Authority and Level of Automation

Lessons to Be Learned in Design of In-vehicle Assistance Systems

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Abstract. Motor vehicles and drivers' relationship with them will change significantly in the next decades. Still, most driving tasks are likely to involve humans behind the wheel, emphasizing the design of in-vehicle assistance systems. A framework for distribution of control between human beings and technology is presented, as well as a model to be used in analysis, design, development, and deployment of decision support systems. The framework and the model are applied in a project aiming for design of in-vehicle systems for future long-haul vehicles. The empirical investigations conducted support the design-as-hypotheses approach. The search for improvements of design concepts and levels of automation leads to a shift away from abstract ideas of autonomous cars to empirical issues such as how to support the driver. The need to discuss authority in relation to levels of automation is recognized, emphasizing the fact that human-machine interaction takes place on two distinct levels.

Keywords: Automation, Autonomy, Authority, Decision-making.

1 Introduction

The US National Highway Traffic Safety Administration anticipates that motor vehicles and drivers' relationship with them are likely to change dramatically in a near future [1]. Advances in automotive technology and vehicle innovations, such as self-driving cars, have the potential to improve highway safety and efficiency, mobility, and economic growth. Still, most driving tasks are likely to involve humans behind the wheel, emphasizing the design of in-vehicle assistance systems and the issue of cooperation between the human agent and the automation. In managing this threshold of significant changes in capabilities and expectations, we propose that there are lessons to be learned from application domains where automation has been around for a while, such as in aviation [2], high-speed ferries [3], and train traffic control [4].

As the first contribution of this paper we present a framework for distribution of control between humans and technology, called the Human-Machine Discrimination

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(HMD) framework. A fundamental premise is emphasized: human beings and machines are categorically different [5]. This has two important implications for design of automated systems. First, technology cannot be introduced as a simple substitution of machines for people [6]. On the contrary, designers need to: (1) recognize that *design concepts represent hypotheses* or beliefs about the relationship between technology and cognition/collaboration; (2) subject these beliefs to empirical jeopardy by a *search for disconfirming and confirming evidence*; and (3) recognize that these beliefs about what would be useful are *tentative and open to revision* as we learn more about the mutual shaping that goes on between artefacts and actors in a field of practice [7, italics added]. Second, in order to fully capture and understand issues of authority, human-computer interaction research must recognize that communication between humans and machines does in fact manifest itself on two different levels.

Assuming design concepts as hypotheses, one important step is to present an approach to how this translates into practical research. Therefore, as the second contribution of this paper, we suggest the GMOC model (acronym for Goal, Model, Observability, and Controllability) that supports the division of roles between humans and machines by allocating properties between humans and automation as, for example, decision support systems. GMOC is based on Dynamic Decision Making, (DDM; e.g. [8]) an approach to human decision-making based on the premise that the very object of decision making can be regarded as that of control. With GMOC as a model for design, development, and deployment of systems, we operationalize the idea of design concepts as hypotheses by the general problem formulation:

> How can drivers' mental model development and goal formulation processes be supported by enhanced observability and augmented control functions?

We end the paper with a description of how the HMD-framework and the GMOC-model are applied in an ongoing project. MODAS (Methods for Designing Autonomous Systems; [9]) is a project that is concerned with the design of the driver environment for future long-haul vehicles. It incorporates a range of automated driving technologies assumed to be part of the driver environment in the future, including new and different forms of information displays, higher levels of automation, and forms of communication that are qualitatively different from what current systems offer. We describe how the scope of the project has changed so far as a consequence of the understanding and incorporation of the GMOC-model.

2 Autonomy/Heteronomy Distinction

As many other projects with connection to high-level automation systems, MODAS is one example of how the term *autonomous* is used to describe sub-systems with the ability to act independently. But this is not the only definition of autonomy. The concept of autonomy can mean very different things and have been found to be used in three very different ways in the literature today: (1) as a negative byproduct of automation; (2) as a desirable attribute in high-tech industry; and (3) as a differentiation in human thought and action. These different interpretations are a cause for confusion because, when a concept has multiple definitions, expectations can be maladaptive.

