ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/329277016

How to keep drivers engaged while supervising driving automation? A literature survey and categorization of six solution areas

Preprint · September 2018
DOI: 10.1080/1463922X.2018.1528484

CITATIONS
0

READS
225

5 authors, including:

Christopher Cabrall
Delft University of Technology
64 PUBLICATIONS **245** CITATIONS
SEE PROFILE

Alexander Eriksson
Transportøkonomisk institutt, TØI
40 PUBLICATIONS **147** CITATIONS
SEE PROFILE

Joost de Winter
Delft University of Technology
237 PUBLICATIONS **3,199** CITATIONS
SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project Human Factors of Automated Driving (HFAuto) View project

Project Safety through automation? View project

All content following this page was uploaded by Christopher Cabrall on 29 November 2018.

The user has requested enhancement of the downloaded file.

Cabrall, C.D.D., Eriksson, A., Dreger, F., Happee, R., & De Winter, J.C.F. (2018). How to keep drivers engaged while supervising automation? A literature survey and categorisation of six solution areas. *Theoretical Issues in Ergonomics Science*. https://doi.org/10.1080/1463922X.2018.1528484

How to keep drivers engaged while supervising driving automation? A literature survey and categorization of six solution areas

Christopher D. D. Cabrall[a], Alexander Eriksson[b], Felix Dreger[a], Riender Happee[a], and Joost C. F. de Winter[a,c]

[a]Cognitive Robotics Department, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Delft, The Netherlands

[b]Norwegian Centre for Transport Research (TØI, Transportøkonomisk Institutt), Automation and Digitalisation, Forskningsparken – Oslo Science Park, Oslo, Norway

[c]Biomechanical Engineering Department, Faculty of Mechanical, Maritime and Materials Engineering, Delft University of Technology, Delft, The Netherlands

Abstract. This work aimed to organize recommendations for keeping people engaged during human supervision of driving automation, encouraging a safe and acceptable introduction of automated driving systems. First, heuristic knowledge of human factors, ergonomics, and psychological theory was used to propose solution areas to human supervisory control problems of sustained attention. Driving and non-driving research examples were drawn to substantiate the solution areas. Automotive manufactures might (1) avoid this supervisory role altogether, (2) reduce it in objective ways or (3) alter its subjective experiences, (4) utilize conditioning learning principles such as with gamification and/or selection/training techniques, (5) support internal driver cognitive processes and mental models and/or (6) leverage externally situated information regarding relations between the driver, the driving task, and the driving environment. Second, a cross-domain literature survey of influential human-automation interaction research was conducted for how to keep engagement/attention in supervisory control. The solution areas (via numeric theme codes) were found to be reliably applied from independent rater categorizations of research recommendations. Areas (5) and (6) were addressed by around 70% or more of the studies, areas (2) and (4) in around 50% of the studies, and areas (3) and (1) in less than around 20% and 5% respectively. The present contribution offers a guiding organizational framework towards improving human attention while supervising driving automation.

Keywords. attention; engagement; supervisory control; automated driving; human monitoring of automation

Background

Addressing human driving errors with automation technology

Traffic safety literature has predominately implicated human behaviour and cognition as principal factors that cause motor vehicle crashes and fatalities. Treat et al. (1979) performed 2,258 on-site and 420 in-depth accident investigations and found that human errors and deficiencies were a cause in at least 64% of accidents, and were a probable cause in about 90-93% of the investigated accidents. Treat et al. (1979) identified major human causes as including aspects such as improper lookout, excessive speed, inattention, improper evasive action, and internal distraction. The National Highway Traffic Safety Administration (NHTSA, 2008) conducted a nationwide survey of 5,471 crashes involving light passenger vehicles across a three year period (January 2005 to December 2007). NHTSA (2008) determined the critical reason for pre-crash events to be attributable to human drivers for 93% of the cases. Critical reasons attributed to the driver by NHTSA (2008) included recognition errors (inattention, internal and external distractions, inadequate surveillance, etc.), decision errors (driving aggressively, driving too fast, etc.), and performance errors (overcompensation, improper directional control, etc.).

Consequentially, Advanced Driving Assistance Systems (ADAS) and Automated Driving Systems (ADS) are commonly motivated as solutions to address transportation safety problems of human errors (Kyriakidis et al., 2015; Gao et al., 2014; NHTSA, 2017). The Society of Automotive Engineers International (SAE) originally released a standard J3016_201401 (SAE, 2014) that conveyed an evolutionary staged approach of five successive levels of driving automation ranging from '*no automation*' to '*full automation*' (herein referred to as SAE Level 0-5). While the SAE standard has been revised several times to its most current version available as of June 2018 (SAE, 2018), its principal levels have been retained and continue to be a common reference point for the automotive automated/autonomous vehicles (AVs) research domain. Automotive manufacturers have already begun to release various SAE Level 2 '*Partial Automation*' systems within their on-market vehicles, which allow combined automatic execution of both lateral and longitudinal vehicle control under specific operational design domains. At SAE Level 2, drivers are still expected to complete object and event detection and response duties while retaining full responsibility as a fall-back to the driving automation (SAE, 2018).

