaction and the question whether a reasonable workload remains. For the latter, it is important that cognitive workload is not too much, but certainly also not too little and it should be considered that humans often retrieve satisfaction from mastering a demanding task (Wickens, 1992).

6. Reconsider allocation

Allocating tasks between human or computer performance is basically a matter of system design. Design considers the development of solutions within a 'design-space' that contains a multitude of aspects which might be conflicting and need all to be accounted for. Therefore it is important to apply task allocation within a series of iterative steps. A chosen allocation might upon closer consideration be less advantageous, e.g. because of low satisfaction. Moreover, the implementation of automation does often not only cause re-

placement of (sub)tasks, but also the introduction of new (sub)tasks. An example is shown with adaptive cruise control: it replaces longitudinal control, however it also introduces new tasks for setting desired travel distance and monitoring the system's status. Whilst reconsidering the previous steps it should also be assessed to what respect the new tasks are acceptable, appropriate and feasible.

Although the steps are numbered, it is not necessary to strictly remain to the same order. However, it is reasonable to start with obligatory allocation and to end with an iterative loop.

4 Example of task allocation: Semi-automated parking

To exemplify the proposed method, task allocation for a system to (partly) automate reverse parking is being assessed. The evaluated system functions as follows, see figure 1. After activation, the system scans for available parking places. An interface indicates when a parking place has sufficient size. As soon as the driver selects reverse driving, the vehicle steers automatically and obtains the correct path. During this reverse parking manoeuvre the driver operates backing up-speed (longitudinal control) himself, using gas and brake pedals.

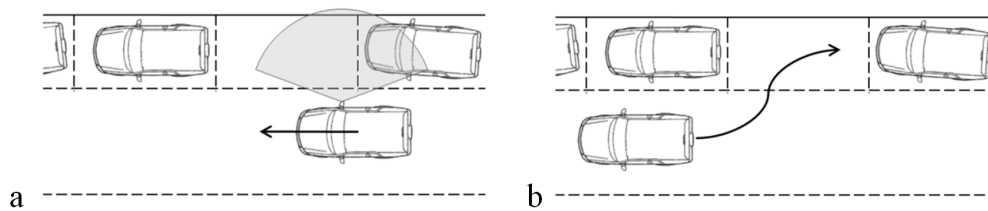


Figure 1: Schematically overview of parallel parking; a) scanning; b) choosing trajectory

Before we start, we will first analyse the involved subtasks for reverse parking. Obviously, an appropriate parking spot has to be selected. This selection-task is executed at rather knowledge-based level, requiring considerable attention. Next, the appropriate trajectory needs to be defined to manoeuvre the vehicle along. This subtask is typically knowledge-based and requires analysis-skills. Then, the operation needs to be appropriately timed to avoid hindrance of other road users and speed needs to be regulated to move the vehicle along the trajectory. Finally, the appropriate trajectory needs to be evaluated and possibly be refined. Which is a delicate task.

Now, we will go through the steps as defined in the previous chapter. With respect to *obligatory allocation* (step 1), current legislation requires that the driver is responsible for safe driving. With respect to manoeuvring (like reverse parking), the rule applies not to hinder other traffic. It is therefore advantageous that human performance is being selected for the longitudinal control. In this way the driver has the opportunity to take responsibility and remains within the control-loop. Concerning *feasibility* (step 2), object recognition and calculating the optimal trajectory are subtasks that are very well realized from a technical point of

view. On the other hand, interpreting objects and predicting how a situation will proceed in the near future (e.g. judging whether precedence of a pedestrian needs to be accounted for or not) are tasks rather difficult or inefficient to automate. Concerning the *avoidance of errors* (step 3) we see that the system changes the attention requiring knowledge-based task of recognising an appropriate parking spot into a skill-based task of requesting information. This is advantageous, because skill- and rule-based tasks do not ask much human effort. Furthermore, the ‘knowledge’ part, which involves estimating and continuous assessment of the ideal trajectory, is taken over by the system. As automation of the trajectory also reduces the amount of parallel subtask the driver is involved in, the chosen allocation frees up cognitive demand for attention to the surveillance tasks and timing the operation. Altogether, this helps avoiding errors. With regard to *recovery* (step 4), the choice for computer-based lateral control and human’s longitudinal control is advantageous. Because, therewith the human remains involved in the execution part, as being recommended. Furthermore, it allows the human operator to take full control after take-over. With respect to *acceptance* (step 5) it should be noted that reverse parking is for many a difficult task (observations show that it often requires several attempts) and the system relieves users from the most demanding subtasks. Nevertheless, personal opinion and trust might be very diverse. Furthermore, comfort might be deteriorated by the introduction of new tasks, as considered in the last step: Of course, ease of performing (new) tasks is largely a matter of design. Nonetheless, the scope and scale of the surveillance task might cause confusion. Problems have been reported by users who expected the vehicle to also take over longitudinal control or were somewhat confused about their roles.

Going through the steps shows that the method is successful in explaining and interpreting how this system is successful in relieving the original task. It shows how accounting for particular benefits of allocating to either driver or vehicle results in a system with potentially improved overall performance, whilst allowing the driver to remain fully responsible.

5 Concluding remarks

This research resulted in the development of a method for distinct allocation of (sub)tasks to either driver or vehicle in order to support the development of systems for partly automated driving. To avoid out-of-the-loop performance problems, the method successfully accounts for the impact of aspects as system complexity, avoidance of errors, ability to correct and comfort.

In the development five types of task allocation between driver and vehicle relevant for partly automated driving have been distinguished. Based on existing research we recommend to allocate the implementation part of a task to the driver, because this improves the ability to recover. Moreover, allocation of joint human and machine performance for the decision-making part of a task needs to be avoided as it causes confusion and deteriorated overall performance. Considering human effort and attention, allocation of driving tasks to the vehicle is mainly recommendable in order to reduce the amount of (sub)tasks a human operator is simultaneously involved in, freeing up cognitive resources for more demanding, knowledge-

based tasks. The developed method particularly addresses the avoidance of errors and the ability to correct. Accounting for these aspects helps avoiding out-of-the-loop performance problems, which causes the greatest concerns when applying partly automated driving. However, future research is recommended to gain more specific insight in how acceptance and trust should additionally be taken into consideration.

The research presented in this paper resulted in a concise six-step method that showed to be successful in assessing and interpreting the quality of a chosen task allocation for an existing automated-parking system. However, the scope of the presented method goes beyond assessment of existing systems. The method is intended to facilitate the design of new systems for partly automated driving. Future application of the method in the development of such systems will allow for further improvement and adaptation of the method.

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