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The road to automated driving: dual mode and human factors considerations

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Abstract— **Recent technological developments have shown a transition from informative driving support systems to more automated vehicles. Although automated vehicles are designed to overcome limitations in human perception, decision making and response, there may be a downside to introducing these technologies. The downside is based on the new cooperation between the driver and the vehicle, leaving room for misinterpretation, overreliance on system performance and loss of situation awareness in case of requested transfer of control from the automated vehicle back to the driver. This article raises several human factors issues that are of importance when designing (semi-)automated vehicles, such as: the driver as a system monitor, situation awareness and system limitations. Various implications for the design of automated systems are discussed.**

I. Introduction

Recent technical advances have enabled the development of vehicles that can support continuous driver tasks or even take over driving in emergency situations. This automation can range from partial automation (also called semi-automation) where only one or several tasks are automated, to complete automation, where the vehicle drives by itself and the driver's role is reduced to that of an operator monitoring if the systems are performing properly (also called full automation). Although complete automation without a human driver has become possible from a technological point of view, in this paper we do not address driverless vehicles, but rather automation of dual mode vehicles. In dual mode vehicles, the driver can drive completely manually (manual driving), can be supported by some automated tasks (semi-automated driving) or can switch the car to automated driving under some conditions (fully automated driving). The reason for focussing on dual mode vehicles is that we are specifically addressing the human factor issues. As long as driverless vehicles are not 100% reliable and safe under all conditions, the driver will remain the responsible person for safe driving, needing to compensate for technical system failures or limitations. In this paper, human factors issues related to the transfer of manual driving (driver in the loop) to more and more automation (driver getting out of the loop) will be discussed, such as mode confusion, driving in mixed traffic, awareness of the level of automation, and responding to system failures. This paper ends with design recommendations.

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II. Human Factors Issues

Especially for technical automotive engineers, the development towards automated driving sounds very promising, for instance in terms of safety benefits. However, there are crucial human factors that need to be considered for successful implementation of automated vehicles on our roads. The human factors issues explained below focus on overall human abilities to deal with automation. The main focus will be on cognitive abilities, and not so much on cultural or personality issues, since these primarily have an effect on the extent to which drivers use automation [1].

A. Mode confusion

When either the driver is in complete manual control or when the vehicle is in complete automated control, there is no misunderstanding about who is performing what part of the driving task. However, in the middle range of automation, expected to increase the coming years, no confusion is allowed about who is handling which part of the teamwork to guide the vehicle safely and efficiently to its destination.

Experiences from other domains have shown time and again that such mode confusion can have severe consequences. One example is the grounding of the MS Royal Majesty close to Nantucket island in 1995. At the time the equipment of the vessel was modern, including an autopilot and a GPS. As usual, the crew opted for GPS-based navigation, but was not aware of the fact that the GPS antenna was disconnected. While the crew relied on the system to deliver correct data about where the vessel was located, in fact it showed where it was supposed to be according to a pre-programmed schedule. The mode shift was only indicated as two small letters that could easily be overlooked on a display. The crew relied on the information they read from the technical systems and not on visual inspection. Only far too late they realised that they were completely off course, not being able to avoid running aground, causing damage of two million USD.

Also in the driving domain it is crucial that the automation and the human understand and are adjusted to each other.

B. Driving in mixed traffic

In the coming years, road traffic will change when a mix of completely manual, semi-automated and fully automated vehicles will interact on the same roads. Automated vehicles will change the vehicle behaviour compared to driver behaviour in case of manual driving.

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For example, Cooperative Adaptive Cruise Control (C-ACC) will enable vehicles to drive at shorter headways, since the response time to decelerating lead vehicles approaches 0. However, if drivers of non-equipped vehicles (completely manual driving) see the short headways and start to copy this behaviour during manual driving, unsafe driving situations will result since here the driver response times will be much longer compared to system response time.

Another example of a human factors issue is that in case of highway driving, an automated vehicle may have additional information about approaching congestions and may respond by decreasing speed while manually driving road users do not yet have this information. This may result in many overtaking manoeuvres, tailgating and large differences in speed.