New roles, new errors: Supervisors of mid-level driving automation

A complicating issue along the path to fully autonomous self-driving cars exists for the SAE Level 2 partial automation systems in regards to a state of driver supervisory engagement and retention of responsibility. Owners' manuals, manufacturer websites, and press releases of recent on-market SAE Level 2 systems were collected as background material to understand how the industry is presently addressing this issue. A sample of recently released SAE Level 2 driving automation system terminology and Human Machine Interfaces (HMI) regarding human disengagement is organized in Table 1. This overview suggests that vehicle manufacturers do share some concern for the topic of human supervisory oversight of their driving automation. Notably, such concerns appear mostly in arguably passive (e.g., instructional guidelines and warnings), indirect (e.g., surrogate sensing of attention/involvement), and/or reactive (e.g., post-incident alerting) manners.

Most manufacturers kept their descriptions of driver engagement responsibilities and requirements during use of their SAE Level 2 systems at a higher level than commonly found in research communities (e.g., specifications of aberrant driver state terminology such as drowsiness, distraction, inebriation). Instead, manufacturer examples included abstracted aspects like always being aware of and acting appropriately in traffic situations or being '*in control*'. Some notable specifics for the remaining driver responsibility include Mercedes' detailing of vehicle speed, braking, and staying in the lane (Mercedes-Benz, 2017, p. 177), a few statements from BMW that hands must be kept on the steering wheel (BMW, 2017), and repetitive remarks from Tesla regarding their hands-on requirements (Tesla, 2017, p. 73), including an entire sub-section entitled '*Hold Steering Wheel*' (Tesla, 2017, p. 74).

Across the various inputs that are interpreted as aberrant driver engagement/readiness (e.g., inadequate braking levels, unbuckled seatbelts, open doors, and driver facing cameras), the most common classification was that of measures associated with lateral vehicle control (i.e., steering wheel touch/torque and/or lane position). GM/Cadillac currently stands out as the only one so far to use a visual modality of a driver-facing camera to ascertain driver inattention. The consequential output modalities of auditory, visual, and transitions of control (ToC) were found to be used by all manufacturers in their reactive HMI strategies. One manufacturer officially mentioned use of a tactile modality alert (GM/Cadillac) while a few others (Mercedes, BMW) were found in unofficial reports (MercBenzKing, 2016; Sherman, 2016).

By counting stages beyond a first warning (i.e., escalation intervals), Tesla was found to use the highest number of escalations in their reactive HMI. At least five escalations were observable from online Tesla owner videos (e.g., Black Tesla, 2016; Super Cars, 2017). Descriptions and approximated timings of the following escalations are in regards to coming after the initial warning of a grey filled textbox with wheel icon and '*Hold Steering Wheel*' message at the bottom of the dashboard instrument cluster.

1) +2 seconds after first warning - dashboard instrument cluster border pulses in white with an increasing rate;
2) +15 seconds after first warning - one pair of two successive beeps;
3) +25 seconds after first warning - two pairs of two successive beeps;
4) +30 seconds after first warning - at the bottom of the instrument cluster, a red filled textbox plus triangle exclamation point icon with two line written messages of '*Autosteer Unavailable for the Rest of This Drive*' on line one, and '*Hold Steering Wheel to Drive Manually*' on line two in smaller font, along with a central image of two red forearm/hands holding a steering wheel that replaces the vehicle's lane positioning animation, the same previous pairs of successive beeps are repeated in a continuous manner; the vehicle gradually reduces speed
5) +37 seconds after first warning – all alerts from previous level remain, two yellow dots are added at the beginning of each forearm; the vehicle hazard blinkers are activated

A few manufacturers could be determined as having more than one escalation (GM/Cadillac, Audi), a few others as exactly one escalation (BMW, Daimler/Mercedes-Benz), and Volvo appeared to have a single first level/stage warning with no further escalation. Infiniti appeared to have no HMI reactive to driver disengagement/misuse of their Level 2 system (Active Lane Control). All but one manufacturer (Infiniti) were found to use at least the visual modality in their first stage of warning against driver disengagement.