2.1 Autonomy as a Problematic Attribute

In the literature on automation, autonomy is described as something very problematic. The clearest example of this is Billings who brought up autonomy as one of the automation attributes that have been found in aviation mishaps [2]. According to Billings, the four most central attributes in flight accidents are: (1) complexity; (2) coupling; (3) autonomy; and (4) inadequate feedback. Autonomy was at least one of the common factors that caused the mishaps in the following accidents: A320 accident at Mulhouse-Habsheim; A300 accident at Nagoya; A320 accident at Bangalore; A310 approach at Orly; and, B737 wind shear at Charlotte. Billings continues with a definition of autonomy in [2]:

> Autonomy is a characteristic of advanced automation; the term describes real or apparent self-initiated machine behavior. When autonomous behavior is unexpected by a human monitor, it is often perceived as animate; the automation appears to have a mind of its own. The human must decide, sometimes rather quickly, whether the observed behavior is appropriate or inappropriate. This decision can be difficult, in part because of the coupling just mentioned and in part because the automation may not provide adequate feedback about its activities.

This definition is not exclusive to the work of Billings. Sarter and Woods reasoned along the same lines in [10]. Sandblad et al. and Golightly et al. use the term autonomy similar to Billings [4], [11]. They speak of autonomous algorithms in train traffic control as something very problematic. They describe how different forms of automation surprise the operators in the train traffic control centers and that the immediate effect is that the automation has to be turned off. Sandblad et al. strongly recommend not using autonomous automation [4]; they even use the term non-autonomous automation to describe their approach [11]. Another example is Balfe et al., who have labeled the "turn-it-off-syndrome", that is, the fact that automation has to be turned-off when it does not meet the requirements from the train dispatchers in specific situations [12]. They too take a clear stance when it comes to autonomous systems: they do not use the term at all, presumably because they are aware of the fact that the concept has transformed.

2.2 Autonomy as a Desirable Attribute

In the high-tech industry, the term autonomy is used for high-tech systems, particularly in the military industry. Stensson and Jansson, in their review of the literature [5], found that this view is ubiquitous, manifested by numerous organizations, research projects, and phrasings that contain the word autonomous in conjunction with technology and systems. In fact, "autonomous systems" is currently being used for systems, artefacts, and vehicles for which a high level of self-operation obviously is desirable [5]. This approach can be illustrated by a video recorded talk by Mark Campbell [13]. As can be realized from this talk, there is a chain of activities, starting with sensors followed by perception and finally planning, conveying in each step data, information, and decisions. Sensors receive input from the environment, a remote system or human operator, either in the form of signals, signs, or symbols, and deliver this as data to the perception phase. During perception, different forms of recognition and feature detection activities transform the data into pieces of information, which means that the stream of data is no longer a meaningless stream of bits, but pieces of information which means they carry with them templates or structures of meaning. These carry with them a certain amount of interpreted information structures which can be used for planning because they can be brought together in sequences which allow the system to look ahead and plan for the next sequence. The plans result in decisions suggested for implementation.

2.3 Autonomy as a Way of Thinking and Acting

Stensson and Jansson explained why concepts like autonomy and intelligence are used for artefacts even though there is no scientific basis for doing so [5]. They suggested that one way to correct this matter is to remind people of Kant's distinction between autonomy and heteronomy in human reasoning, and reintroduce it to for use in the human factors community. They suggested that this helps to signify the relevance of the division of roles between human beings and artefacts.

Kant referred to autonomy as the ability of human beings to reason as free agents without the influence of authority or inclination [14]. This statement is based on the Categorical Imperative, the basic central philosophical concept of Kant's deontological moral philosophy. Kant himself called this "the principle of autonomy of the will, in contrast with every other which I accordingly reckon as heteronomy" [14]. This view of autonomy is that of someone who is supposedly autonomous. It is about the rights and obligations that come from being an autonomous entity. Heteronomy, on the other hand, infers that thinking is constrained by previous knowledge and authorities, rules, and procedures, or biases and heuristics [15].

