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Human–machine cooperation in smart cars. An empirical investigation of the loss-of-control thesis

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ABSTRACT

In socio-technical systems such as modern planes or cars, assistance systems are used to increase performance and to maintain safety. This raises the questions, how they cooperate with human drivers and whether human operators face a loss of control. The article examines the loss-of-control argument empirically by means of a survey of a sample of car drivers with a number of driver assistance systems. It takes personal experiences with these systems into account, as reported by interviewees, and also figures out main factors that influence the drivers' perceptions. We want to assess if the cooperation of driver assistance systems in modern cars raises the complexity and non-controllability of the whole system to a degree that is evaluated negatively by respondents in terms of loss-of-control. Additionally, our study asks how the interviewees perceive the current role distribution in modern cars and which future role distribution between humans and autonomous technology they expect.

Our analysis will show that our respondents mostly feel comfortable with driver assistance systems, and satisfaction with automated driving does not decrease, but rather increase if more driver assistance systems of the maneuver type are implemented. At the same time, the number of automation malfunctions, reported by our interviewees, proved to be much smaller than we expected. In contrast to the assertion of a loss-of-control in highly automated systems, our data will show, that this hypothesis cannot be confirmed, at least not at the level of self-reported personal experiences and subjective perceptions of non-professional users such as car drivers.

1. Introduction

In scientific debates as well as in public discourses about modern technology we frequently find the argument that operators of highly automated systems may face a loss of control (Perrow, 1984). Accidents such as the crash of a Lufthansa Airbus in Warsaw in 1993, the midair collision of Ueberlingen in 2002 or the loss of the Air France AF-447 over the Atlantic Ocean in 2009 serve as examples to confirm this argument (cf. Grote, 2009: 103ff.; Brooker, 2008).

Research on human factors has tackled the loss-of-control issue by pointing at shortcomings in human–machine interaction (HMI) or in crew resource management (CRM). Highly automated systems, which for instance control a plane and fail only very seldom, may result in complacency and overreliance in automation on part of the pilots. This can lead to a lacking situational awareness and, finally, to the inability even of well-trained people to cope with automation surprises (Parasuraman et al., 2008; Manzey et al., 2008; Sarter et al., 1997; Manzey and Bahner, 2005).

In a crisis situation, human operators often find themselves "out-of-the-loop", being unable to understand, what the automation currently does, and to take appropriate measures (Endsley and Kiris, 1995). This may not only happen to well-trained pilots, but also to car drivers, who mostly haven't been trained to handle sophisticated technical devices (Stanton and Young, 2005).

Surveys of pilots give evidence of loss-of-control, caused by lacking reliability of human–computer interaction in highly automated aircraft. In a survey of 1.268 pilots, conducted by researchers of the Australian Bureau of Air Safety Investigation in 1998, 61% of the respondents "agreed that with automation there are still some things that took them by surprise" (BASI, 1998: 20). Additionally concerning mode confusion, 73% of all respondents agreed that they occasionally "had inadvertently selected a wrong mode" (44, cf. also BASI, 1999; Joshi et al., 2003).

Similarly, in a survey of 278 German pilots, conducted in 2008, 43.1% agreed with the statement "The aircraft is a black box. You

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know how to operate it, but you don't know, how it really works" (Graeser and Weyer, 2010: 43). These findings confirm the analysis of 1998 and underline the assertion that the introduction of electronic flight management in the 1980s has increased the complexity and intransparency of modern aircraft, resulting in a loss of control.

Additionally the role of the pilot has changed fundamentally – from flying the plane to supervising a complex socio-technical system (Sheridan, 1999). The human-centered approach (Billings, 1997) or the level-of automation taxonomy (Parasuraman et al., 2000) thus has to be supplemented by other approaches in order to describe more adequately the manifold aspects of cooperation of humans and autonomous technical systems (Cummings and Bruni, 2009).

Compared to the long-lasting tradition of research on HMI issues in aviation (Wiener and Curry, 1980; Billings, 1997), there is still lacking knowledge on human-automation cooperation in modern cars. In 1988, the A 320 has been put into operation as the first civilian aircraft with electronic flight management systems. Since then manufacturers transferred many concepts, which have been developed and tested in aviation, to road traffic. Fly-by-wire became steer-by-wire (Stanton and Marsden, 1996), and the autopilot found its way into the car e.g. as adaptive cruise control (ACC, Stanton and Young, 2005). Automation philosophies seem to resemble in both fields, e.g. in replacing the human by assistance systems for the sake of comfort and safety (Young and Stanton, 2007).