Introduction of Solution Grouping Framework

Proactive solution strategies for human engagement in supervisory control

To complement the passive, indirect, and/or reactive approaches presently available in the aforementioned on-market industry examples, a set of proactive solution strategies towards human engagement in supervisory control might be helpful. Longstanding human factors and ergonomics principles have previously suggested risks in relying on humans as monitors of automated (e.g., invariant, predictable, monotonous, etc.) processes over extended periods (Greenlee et al., 2018; Hancock, 2017a; Molloy & Parasuraman, 1996; Bainbridge, 1983; Mackworth, 1950). Thus, it was expected that many solutions might exist across the academic literature and could benefit from a qualitative framework for organizing trends and patterns in their recommendations.

A natural starting point to the difficulties in human supervisory control of driving automation is to avoid the supervisory role outright (e.g., skip SAE Level 2). Logically, softer versions of such a hard stance might also be realizable in either objective or subjective ways. Objectively, the amount of time or envelope of automated functionality could be reduced. Subjectively, the supervisory experience of responsibility could be refashioned with altered perceptions of the human's role towards shared or even fully manual authority. Furthermore, extensive research conducted under multiple paradigms of psychological theory might suggest approaches out of different schools of thought. The behaviourism paradigm centres around conditioning learning theories and suggests associative stimuli and/or stimulus-response pairing principles to promote the desired behaviour and discourage that which is undesirable. The cognitivism paradigm focuses on internal information processes and advises ways to support limited mental resources, representations, and awareness. Lastly, ecological approaches emphasize inclusion of external considerations of the task and the environment surrounding the worker/learner towards enhanced relational performance from a broader systems-level view.

In summary, a grouping framework of six proactive solution areas is proposed to help answer the question '*How do we keep people engaged while supervising (driving) automation?*' In each case, the solution areas are introduced first in a general manner of various automation domains, before exemplifying relevancy specifically for engagement in supervisory control of driving automation.

Solution Area (1): Avoid the role of sustained human supervision of automation
- Suspend/repeal/skip levels of automation requiring human oversight and backup
    - '*just don't do it*'

Solution Area (2): Reduce the supervising role along an objective dimension
- Change the amount of time or envelope of automated operations
    - '*don't do it as much*'

Solution Area (3): Reduce the supervising role along a subjective dimension
- Share responsibilities and/or alter the end user experience and impressions
    - '*do it without drivers having to know about it*'

Solution Area (4): Support the supervising role from the behaviourism paradigm
- Condition the desired target behaviours through training and selection
    - '*make or find drivers who do it better*'

Solution Area (5): Support the supervising role from the dyadic cognitivism paradigm
- Inform designs to support cognitive processes and mental models
    - '*focus on internal mental constructs*'

Solution Area (6): Support the supervising role from the triadic ecological paradigm

- Inform designs to leverage external environment contexts and task considerations
    - ‘*focus on external task/environment factors*’

Solution Area (1): Avoid the role of human supervision of automation

The most parsimonious proactive solution could be to avoid subjecting drivers to the unnatural requirement of monitoring automated processes. Decades of human factors and ergonomics research have echoed that this is not something humans do well. A resounding result from Norman Mackworth (1948) was that despite instruction and motivation to succeed in a sustained attention task (used as an analogy to the critical vigilance of WWII radar operators watching and waiting for enemy target blips on their monitor screens), human detection performance dropped in relation to time-on-task. Thousands of reports have since been published on the challenges of human vigilance, also known as ‘*sustained attention’* (Frankmann & Adams, 1962; Craig, 1984; Cabrall et al., 2016). Bainbridge (1983) observed the irony that human supervisory errors are expected when operators are left to supervise an automated process put in place to resolve manual control errors. Humans were described as deficient compared to machines in prolonged routine monitoring tasks, as seen in the MABA-MABA (Men Are Better At – Machines Are Better At) list by Fitts (1951), and such characterizations persist today (De Winter & Dodou, 2011). In a review of automation-related aircraft accidents, Wiener and Curry (1980) suggested that it is highly questionable to assume that system safety is always enhanced by allocating functions to automatic devices rather than human operators. They instead consider first-hand whether a function *should* be automated rather than simply proceeding because it *can* be.

Driver responses have been found to be negatively impacted when having to respond to simulated automation failures while supervising combined automatic lateral and longitudinal driving control (De Waard et al., 1999; Stanton et al., 2001; Strand et al., 2014). From elaborated operator sequence diagram models, Banks et al. (2014) indicated that far from reducing driver workload, additional sub-system tasks associated with monitoring driving automation actually would increase cognitive loads on a driver. Banks et al. (2018) analysed on-road video observations of participants operating a Tesla Model S in Autopilot mode (i.e., SAE Level 2 driving automation). They found that drivers were not properly supported in adhering to their new monitoring responsibilities, and were showing signs of complacency and over-trust. Accordingly, Banks et al. (2018) discussed a possibility that certain levels of driving automation (DM, driver monitoring) need not be implemented even if they are feasible from a technical point of view, and that a simplified set of roles of only DD (driver driving) and DND (driver not driving) could be preferred from a human factors role/responsibility point of view.