C. *Limitations in technology*

Automation functions are often selected in order to rule out human error or to compensate for human limitations. Often, the idea is that in order to improve safety, the human driver - who is seen as the unpredictable element - should be taken out of the loop, thereby guaranteeing a safe solution. With this notion as a starting point, most developments focus on technology alone, striving for fail-safe technical systems. However, these technological developments are not bringing the combination of the human driver/supervisor and the automated car to its optimal level. One of the reasons that technology alone will not be a solution for the next decades is the variety of driving situations. Automation functions within an operational envelope, depending on technical boundaries provided by e.g. sensors. These operational envelopes typically do not apply to all driving or road situations. An example is an ACC-radar which does not detect stationary objects, causing difficulties to apply this technology for longitudinal control in urban environments. This means that a driver is not always completely “in the loop” or “out of the loop”. Being in-the-loop means that the driver plays an active role in the driver-vehicle system and being out-of-the-loop means the driver is more or less a passenger. This means that a driver should be present to take control in case of system failure or limitations. Therefore, a driver should be fully aware of the operational envelope of the system and be ready to respond under all situations, including time critical situations. An example is automated lane keeping. At this moment, lateral control can be automated by means of the detection of road markings. However if these road markings are not present, the quality is not sufficient, the weather conditions are not optimal (e.g. wet road surface) or several road markings are present in close proximity (e.g. during road works), the system may fail. Under these situations, the system will need to provide a timely warning to the driver that (s)he needs to take back control.

Another dangerous situations may occur in case the system cannot cope with the situation in case of extremely critical situations, since drivers always need some time to respond. In case of being partly or completely out of the loop, these response times are expecting to be even higher than under normal driving conditions. If a system hands back control to the driver when it cannot decelerate with sufficient force in order to prevent a collision, it is very likely that the driver will not be able to take over control in a safe manner and apply forces that go beyond system control. Therefore, it is important to clearly think about the risks of systems that are not 100% reliable or capable due to sensor limitations or sensor characteristics in combination with a specific environment.

D. *Change in role of driver*

As described in the CityMobil project [2], [3], the development of assisted driving, via semi-automated vehicles towards (supervised) automated driving, transforms the function of the human driver. The transition from assisted driving to automated driving implies transforming the active driver to a more passive passenger, back to an active driver in case that the system fails.

In case of driver assistance, the driver will stay in the loop and will receive enriched information. In case of semi-automated vehicles, the role of the active driver is replaced by the role of an operator who mainly monitors the specific actions of the automated vehicle (while still performing some part of the driving task him/herself) and is expected to intervene or overrule the system when something goes wrong, when (s)he expects something to go wrong, or when (s)he does not trust the system. In case of highly automated driving, the vehicle performs most of the driving task, with the driver only performing some small part of the driving task, such as indicating the need for a lane change. In case of a fully automated vehicle, the driver is completely out of the loop. In that case, the operator is more of a passive monitor with supervisory control, that is, the responsibility of responding in emergency situations as back-up or being able to drive the car when control is handed back to the driver (e.g. when leaving the motorway). However, being out of the loop may lead to overreliance, behavioural adaptation, erratic mental workload, skill degradation, reduced situation awareness, and an inadequate mental model of automation capabilities [4], [5]. Instead of technology taking over when the human driver cannot cope with the situation, the driver now needs to take over control in case of system limitations. In order to do this, the human needs to understand what the system does and does not do, and the human needs to be ready to take back control whenever the system asks him/her to. If the driver is not ready, not alert, has lost situational awareness, is engaged in other activities, has lost certain skills (due to automation) or is not capable to take over control in the situations that the system cannot cope with either (e.g. close following at high speeds with extremely short headways), safety will be jeopardized.

This shows that supervisory control can be seen as a more difficult human task than manual control, since the demand on human cognition is increased, while the demand on human action is decreased [7]. We therefore get the worst combination: low arousal and high momentary stress when things go wrong. Therefore we can expect that, in a critical situation that occurs after a sustained period of automated driving, the driver will be out of the loop and unable to resume control effectively.