2.4 The Human-Machine Discrimination Framework

In a way, systems functioning all the way from sensors receiving signals to planning with decisions ready to implement can be described as something semi-autonomous. But the concept of autonomy is not just a higher order of automation. It is a qualitatively different concept. The following quote from Wood et al. in [16] illustrates very well the conceptual change currently going on:

> This Article generally uses the term "autonomous," instead of the term "automated." We have chosen to use the term "autonomous" because it is the term that is currently in more widespread use (and thus is more familiar to the general public). However, the latter term is arguably more accurate. "Automated" connotes control or operation by a machine, while "autonomous" connotes acting alone or independently. Most of the vehicle concepts (that we are currently aware of) have a person in the driver's seat, utilize a communication connection to the cloud or other vehicles, and do not independently select either destinations or routes for reaching them. Thus, the term "automated" would more accurately describe these vehicle concepts.

We agree with the final sentence in the quote above, but see no reason to accept the term autonomous for artefacts. It is an example of "lack of scientifically-based philosophy of automation" as the Air Transport Association of America wrote in their report [17]. Billings' work is the result of that call [2]. The reason for this is the following: All kinds of automation and all kinds of automatic devices can be described from a bottom-up perspective. They are built in pieces and can be broken down into the same pieces. This makes it possible to speak about different levels of automation and different levels of automaticity. Autonomy, on the other hand, is a top-down concept. It is a holistic concept, which in principle is impossible to reduce into pieces, as more or less autonomous, or a high or low level of autonomy. You are either an autonomous individual or not [5]. Kavathatzopoulos described, analogously with intelligence and the Turing-test, that if we would like to know if something is purely autonomous or not, we would expect it to be able to choose for itself whether to be autonomous or heteronomous, because this is an act we can expect from an autonomous system [18]. In a distant future, would we like a truly autonomous car to pick up our neighbor instead of ourselves?

One consequence of the fundamental premise that human beings and machines are categorically different is the fact that the interaction between these two cognitive systems manifests itself on two different levels. This fact is not explicitly recognized in human-computer interaction research to the degree we believe it deserves. Mishaps in terms of automation surprises should be evaluated differently from errors caused by non-intuitive design solutions. Figure 1 below illustrates the fundamental premise and the two levels of interaction.

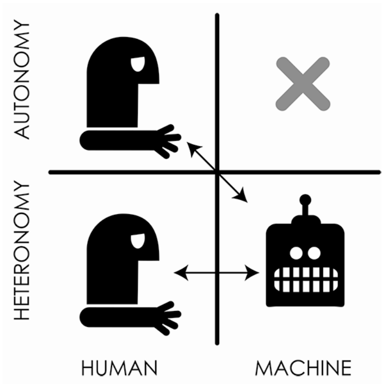

Fig. 1. Illustration of human autonomous and heteronomous decision making in contrast to heteronomous decision making of a machine. Human-machine interaction occurs on two levels.

3 GMOC: Human Decision Making in Dynamic Systems

Evaluation of the quality of human judgments requires an assessment of the predictability of the environment in which the judgment is made, and of the individual's opportunity to learn the regularities of that environment [19]. If end-users and operators can develop their mental models and formulate better goals as a consequence of augmented observability and enhanced control functions, this leads to higher predictability, thus making it easier for the human agent in such a system to predict what will happen in the close surrounding and in a near future. When humans interact with in-vehicle systems, they normally do so in order to achieve some goal. Goals can be found on different levels. They can be of a general kind, such as driving safely, deliver quality, or producing certain quantities. But goals can also be more specific, for example, a train driver brakes in order to keep the speed limit, a high-speed ferry operator navigates in order to reduce overall energy consumption while maintaining safety, and a train-dispatcher schedules incoming trains in order to avoid traffic jams. One way to understand such purposive actions is to interpret them as a way to achieve control, that is, the operator wants to reach or keep the system in some desired state. Humans interacting with complex systems need decision support systems that allow them to achieve full control in an efficient way.