> *‘…it seems more appropriate at the time to accept that the DD and the DND) roles are the only two viable options that can fully protect the role of the human within automated driving systems. This in turn means that* either *the human driver should remain in control of longitudinal and/or lateral aspects of control (i.e., one of the other) or they are removed entirely from the control-feedback loop (essentially moving straight to SAE 4)’. (p. 144).*

Solution Area (2): Reduce the role along an objective dimension

In the mid-1990s, several key studies suggested a less strict avoidance approach in the human supervision of automation. Various schemes for alternating periods of manual and automated control were investigated (Parasuraman et al., 1996; Scallen et al., 1995; Endsley & Kiris, 1995). In Parasuraman et al. (1996), adaptive control conditions where control was temporally returned to a human operator showed subsequent increases in monitoring performance compared to a non-adaptive full automated condition. In Scallen et al. (1995), adaptive switching between manual and automated control was investigated at short time scale intervals (i.e., 15, 30, and 60 seconds). Objective performance data indicated better performance with shorter rather than longer cycles. However, such benefits were associated with increased workload during the shorter cycle durations (i.e., the participants did better only at the cost of working harder and prioritizing a specific sub task). Thus, the authors concluded that if the goal of the operator is to maintain consistency '*on all sub-tasks, at all times*' then the performance immediately following episodes of short automation warrants particular concern: i.e., '*the results support the contention that excessively short cycles of automation prove disruptive to performance in multi-task conditions*'. In Endsley and Kiris (1995) the level of automated control was investigated. Rather than manipulating the length of time of automated control, a shift from human active to passive processing was deemed responsible for decreased situation awareness and response time performance. Manual control response times immediately following an automation failure were observably slower compared to baseline manual control periods. However, the effect was less severe under partial automation conditions compared to the full automation condition.

In Merat et al. (2014), a motion-based driving simulator experiment study was conducted with adaptive automation. They compared a predictable fixed schedule for triggering ToC to manual control with a real-time criterion which switched to manual based on the length of time drivers were looking away from the road. The authors concluded that better vehicular control performance was achieved when the automated to manual ToC was predictable and based on a fixed time interval.

Solution Area (3): Reduce the role along a subjective dimension

Rather than altering the objective amount of automated aid as in solution area (2), automation system design can also focus on the driver's psychological subjective experience or perception of responsibility and/or capability. In other words, manual human operator behaviour is not replaced in solution area (3) but augmented, extended, and/or accommodated. Such subjective shaping might take the form either as help (e.g., automatic backup) or even as hindrance (e.g., to provoke positive adaptive responses). Schutte (1999) introduced the concept of '*complemation*' to describe technology that is designed to enhance humans by augmenting their innate manual control skills and abilities rather than to replace them. With such complementary technology, many of the sub-tasks that could be automated are deliberately not automated, so that the human remains involved in the task. Flemisch et al. (2016) relayed similar theoretical concepts and design approaches where both the human and the machine should act together at the same time under a '*plethora*' of names, such as shared control, cooperative control, human-machine cooperation, cooperative automation, collaborative control, co-active design, etc. Young & Stanton (2002) proposed a Malleable Attentional Resources Theory positing that the size of relevant attentional resource pools can temporally adapt to changes in task demands (within limits). Thus, cognitive resources may actually be able to shrink/grow to accommodate various decreases/increases in *perceived* demands (e.g., even while retaining objective protections in the background).

Janssen (2016) evaluated simulated automated driving as a backup and found improved lateral performance and user acceptance (workload and acceptance) compared to adaptive automated-to-manual ToC. Mulder et al. (2012) improved safety performance and decreased steering variation in a fixed-base driving simulator through the use of haptic shared control. By requiring and retaining some level of active control from the human driver (i.e., amplification of a suggested torque), the shared control model was expected by Mulder et al. (2012) to maintain some levels of engagement, situation awareness, and skill as compared to the supervisory control of automation.