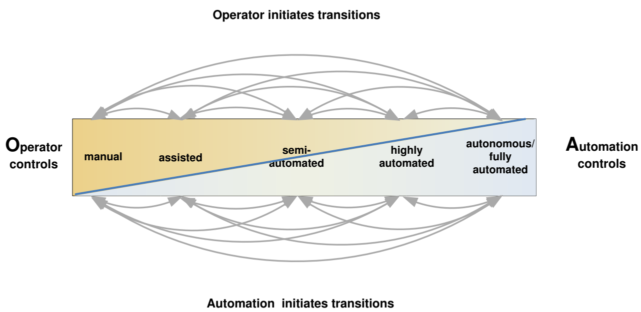

Figure 1. Figure 1: All possible transitions occurring between operator and automation at different levels of automation (grey arrows).

Figure 1 [2] points out the basic principles of transitions between different levels of automation. The human is called 'operator'(supervisor) and the automated subsystem is named 'automation'. Usually, the lower levels of automation are mainly concerned with the so-called operational level of the driving task, that is, the longitudinal and lateral control. More advanced automation is already entering the domain of tactical control, which includes rule-based decision making.

Over the last couple of years there has been a tremendous increase in demonstration projects for automated systems, primarily focusing on the technological developments without paying much attention to the interaction with the human driver. Examples are the Connect&Drive project (the Netherlands) and the Grand Cooperative Driving Challenge (International) and the Darpa Grand challenge (USA).

Systems already on the market such as ACC (Adaptive Cruise Control) and LKA (Lane Keeping Assist) will within a few years be accompanied by systems with a higher degree of automation such as Traffic Jam Assist, Cooperative-ACC and Platooning. Even fully automated vehicles are being developed and tested by most vehicle manufacturers as well as universities and private companies. But, given the significant legislative and safety concerns of introducing such vehicles, for the next decade it is expected to be necessary even for fully automated vehicles that the driver remains behind the steering wheel, retaining ultimate responsibility for the vehicle, with all the problems described above. So now we are in the difficult situation that the technology is already getting ready for market introduction, but there is little or no information on human behaviour with respect to automation in driving, and even less on how to design the HMI in such a way that the driver-vehicle unit can cooperate safely and comfortably.

III. Design Solutions

A. *Awareness of operational envelope*

At this moment, manufacturers try to solve the issue of how to keep the driver informed about a shift from e.g. a Traffic Jam Assist system to a Highway Automation system. The idea here is to make the driver aware of the current mode in which the vehicle is operating, with all the conditions and limitations that apply to this mode. This is important, as the two modes have different so-called operational envelopes.

Any driver assistance system or automated driving system has certain limits or limitations that define its operational envelope. These limits will generally be set in software but can also be the result of sensor limitations. As an example the ISO standard for Adaptive Cruise Control defines among other things a minimum speed at which the system can be activated, and a maximum deceleration capability — when the situation requires greater deceleration, the driver must intervene.

The driver needs to understand the limits and limitations of the system being used, so that surprises do not occur when the system unexpectedly goes into standby or does not intervene (as in a severe braking event with an ACC). This presents the design challenge of how to best inform the driver of system limits, since the driver cannot be expected to read or retain the user manual and to recall this information accurately and immediately in an emergency situation.

B. *Optimal driver vehicle performance*

The ultimate goal should be that the automation does not only take over some of the driver's tasks but that the driver-vehicle unit together performs better than what the driver or the vehicle can do individually. To achieve this ambitious goal designers are in need of guidelines and design principles. In order to achieve this, a deeper understanding of the driver's expectations on automation and of the resulting interplay between driver and automation in the context of an ever-changing, dynamic traffic environment is necessary. In order to do this, the order and timing for the handover of information and control needs to be considered. The topics that need to be thoroughly understood to optimise the driver-vehicle performance include recovering control and shifts in level of control [7], mode errors [8], skill degeneration [9], mental under- or overload [9], a shift from operational task to problem solving [10], driver state and vigilance [11] and emotional issues like satisfaction, acceptance, reliance and shift in the locus of control [12], [9], [13].