Brehmer [8], [20] proposed DDM as a way to understand the activities carried out by a human operator. GMOC can be seen as the applied version of this approach. In order to achieve control, there are four prerequisites that need to be met. These are Goals, Models, Observability, and Controllability. Goals and models are properties of a human operator. Observability and controllability, on the other hand, are properties of the technical environment and are thus features of a system. The GMOC-model has been proven useful in a number of application domains (e.g. [3-4], [21-22]). Here, GMOC is proposed as a model for description, analysis, design, and evaluation of control and support systems. It gives the system designer a structure to identify connections between the four prerequisites, to analyze to what extent they are fulfilled, and how they can be further developed. It guides the system designers so that they do neither miss specific parts nor lose track of the whole picture. It provides the model needed in order to systematically analyze changes and limitations in any of the four main prerequisites. Analysis with GMOC reveals aspects that influence the efficiency of task fulfillment. Specifically, GMOC is useful when it comes to discriminating between observable and non-observable actions, as well as between behaviors related to goal-achievement and system-dependent behaviors. Non-observable actions refer to the judgments and decisions made by the user, often implicitly and with tacit knowledge. These behaviors are the hallmark of expertise and it is sometimes critical to identify them in order to fully understand the purposive actions of the users. System-dependent behaviors, on the other hand, refer to the measures taken or the actions implemented in order to get a particular technical system to carry out or execute the commands that is necessary to reach the goals. These insights, we claim, lead to design of systems that support good user performance and user experience, improve efficiency and safety as well as the overall system performance.

Let us look at an example of how GMOC translates into the work of a long-haul truck driver. The overall goal (G) for a truck driver is to transport cargo from the trailer depot and deliver it to a certain address at a specified time. This goal includes subgoals like doing so in a safe, effective, and efficient way, while also sustaining a good reputation and following regulations. Even more specific goals can be to plan ahead and in this way approach different upcoming traffic situations with appropriate speed and avoid complicated maneuvers. In order to achieve these goals, the driver needs a good understanding of the truck and its surroundings as manifested through sufficiently developed mental models (M). The driver needs to observe (O) many different states of the environment, for example, behavior of other vehicles, the truck speed and different truck states, road conditions, traffic signs, and of course, all the in-vehicle systems conveying information relevant for different situations. To be able to achieve the desired goals, the driver also controls (C) the truck, for example, in lateral and longitudinal direction (either manually or through changing settings of automated control) and by manipulating the navigator. During evaluation it is important to understand that the GMOC prerequisites are interconnected, it is not enough to consider them separately.

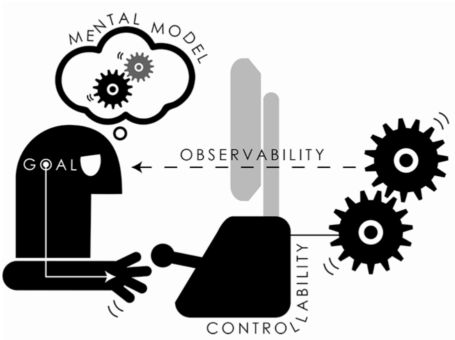

Fig. 2. The GMOC-model for design, development, and deployment systems

4 The Case Study – MODAS

MODAS [9] started out as an innovation and research project involving one of the major Swedish manufacturers of trucks for long haul driving and representatives from different Swedish universities. It started early 2013 and is expected to be completed by the end of 2014. In a way, MODAS is a project encompassing both current and future technology. It is based on current technology when it comes to all the data that are acquired in the different empirical parts. When it comes to test scenarios, it is based on models of future traffic states including models of what the future will look like in terms of complex driving environments, as well as hypotheses about what technical solutions there will be in terms of functions available in the in-vehicle driver system. Future traffic scenarios are envisaged to include a traffic environment that is high to very high in density (around 1250-1750 vehicles per hour), and with minimal vehicle separation (to sub-second separation). Further, a connected environment including vehicle-to-vehicle communication and vehicle-to-infrastructure communication is assumed.