A concept of promoting increased care in driving from the end-user by a seemingly reductive or even counter-productive human automation interface design can be found in Norman (2007). In order to keep human drivers informed and attentive, the proposition suggested that more requirements for human participation might be presented than is really needed. In other words, an automated driving system can encourage more attention from the human supervisor by giving an appearance of being less capable, of doing less, or even doing the wrong thing. Norman (2007) exemplified this framework of '*reverse risk compensation*' by reference to Hans Monderman (1945-2008) and then to Elliot et al. (2003). In Monderman's designs, the demarcations, rules, and right of ways of a designed traffic system are purposefully diminished/removed in favour of shared spaces. The idea is to provoke end-users (drivers, pedestrians, cyclists, etc.) to collectively combat complacency and over-reliance on rules/assumptions by being forced to look out for themselves (and one another). Norman (2007) cited results from Elliot et al. (2003) where artificial increases in perceived uncertainty resulted in driver adoption of safer behaviours such as increased information seeking and heightened awareness. In sum, Norman (2007) described an interesting potential of designed automated processes in futuristic cars where there could be an approach of shaping psychological experiences.

> '*…we can control not only how a car behaves but also how it feels to the driver. As a result, we could do a better job of coupling the driver to the situation, in a natural manner, without requiring signals that need to be interpreted, deciphered, and acted upon … The neat thing about smart technology is that we could provide precise, accurate control, even while giving the driver the perception of loose, wobbly controllability*'. (p. 83).

Solution Area (4): Support the role from the behaviourism paradigm

A historical psychological perspective on shaping people to behave as desired can be traced back to the early 1900s behaviourism learning models of Ivan Petrovich Pavlov ('*classical conditioning*') and Burrhus Frederic Skinner ('*operant conditioning*'). Broadbent and Gregory (1965) attributed prolonged watch detriments to a shift in response criterion whereby operators might be better persuaded towards reacting to doubtful signals (e.g., manipulation of payoff). More recently, the term '*gamification*' has been defined as the '*use of game design elements in non-game contexts*' (Groh, 2012) and was recognized in positive and negative ways to exemplify conditional learning aspects (Terry, 2011). In gamification, interface designs utilize the mechanics and styles of games towards increased immersion. Related approaches include an emphasis on skills either acquired over practice (e.g., training focus) and/or from innate pre-dispositions (e.g., personnel selection, individual differences, etc.). Neuro-ergonomic approaches in Nelson et al. (2014) improved vigilance task performance via transcranial direct current stimulation. Parasuraman et al. (2014) identified a genotype associated with higher skill acquisition for executive function and supervisory control. Sarter and Woods (1993, p. 118) advised directions to support awareness through '*new approaches to training human supervisory controllers*', and Gopher (1991) suggested potential promise via the enhancement of '*skill at the control of attention*'.

Behaviouristic dispositions are also observable in the automotive domain concerning increased driver vigilance with ADAS. Similar to the aforementioned investigations of selection interest (e.g., neurological disposition for enhanced cognitive executive control), automotive research recommendations have included the implementation of training programs and/or gamified concepts. This solution area aims to enhance operators without enough attentive skills, or executive control for sustained focus, to instead obtain such skill/focus via extra practice, immersion, and/or motivation. Diewald et al. (2013) reviewed '*gameful design*' and saw promise for its use for in-vehicle applications (e.g., navigation, safety, and fuel efficiency). For driving safety, virtual money/points and virtual avatar passengers were identified as rewards/punishments tied to onboard diagnostics of driving styles. In Lutteken et al. (2016), a simulated highly automated highway driving vehicle performed longitudinal and lateral control while the human driver controlled lane changes as a manager of consent. A gamified concept consisting of partner teaming, virtual currency points that could be earned/spent, and time scores was found to motivate and increase the desired cooperative driver behaviours. In a test-track study, Rudin-Brown and Parker (2004) found increased response times to a hazard detection task while using adaptive cruise control (ACC). Rudin-Brown and Parker (2004) concluded that response times to the ACC failure were related to drivers' locus of control and suggested driver awareness training as a potential preventive strategy that could minimize negative consequences with using novel ADAS. The TRAIN-ALL (European Commission co-funded) project had the objective to develop training schemes and scenarios for computer-based training in the use of new ADAS (Panou et al., 2010). Panou et al. (2010) evaluated various ADAS training simulations so that trainees would learn how to optimally use ADAS without overestimating their functionality and maintain appropriate knowledge of their limitations.