C. *Driver in the loop*

As pointed out in Figure 1, there are different levels of automation ranging from assistance of the operating task to full automation control, including decision making. In parallel to the automation, also different levels of being in-the-loop can be distinguished. In the current literature, the discussion of the advantages and disadvantages of having the driver in or out of the loop in case of automation plays an important role. In case of the drivers in the loop, they actively monitor information, recognise emerging situations, make decisions and mostly respond as required. By contrast, out-of-loop performance means that the driver is not immediately aware of the vehicle in relation to the road traffic situation because (s)he is not actively monitoring, making decisions or providing input to the driving task [14]. Reduced levels of being in-the-loop lead to a diminished ability to detect system errors and manually respond in the right manner [4]. Research on drivers in- versus out-of-the-loop is rather extensive, but the results are somewhat inconclusive, with some finding benefits and some finding performance decrements due to automation. Rudin-Brown and Parker [16] studied behaviour in a test vehicle while using ACC and performing a secondary task (i.e. reduced level of being in the loop). Participants showed a significant increase in response time to hazard detection and a significant decrease in driving performance (lane keeping). However, a driver simulator study of Ma and Kaber [17] with participants using ACC and having cell phone conversation showed that the ACC system improves driving performance along multiple dimensions (variation in headway distance and following speed control), without cell phone conversation affecting driving performance. Keeping the driver in the loop in the case of (partial) automation is commonly viewed as particularly relevant for minimising the risk of traffic incidents, where good situation awareness is crucial for drivers to be able to effectively cope with the situation. A premise based on the above-mentioned human factors in vehicle automation is that driver involvement in car driving would be maintained at an optimal level if:

- mental workload would be at a moderate level (not too high and not too low)
- there would be good situation awareness throughout the drive (or at least just before a transition takes place)
- drivers would have appropriate trust in the automated system(s), and
- negative behavioural adaptation (compensating behaviour) would not occur.

While it is important to keep the driver in the loop for ADAS and automation that only supports or takes over a limited part of the driving task, the more advanced automation systems allow for a new mental concept. One of the main ideas of increasing automation is to allow the driver to do other things than driving without compromising, or better, while improving safety at the same time. To expect the driver to stay in the loop, even though the automation is fully capable of handling the situation, is both unrealistic and unnecessary. Therefore, we propose to view the operator and the automation as one team (so far called the driver-vehicle unit) that needs to be in the loop. However, it is not specified whether it is the operator, the automation or both team partners that are in control at any given moment. We propose to adopt a concept of "extended shared control", in the style of the shared control described by Flemisch et al. [18] and Abbink et al. [19], for example. The original idea of shared control was to have the automation deliver its input only when necessitated by an outer cue, while still letting the driver override the suggestion, thereby keeping the driver in-the-loop. We suggest, however, to extend this shared control over time, such that the driver and the automation agree on who is going to take how much of the control, up to a hundred per cent. This includes an agreement on how control on all levels is handed back to the other team player when it becomes necessary.

D. *Driver readiness and situation awareness*

Driver readiness refers to how much time the driver needs to recover control and to situations in which the driver is not capable of regaining adequate control. Driver readiness can be affected by fatigue or by engagement in non-driving related tasks. The readiness to respond also differs between individuals and driving conditions. Also, some drivers will use the automated functionality for the first time without any education, training or experience. The interaction design must work on the whole range from a sleepy or distracted novice driver using an automated vehicle for the first time to an experienced driver using automation on a daily basis.

In the transition back to manual driving, drivers need to recover situation awareness of the road conditions, the surrounding traffic, the vehicle state, and the upcoming route, including route choices. Thus, prior to assuming manual control, drivers also need to recover awareness of the tactical and strategic situation. This does not necessarily mean that the human needs to know everything about different automation stages and the technical background, but rather, that the human knows what can be expected at what moment in time of the automation. The automation, on the other hand, should be able to provide output that is directly intuitive for the operator, and is transferred fast. For the latter, system-output used as user-input and transferred via the neuro-muscular system, e.g. by means of force-feedback, seems promising [20]. Moreover, the automation should also be capable of deducing from the operator's actions whether the operator is in the loop or not.