Despite these communalities (and an ongoing gradual conversion of systems' architectures), the two transportation systems differ with regard to the small amount of vehicles in aviation compared to the large number on the roads; to the professional training of pilots compared to (mostly) non-professional car drivers; and the weak regulation of roads compared to the strict regulation and control of air traffic.

Regarding similarities and differences, the question arises if car drivers face similar problems as pilots, such as complacency, lacking situational awareness and automation surprises. Additionally, it may be worthwhile to figure out if their role perception has also changed – from a driver to a member of a team of humans and non-humans, which co-operate in order to make decisions (Inagaki, 2010).

2. Driving automation

Recent research on driving automation has highlighted several issues, but has not yet generated a coherent picture as research on aviation automation. The following strands of research can be identified, which are accompanied by different methods of investigating human-automation issues.

By means of a survey of 503 persons, Arndt and Engeln (2008) have analyzed the factors that may predict the *acceptance* of driver assistance systems on part of drivers, but did find "no clear pattern" (331). However, Young and Regan (2007) figured out that people from rural areas of Australia use (conventional) cruise control more frequently than people from metropolitan areas, applying the method of focus group discussions.

A group of German researchers argues, that the level of (human) control of smart devices will determine their acceptance (TAUCIS, 2006: 83). They presented different scenarios (among others a smart car) to test persons and asked them about (i) their need for control and (ii) the actually perceived control. In every scenario the balance of (i) and (ii) was negative, i.e. the test persons perceived less control than they preferred to have (194f.). Since this attitude significantly affected acceptance rates, the researchers concluded that the acceptance of smart technology would rise if the user has the means to exert control to the system (195).[2]

Concerning the allocation of control, de Vries et al. (2003) have analyzed the effects of *errors*, made by a route planning system. Applying the method of computer-based experiments they found out, that a high rate of automation errors leads to decreased levels of system trust on part of probands. On the other hand, Young and Salmon (2012) point to our gaps in knowledge, concerning e.g. the amount of distraction-induced errors.

The *interaction* of drivers and adaptive cruise control (ACC) has been subject of several studies. According to Larsson (2012), ACC occasionally hands over control to the driver, who can manage this switch if s/he is still integral part of the control loop. By interviewing 130 ACC users she found out, the longer drivers use ACC, the higher the familiarity with the system is.

Trust in automation has been investigated by Rajaonah et al. (2008), using the method of simulator experiments with ACC. They identified different groups of drivers, but failed to find "significant links between ACC use and trust in the device and self-confidence" (194).

Stanton and Young (2005) conducted *experiments* in a driving simulator. 110 test persons had to drive a car with adaptive cruise control (ACC) at different levels of workload, traffic, and feedback of the ACC system. Stanton and Young investigated the question whether "drivers in the automated condition report greater externality than when they are in the manual condition" (1297). Regarding this point, their findings are unequivocal: "the locus of control scales were highly stable, which means that control loci were not affected by automation" (1308). In other words: drivers did not experience a loss of control when driving with adaptive cruise control instead of manually.

Contrary to these findings, experiments on the interaction of humans and smart systems in an artificial driving scenario conducted by Fink and Weyer (2014) proved that randomly chosen test persons prefer experimental settings which entail a higher level of control, even if the gains are lower than in other scenarios.

Another method for the investigation of these issues has been applied by Nordfjærn et al. (2010), who relied on *self-reported attitudes* and behavior of 6203 Norwegian drivers, concluding that demographic characteristics best help to explain differences in attitude and behavior than other variables.

Finally, it is worth to mention Inagaki's (2008, 2010, cf. Moray et al., 2000) conceptual considerations about the distribution of authority and responsibility in future cars, which he regards as joint cognitive systems. Similar to sociological concepts of hybrid interaction (Latour, 1996; Rammert and Schulz-Schaeffer, 2002) he talks of "coagency" (Inagaki, 2010) of human and technology. And he proposes to consider this fact when designing future cars.

Although this overview of current research doesn't claim to be complete, it gives a clear picture of the diversity of subjects and methodological approaches of current research on driving automation. The applied – and often combined – methods are field observations, simulator experiments, surveys, and focus group discussions. Among the large number of driver assistance systems, ACC seems to be the one that has attracted most attention.

However, data on everyday experiences of drivers still are rare (cf. Larsson, 2012). Most studies have been conducted and most statements of users have been recorded in artificial scenarios, e.g. in simulator experiments, or by modeling and simulating driver behavior (Cacciabue et al., 2007). Although worthwhile, those studies only seldom reflect personal experiences drivers have had

[2] Certain ambivalence may arise here, since smart technology – by definition – reduces human control, whereas acceptance is determined by perceived control and can be raised by higher levels of control. The authors of the TAUCIS study do not answer the question, how to resolve this contradiction.