Solution Area (5): Support the role from the dyadic cognitivism paradigm

The internal human mind is the focus of solution area (5). The chapter '*The Human Information-Processer*' of Card et al. (1983) described a model of communication and information processing where sensory information flows into working memory through a perceptual processor, working memory consists of activated chunks in long-term memory, and the most basic principle operation consists of cycles of recognizing and acting (e.g., resulting in commands to a motor processor). In accord with this seminal work, cognitive user-centric interface design theory and practices (e.g., Johnson, 2010) have generally used metaphors and constructs to align content, structure, and functions of computerized systems with content, structure, and functions of human minds: attention (Sternberg, 1969; Posner, 1978), workload (Ogden et al., 1979, Moray, 1982), situation awareness (Endsley, 1995), (mental-spatial) proximity compatibility principle (Wickens & Carswell, 1995), and multiple (modality) resource theory (Wickens, 1980, 1984). Similar mentally focused accounts persist for the topic of sustained attention and monitoring. Parasuraman (1979) concluded that loads placed on attention and memory are what drive decrements in vigilance. See et al. (1995) argued for the addition of a sensory-cognitive distinction to the taxonomy of Parasuraman (1979), where it was emphasized that target stimuli that are (made to be) more cognitively familiar would reduce vigilance decrement consequences. Olson and Wuennenberg (1984) provided information recommendations for user interface design guidelines regarding supervisory control of Unmanned Aerial Vehicles (UAVs) in a list that covered cognitive topics of transparency, information access cost minimisation, projections, predictions, expectations, and end-user understanding of automation. Sheridan et al. (1986) described the importance of mental models in all functions of supervisory control, including aspects for monitoring (e.g., sources of state information, expected results of past actions, and likely causes of failures) and intervening (options and criteria for abort and for task completion). Lastly, the highly cited human trust of automation theory from Lee and See (2004) underscored arriving at *appropriate* trust via cognitive aspects of users' mental models of automation: understandable algorithms, comprehensible intermediate results, purposes aligned to user goals, expectancies of reliability, and user intentions.

The importance of mental process components is shared by SAE Level 2 simulator studies (De Waard et al., 1999; Strand et al., 2014; Beggiato et al., 2015) and theoretical accounts (Beggiato et al., 2015; Li et al., 2012). De Waard et al. (1999) were concerned with reduced driver alertness and attention in the monotonous supervision of automated driving. They found emergency response complacency errors in about half of their participants, and advocated providing feedback warnings pertaining to automation failures (e.g., clear and salient status indicators). Strand et al. (2014) appealed to an account of situation awareness to explain their findings of higher levels of non-response as well as decreased minimum times to collision when simulated driving automation was increased from an ACC to an ACC plus automatic steering system. Beggiato et al. (2015) used both a driving simulator study (post-trial questionnaires and interviews as well as eye gaze behaviour) and an expert focus group to investigate information needs between SAE Levels 0, 2, and 3, where they found the second level to be more exhausting than the other conditions due to the continuous supervision task. Beggiato et al. (2015) concluded that in contrast to manual driving where needs are more oriented around driving-task related information, for partially and highly automated driving requested information is primarily focused on status, transparency, and comprehensibility of the automated system. Li et al. (2012) conducted a survey of recent works on cognitive cars and proposed a staged/levelled alignment of automation functions (e.g., perception enhancement, action suggestion, and function delegation) with driver-oriented processes (stimuli sensation, decision making, and action execution) (cf. Parasuraman et al., 2000; Eriksson et al., in press).

Solution Area (6): Support the role from the triadic ecological paradigm

A broad ecological systems view is represented by solution area (6). This perspective relates vigilance problems to an artificial separation of naturally coupled observation-action-environment ecologies. As an extension to information processing approaches, the chapter '*A Meaning Processing Approach*' of Bennett and Flach (2011) described a semiotics model dating back to work of Charles Peirce (1839-1914) that widens a dyadic human-computer paradigm into a triadic paradigm of human-computer-ecology with functionally adaptive rather than symbolically interpretive behaviour. Flach (2018) observed that minds tend to be situated, in the sense that they adapt to the constraints of situations (like the shape of water within a glass). Gibson (1979) promoted a theory of affordances not as properties of objects but as direct perception of ecological relations and constraints. Particularly in the chapter '*Locomotion and Manipulation*', Gibson (1979) suggested that the dichotomy of the "*mental*" apart from the "*physical*" is an ineffective fallacy. Gibson promotes units of direct perception to be not of things, but of actions with things. Moreover he conveys that such affordances are not available equally in some universal manner, but instead are relatively bounded in a holistic manner. Wickens and Kessel (1979) accounted for a manual control superiority because of a task ecology of continual sensing and correcting of errors together (active adaptation) where additional information (i.e., physical forces) is provided beyond those available from prolonged sensing alone without continual action. Neisser (1978) dismissed accounts of humans as passive serial information processors and instead promoted an indivisible and cyclic account of simultaneous processes. Thus, from such a point of view, vigilance tasks could be considered as problematic because of artificial assumptions and attempts to separate perception and action (i.e., thinking before acting, perceiving without acting, etc.) and to unnaturally isolate a state of knowledge at a singular specific point in time or sensory modality.