For situation awareness it is important to realise that mode transitions can occur even without driver intervention because of the operational envelope designed into the system. Thus, a system which only functions at low speed might be automatically disabled as speed increases, at which point a system with a fixed minimum speed may or may not be available. The two systems might have similar, but not totally equal functionalities, leading to potential mode confusion and a lack of awareness by the driver about what automation functions are currently supporting him/her. How to inform the driver about such transitions and functionalities is not obvious. Just naming a function as being in operation (or on standby) requires driver knowledge of system capabilities and hence training. A continuous display of detailed capabilities and operational envelopes could result in display clutter and hence confusion and distraction. Ecological, simple and self-explaining displays need to be designed that are tuned to the specific driver (either being in or out of the loop).

E. *Adaptive versus adaptable automation*

This goes along well with the more intensively investigated concepts of adaptive vs. adaptable automation [21]. The former functions such that the automation adapts itself to the driver – an example could be a lane keeping assistance system that adds extra safety margins when it senses that the driver is sleepy. Adaptable automation, on the other hand, places ultimate responsibility for controlling the level of automation with the driver. Both types of automation have been found to alleviate drawbacks that were attributed to static automation [22], For example, Kaber and Endsley [23] revealed in a task performance test involving different levels of automation, that system performance benefits most from automation of the operational part of the driving task, but only under non-critical conditions. In contrast, if the automated system failed, the removal of human control from the operational part resulted in inability to recovery. Moreover, Miller and Parasuraman [24], [25] suggested that delegation offers a method for flexible human-automation interaction which enhances system performance while maintaining user workload at a manageable level. Experiments from Parasuraman et al. [26], [27] showed that an interface which allowed delegation of control between human and machine increased overall performance and reduced task completion time for unpredictable situations. It is worthwhile mentioning that especially adaptable information is not intended to minimise the operator's workload, but rather to give him or her the possibility to adapt the automation to one's own needs and comfort levels [28], [29]. The act of delegation itself may also serve to reduce a user's tendency to be complacent and instead promote attention towards monitoring system status and task completion.

F. Influence of time on transitions of control

From the review of involved Human Factors aspects, it becomes clear that timing aspects of resolving knowledge and understanding of the driving situation (e.g. situation awareness) need special attention when developing an HMI for automated driving. Whereas some of the listed Human Factors aspects have long term consequences, slower reaction times and misunderstanding of appropriate intervention is something that can already occur during first use. Therefore it is important that HMI solutions accommodate drivers to take back control in time-critical and unexpected situations. From a driving simulator study [30] involving a take-over task in time-critical driving situations by drivers which were out-of-the-loop, we know that when 1,5 seconds was available to avoid an accident, in almost half of these occasions (47,5%) accidents occurred. In contrast, in manual driving conditions (i.e. drivers who are in-the-loop) time-headways of 1,5 seconds are considered acceptable and safe. This might have consequences for the situations in which automation is available. Situations in which timely warnings in case of critical events are not possible need to be excluded for application of automated driving that may still need some driver control. However, this study also showed that providing an improved level of SA also improves the change for successfully taking back control. This indicates that although the applied take-over conditions were time-critical (i.e. requiring quick responses) participants in the less critical conditions were better able to divide their attention between observing the traffic and taking back control. This seems promising: when SA increases, so does the chance for successfully taking over control. Hence, it is to be expected that interface-solutions which help (re-)directing drivers' attention to the traffic scenery and understanding their own vehicle (i.e. increasing SA) will improve drivers' ability to successfully retrieve control after automation, also in time-critical situations.

Although a positive correlation is found in this Van den Beukel and Van der Voort study [30] of SA on the success of retrieving control, understanding how task performance proceeds in sudden take-over situations is nonetheless encompassed with assumptions. It could be that with time-critical and unexpected take-overs, control is more based on intuition, assuming a more or less impulsive step from 'perception' directly to 'action'. Therefore, the effects of cognitive state in time-critical situations need to be further explored. For example, further research is needed how stress-level influences the ability to take over control and on intra- en inter-individual differences.

IV. Design Recommendations

In order to ensure a safe and smooth transition of control between the driver and the (semi-) automated vehicle, an optimal driver-vehicle performance is needed. Human Factors issues in (semi-)automated driving are especially important due to the time-critical nature in case of urgencies and incidents. This is even more important since these incidents and time-critical events do not occur often and are therefore not trained.