In the first version of the project scope document – which was produced just ahead of the project start – it was stated that: From a driver perspective, the ability to operate a fully manual vehicle in the kinds of conditions described above will be difficult or impossible (or legislated against). Autonomous in-vehicle systems provide an opportunity for the driver to survive in the highly complex traffic environment of the future [23]. Thus, initially there was an expectancy that autonomous in-vehicle systems or semi-autonomous sub-systems could provide the solution to the problem of an all too complex environment for a human driver to operate and control.

But the MODAS-project also has a clear focus on human factors and the insight that design concepts represent hypotheses about the relationship between new forms of automation and human cognition/collaboration. These hypotheses need to be tested empirically and they are tentative and open to revision as long as one learns from the mutual shaping that goes on between artefacts and human actors [6]. The MODAS project time frame is too short when it comes to evaluating the final steps of this mutual shaping, but it is an example of how the scope of a project can change, as soon as design concepts and levels of automation are subjected to empirical testing and utilization of human factors competence. Once the project started, the project group realized the need to dig into some of the assumptions above in more detail. Four issues soon became important to clarify:

1. How does the concept “autonomous” relate to topics like automation? Is an autonomous system different from a fully automated system or not?
2. What philosophy of automation should the project build upon? How do we make the best out of technology without losing human authority?
3. How can the GMOC-model be applied in the case of long-haul driving and how does it translate into a method for systems design?
4. What conceptual design solutions can be derived from the initial analyses and how should they be subjected to empirical testing?

4.1 Current Empirical Investigations

The data collection in the MODAS project started with four days of observation of truck drivers driving today’s trucks. The route included highway and country road driving with a variety of situations, weathers, and traffic densities. The truck drivers were well familiar with the route and had between one and thirty years of truck driving experience. To find out more about the truck driver domain, goals, strategies, and priorities during truck driving, two drivers were interviewed while watching video data collected during the observation study. During these interviews, drivers were asked to verbalize whatever came into their mind when watching both themselves and some of their colleagues driving. The method of collegial verbalization has been used before with good results [24-26]. During the interviews, the drivers were also asked for their preferences regarding level of automation. Four different types were shown to them, adapted from [27], together with a rather vivid description of what a future driver task may look like. This was close to the description above with a traffic environment that is very high in density, with minimal vehicle separation, and a lot of communication going on between vehicles and the infrastructure. The different types of automation ranged from information supporting and augmenting the perception of the environment, support for recognition and interpretation, decisions suggested for action, to actions implemented by the truck itself or its in-vehicle support systems.

From the observations and interviews, situations in which more and better information potentially could facilitate the development of the drivers’ mental models were identified. Design concepts were developed based on these situations. These can be seen as design hypotheses, supposed to support the driver’s information need and presenting it in a way that enhance the development of mental models sufficient for the driver to stay in control.

Two of the design concepts were included in user tests which focused on observability. The aim with the interviews was to gain information of whether the concepts support the driver’s understanding of the different situations and enhance the driver’s ability to regain control, for instance, in the event of automation failure. The hypotheses for design were updated using the achieved information.

4.2 The Continuation of MODAS

To further understand possible user goals, different strategies to perform the tasks will be identified. This is because different ways to perform a task can include different sub-goals (G) and therefore also different information requirements and ways to present that information (O). This might also result in different requirements of control (C). More information is also needed about how to develop highly automatic systems supporting (all) sufficient driver strategies, prevent use of less efficient strategies, and enhance the drivers' strategy development (M).

The hypotheses for design will be updated again with the information from the strategies analysis and after that, a second round of user tests will be conducted. To test if the displays developed for the future truck driver environment would develop the drivers' understanding, we need to investigate to what extent the driver can use the displays to achieve the goals and sub-goals, how well the interaction with the system works (O, C), and if this interaction support appropriate mental models.