Such ecological approaches that emphasize the importance of direct perception and informed considerations of adaptation to specific work domains (tasks and situations) are evident in common across multiple human factors and psychological theories: cognitive systems engineering (Rasmussen et al., 1994), situation awareness design (Endsley et al., 2003), ecological psychology (Vicente and Rasmussen, 1990), situated cognition (Suchman, 1987), embodied minds (Gallagher, 2005), the embedded thesis (Brooks, 1991; O'Regan, 1992), and the extension thesis (Clark & Chalmers, 1998; Wilson, 2004). Flach (1990) promoted the importance of ecological considerations by emphasizing that humans naturally explore environments, and thus models of human control behaviour have been limited by the (frequently impoverished) environments under which they were developed. He relayed that an overly simple laboratory tracking task '*turns humans into a trivial machine*' and that real natural task environments (of motion, parallax, and optic arrays, etc.) are comparatively information rich with relevant '*invariants, constraints, or structure*'. Chiappe et al. (2015) supported a situated approach by observing that '*operators rely on interactions between internal and external representations to maintain their understanding of situations*' in contrast to traditional models that claim '*only if information is stored internally does it count as SA*'. Mosier et al. (2013) provided examples that the presence of traffic may affect the extent to which pilots interact with automation and the level of automation they choose and operational features such as time pressure, weather, and terrain may also change pilots' automation strategies as well as individual variables such as experience or fatigue. They found that vignette descriptions of different situational configurations of automation (clumsy vs. efficient), operator characteristics (professional vs. novice), and task constraints (time pressure, task disruptions) led pilots to different predictions of other pilots' behaviours and ratings of cognitive demands. Hutchins et al. (2013) promoted an integrated software system for capturing context through visualization and analysis of multiple streams of time-coded data, high-definition video, transcripts, paper notes, and eye gaze data in order to break through an '*analysis bottleneck*' regarding situated flight crew automation interaction activity. In an UAV vigilance and threat detection task, Gunn et al. (2005) recommended sensory formats and advanced cuing interfaces and accounted for the reduced workload levels they obtained via a pairing of detections to immediately meaningful consequential actions in a simulated real-world setting (i.e., shooting down a target in a military flight simulation) rather than responses devoid of meaning.

Leveraging external contextual information can be found in several recent driving automation theory and experimental studies. Lee and Seppelt (2009) convey that feedback alone is not sufficient for understanding without proper context, abstraction, and integration. Although technically an SAE Level 1 system, ACC also contains supervisory control aspects (i.e., monitoring of automated longitudinal control), and Stanton & Young (2005) concluded that ACC automation designs should depart from conventions that report only their own status, by offering predictive information that identifies cues in the world and relations of vehicle trajectories. Likewise, Seppelt and Lee (2007) promote and found benefits of an ecological interface design that makes limits and behaviour of ACC visible via emergent displays of continuous information (time headway, time to collision, and range rate) that relates the present vehicle to other vehicles across different dynamically evolving traffic contexts. In terms of an SAE Level 2 simulation, participants in Price et al. (2016) observed automated lateral and longitudinal control where vehicle capability was indicated via physically embodied lateral control algorithms (tighter/looser lane centre adherence) as opposed to via typical visual and auditory warnings. Consequentially, drivers' trust was found to be sensitive to such a situated communication of automation capability. Pijnenburg (2017) improved vigilance and decreased mental demand in simulated supervisory control of SAE Level 2 driving automation via a naturalistic interface that avoided arbitrary and static icon properties in its visual design. A recent theory of driving attention proposed not to assume distraction from the identification of specific activities alone but instead underscored a definition that requires relation in respects to a given situation (Kircher & Ahlstrom, 2017). After conducting several driver monitoring system (DMS) studies, a concluding recommendation from a work package deliverable of a human factors of automated driving consortium project was to '*incorporate situated/contextualized aspects into DSM systems*' (Cabrall et al., 2017).

Literature Survey Aims

In the previous section, a qualitative grouping framework of six solution areas was introduced to identify trends and group proactive approaches towards human engagement while supervising automated processes. The aim of the following literature survey was to investigate whether the proposed solution areas might be represented in best practice recommendations and conclusions of influential and relevant works from a variety of human operator domains. Additionally, we aimed to identify trends between the solution areas: would some be more commonly found than others?; which might be more/less favoured by different domains?