What an optimal system performance needs to address to overcome the explained Human Factors issues, is expressed with the following design recommendation:

- Avoid mode confusion by creating the right expectations, making the system intuitive to operate and design for automatic detection whether the driver is in or out of the loop.
- Assume that (semi-)automated vehicles will result in drivers addressing attention to non-driving tasks. It needs to be taken into account that they will be out-of-the loop (at least to some extent).
- Assume that a driver will be (partially) out of the loop when driving a (semi)automated vehicle
- Enable the driver to come back in the loop in a fast and easy way by:
    - Using user input types which transfer information fast, e.g. using force feedback in pedals or on the steering wheel.
    - Intervening in secondary tasks which users are involved in to actively direct attention to the driving task, e.g. interrupting visual information of a nomadic device with a warning overlay when take-over is required.
- Explain the operational envelope, indicating the system boundaries. This may be done by giving reasons after transitions of control in order to enable the user to better understand the system boundaries.
- Make automation adaptable and therewith ensure that the user actively takes decisions about the level of automation (s)he considers appropriate for the situation.

- Provide timely and self-explaining warnings.

Only when these human factors issues are addressed in the development of technological systems, the system performance will outperform either manual driving or fully automated driving.

References

[1] Kidwell, B., Calhoun, G. L., Ruff, H. A., & Parasuraman, R. “Adaptable and Adaptive Automation for Supervisory Control of Multiple Autonomous Vehicles.” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 56(1), 2012, pp. 428–432.

[2] Martens, M.H., Pauwelussen, J., Schieben, A., Flemish, F., Merat, N., Jamson, S. & Caci, P. “Human Factors’ aspects in automated and semi-automated transport systems: State of the art.” Deliverable 3.2.1 of the Citymobil project, 2008

[3] Toffetti,A., Wilschut, E., Martens, M.H., Schieben, A., Rambaldini, A., Merat, N. & Flemisch, F. “CITYMOBIL: Human Factors Issues Regarding Highly-Automated Vehicles on an eLane.” *Transportation Research Record: Journal of the Transportation Research Board*, No. 2110, 2009, pp. 1-8.

[4] Endsley, M. R., & Kiris, E. O. “The Out-of-the-Loop Performance Problem and Level of Control in Automation.” *Human Factors,* 37(2), 1995, pp. 381-394.

[5] Saffarian, M., De Winter, J. C. F., & Happee, R. “Automated Driving: Human-Factors Issues and Design Solutions.” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2012*, 56(1), pp. 2296–2300.

[6] Wickens, C. D. *Engineering psychology and human performance (2nd ed., 1992).* New York: HarperCollins.

[7] Young, M. S., Stanton, N. A. & Harris, D. “Driving automation: learning from aviation about design philosophies.” *International Journal of Vehicle Design,* 45(3), 2007, pp. 323–338.

[8] Sarter, N. B., & Woods, D. D. “How in the world did we ever get into that mode? Mode error and awareness in supervisory control.” *Human Factors,* 37, 1995, pp. 5–19.

[9] Stanton, N. A., & Young, M. S. “A proposed psychological model of driving automation.” *Theoretical Issues in Ergonomics Science*, 1(4), 2000, pp. 315–331.

[10] Wickens, C. D., & Hollands, J. G. *Engineering Psychology and Human Performance (3rd ed, 1999).* Upper Saddle River: Prentice Hall.

[11] Young, M. S., Birrell, S. A. & Davidsson, S. “Task preloading: Designing adaptive systems to counteract mental underload.” In Anderson, M. (ed.) *Contemporary Ergononomics and Human Factors 2011.* pp. 168-176. Taylor & Francis.

[12] Woods D. D. and Sarter, N. “Learning from Automation Surprises and Going Sour Accidents.” In N. Sarter and R. Amalberti (Eds.), *Cognitive Engineering in the Aviation Domain.* pp. 327–254, Erlbaum, Hillsdale NJ, 2000.

[13] Muir, B. M. “Trust between humans and machines, and the design of decision aids.” *International Journal of Man-Machine Studies, 27*, 1987, pp. 527-539.