The results coming out of the MODAS project so far show that once the empirical testing starts, that is, when the drivers are used as expert evaluators, the design concepts used to support the driver will change due to the results of the user testing. Moreover, issues of level and types of automation will also be scrutinized and subject to changes. This is not the same thing as conducting a user-oriented systems analysis, neither descriptive (how users perform the task today) nor normative (how they should complete the task). It is more of a formative approach (how the interaction could work), but in addition to this, the use of the GMOC-model helps out by making it possible to keep in mind the overall objective of human decision making in dynamic systems. By the end of the day, it is the driver that is responsible for the actions implemented during driving, regardless of all the functionality and automation that are there to help out. Level of automation is in the end an issue of authority. With the HMD-framework and the GMOC-model as a guide, the ultimate goal of the MODAS-project is to create a platform for future design, development, and deployment of future in-vehicle systems by creating a method on how to apply GMOC.

5 Discussion

Billings developed his human-centered automation approach starting with the premises that pilots bear the responsibility for safety of the flight, and flight controllers bear the responsibility for traffic separation and safe traffic flow. He then postulated the axioms that pilots must remain in command of their flight, and flight controllers must remain in command of air traffic. The corollaries following from this is: (1) the pilot and controller must be actively involved; (2) they must be adequately informed; (3) they must be able to monitor the automation assisting them; (4) the automated systems must therefore be predictable; (5) the automated systems must also monitor the human operators; and (6) every intelligent system element must know the intent of other intelligent system elements.

It is not difficult to see how these premises can be translated into the design of in-vehicle systems. Bearing in mind the HMD-framework and the division of roles between humans and artefacts, all six corollaries do also count for long-haul trucks as well as other types of self-driving cars. We suggest projects aiming for design, development and deployment of highly automated systems to consider these corollaries. In addition, we would like suggest another corollary: (7) the ability to execute authority requires actively involved operators.

As a way to transform these overall objectives into practical research, we also suggest to use the GMOC-model since it is generic enough to translate to other disciplines. Two advantages with GMOC are: (1) The four prerequisites and the division of properties between human beings and machines are the same regardless of whether the focus is on analysis, design, development or deployment; (2) GMOC helps, with its focus on goals and models, to keep in mind the two levels of communication that are one of the consequences of the HMD-framework.

6 Conclusions

The progress of the MODAS project shows that, once the empirical investigations started, the focus shifted from abstract design hypotheses to issues that focus on how to design to support the driver, and also that authority issues are relevant and need to be addressed carefully. Relocating some of the functions from the driver to automation shows that it is necessary to discuss issues of responsibility and accountability. Just substituting human operators with artefacts will not be enough. DDM is an approach well suited for understanding human decision making in dynamic systems, and it fits very well with the task to drive a long-haul truck. GMOC can be used to operationalize the design-as-a-hypothesis approach with the general problem formulation that changes in observability and controllability will affect the drivers' development of mental models and the formulation of goals. It can also be used to operationalize how the two levels of communication can be kept in mind since goal formulations are manifested on both levels.

Automation and design concepts are hypotheses about the relationship between technology and cognition/collaboration. As such they must be subjected to empirical investigations. In the case of in-vehicle systems, the design process must be open to changes as long as the mutual changes are not sufficiently well known. The HMD-framework specifies the necessity to evaluate the mutual changes along two different levels. Even though the information in the interaction and communication may be conveyed via the same interfaces, it is necessary to evaluate the content from these two separate conceptual levels. It is easy to focus on design solutions for specific situations on the heteronomy-heteronomy level of interaction. This is a natural consequence of how projects develop over time. However, it is at least as important to focus on the drivers' need to easily regain control in situations that are unfamiliar and unusual [28], that is, to utilize the ability and expertise and recognizing the autonomy of the driver. The very objective of decision making in dynamic decision tasks is that of control.

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