[14] Kienle, M., Damböck, D., Kelsch, J., Flemisch, F. & Bengler, K. “Towards an H-Mode for highly automated vehicles: driving with side sticks.” *Proceedings of the First International Conference on Automotive User Interfaces and Interactive Vehicular Applications,* 2009, pp. 19-23, Essen, Germany.

[15] Stanton, N. A. & Young, M. S. “Driver behaviour with adaptive cruise control.” *Ergonomics,* 48, 2005, pp. 1294–1313.

[16] Rudin-Brown, C.M. & Parker, H. “Behavioural adaptation to adaptive cruise control (ACC): implications for preventive strategies.” *Transportation Research Part F: Traffic Psychology and Behaviour*, 7, 2004, pp. 59-76.

[17] Ma, R., & Kaber, D. B. “Situation awareness and workload in driving while using adaptive cruise control and a cell phone.” *International Journal of Industrial Ergonomics,* 35(10), 2005, pp. 939-953.

[18] Flemisch, F., Heesen, M., Hesse, T., Kelsch, J., Schieben, A., & Beller, J. “Towards a dynamic balance between humans and automation: authority, ability, responsibility and control in shared and cooperative control situations.” *Cognition, Technology & Work*, 14(1), 2011, pp. 3–18.

[19] Abbink, D. A., Mulder, M., & Boer, E. R. “Haptic shared control: smoothly shifting control authority?” *Cognition, Technology & Work,* 14, 2012, pp. 19–28.

[20] Mulder, M., Abbink, D. A., & Boer, E. R. (in press). “Sharing Control With Haptics: Seamless Driver Support From Manual to Automatic Control.” *Journal of the Human Factors and Ergonomics Society*, 54, 2012, pp. 786-798.

[21] Opperman, R. *Adaptive user support.* Hillsdale, NJ: Erlbaum, 1994.

[22] Cosenzo, K. A., Parasuraman, R., Novak, A., & Barnes, M. *Implementation of automation for control of robotic systems (ARL-TR-3808).* Human Research and Engineering Directorate, U.S. Army Research Laboratory, Aberdeen Proving Grounds, MD, 2006.

[23] Kaber, D. B., & Endsley, M. R. “The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task.” *Theoretical Issues in Ergonomics Science,* 3, 2003, pp. 1-40.

[24] Miller, C. A., & Parasuraman, R. “Designing for flexible interaction between humans and automation: delegation interfaces for supervisory control.” *Human Factors,* 49 (1), 2007, pp. 57-75.

[25] Miller, C., Funk, H., Goldman, R., Meisner, J., & Wu, P. “Implications of adaptive vs. adaptable UIs on decision making: Why automated adaptiveness is not always the right answer.” *Proceedings of the first international conference on augmented cognition*, 2005, Las Vegas, Nevada, USA.

[26] Parasuraman, R., Galster, S., Squire, P., Furukawa, H., & Miller, C. A “Flexible delegation-type interface enhances system performance in human supervision of multiple robots: Empirical studies with RoboFlag.” *IEEE Systems, Man, and Cybernetics – Part A: Systems and Humans,* 35, 2005, pp. 481–493.

[27] Squire, P. N., & Parasuraman, R. “Effects of automation and task load on task switching during human supervision of multiple semi-autonomous robots in a dynamic environment.” *Ergonomics*, 53(8), 2010, pp. 951–61.

[28] De Visser, E., Shaw, T., Mohamed-Ameen, A., & Parasuraman, R. “Modelling Human-Automation Team Performance in Networked Systems: Individual Differences in Working Memory Count.” *Proceedings of the Human Factors and Ergonomics Society Annual Meeting 2010*, 54(14), pp. 1087–1091.

[29] Chen, J.Y.C., & Barnes, M.J. “Supervisory control of multiple robots: Effects of imperfect automation and individual differences.” *Human Factors,* 54(2), 2012, pp. 157-174.

[30] Van den Beukel, A.P., Van der Voort, M.C. (accepted paper). “Retrieving human control after situations of automated driving: How to measure Situation Awareness.” In: G. Meyer, J. Fischer-Wolfarth (Eds.), *Advanced Microsystems for Automotive Applications 2013*, Springer-Verlag Berlin.

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