Methods of Literature Survey

Inclusion Criteria

A scholarly research literature survey was conducted concerning the topic of keeping prolonged operator attention. In line with the terminology results of the automotive on-market survey (Table 1), our search terms were crafted to diminish potentially restrictive biases: of preferential terminology (vigilance, situation awareness, signal detection theory, trust, etc.), of operationalisation of performance (response/reaction time, fixations, etc.), of state (arousal, distraction, mental workload, etc.), or of specific techniques/applications (levels of automation, autonomous systems, adaptive automation, etc.). Instead, a more general Google Scholar search was performed with two presumably synonymous terms ‘*engagement*’ and ‘*attention*’:

- *keeping engagement in supervisory control*
- *keeping attention in supervisory control*

The proactive term (i.e., ‘*keeping’*) was included at the front of the queries to attempt to focus the literature survey away from reactive research/applications (e.g., concerning measurement paradigms).

Google Scholar was used to reflect general access to semantically indexed returns from a broad set of resources as sorted for relevancy and influence in an automatic way. Literal search strings within more comprehensive coverage of specific repository resources were not presently pursued because the present survey was aimed initially for breadth and accessibility rather than database depth or prestige. Comparisons to a more traditional human-curated database (i.e., Web of Science) have concluded that Google Scholar has seen substantial expansion since its inception and that the majority of works indexed in Web of Science are available via Google Scholar (De Winter et al., 2014). Across various academic and industry research contexts, not all stakeholders might share equivalent repository reach, whereas Google Scholar is purposefully engendered as a disinterested and more even playing field. For such a democratic topic of driving safety risks while monitoring driving automation (i.e., that have already been released onto public roadways and might pose dangers for everyone in general), organization of accessible guideline knowledge collectible from a broad-based Google Scholar resource seemed an appropriate first place methodological motivation ahead of future studies that might make use of more specific in-depth databases.

The 100 titles and abstracts of the first 50 results per each of the 2 search terms were reviewed to exclude work not pertaining to human-computer/automation research. Furthermore, several relevant and comprehensive review works that were returned in the search (e.g., Sheridan, 1992; Chen et al., 2011; Merat & Lee, 2012; etc.) were not included for categorization on the basis that their coverage was much wider than the present purposes of organizing succinct empirical recommendations. Exclusions were also made for works that appeared to focus more on promoting or explaining supervisory control levels or models of automation rather than concluding design strategies to the problem of operator vigilance while monitoring automated processes. One final text was excluded where raters had trouble applying a solution area on the basis that it dealt with remote human operation of a physical robotic manipulator. The research did not seem to share the same sense of human-automation supervisory control as seen in the other texts. The remaining set of 34 publications are listed in Appendix A by reverse chronological order.

Solution Area Categorizations via Numeric Theme Codes

To investigate the reliability of organizing the body of published literature with the proposed solution areas, confederate researchers (i.e., human factors PhD student (co-)

authors on the present paper) were tasked as raters to independently categorize the conclusions of the retrieved research papers. For the sake of anonymity, the results of the three raters are reported with randomly generated pseudonym initials: AV, TX, and CO. Raters were provided an overview of the solution areas with numeric theme codes (i.e., Theme 1-6) and tasked with assigning a single top choice code for each of the publications of the inclusion set. The task was identified to the raters as "*to assign a provided theme code number to each of the provided publications texts based on what you perceive the best fit would be in regards to the authors' conclusions (e.g., solution, strategy, guideline, recommendation)*". Raters were also instructed to rank order any additional theme codes as needed. A survey rather than a deep reading was encouraged, where the raters were asked to sequentially bias their reading towards prioritized sections and continue via an additional as-needed basis (e.g., abstract, conclusions, discussion, results, methods, introduction, etc.) in order to determine the solution area that the author(s) could conceivably be most in favour of. A frequency weighting-scoring system per each theme code was devised where 1 point would be assigned for first choice responses, 0.5 points for second choice responses, and 0 points otherwise.

Results of Rater Categorizations

Inter-rater Reliability

First and second choice (where applicable) theme codes from each rater for each publication are presented in Appendix B. For first choice theme codes, statistical inter-rater Kappa agreement was computed via the online tool of Lowry (2018) with standard error computed in accordance with the simple estimate of Cohen (1960). The Kappa between AV and TX was 0.25, with a standard error of 0.11. The Kappa between AV and CO was 0.23, with a standard error of 0.11. The Kappa between TX and CO was 0.21, with a standard error of 0.09. Such Kappa statistic results (i.e., in the range of 0.21-0.40) may be interpreted as representing a '*fair'* strength of agreement when benchmarked by the scale of Landis and Koch (1977) which qualitatively ranges across descriptors of '*poor'*, '*slight'*, '*fair'*, '*moderate'*, '*substantial'*, and '*almost perfect*' for outcomes within six different possible quantitative ranges of Kappa values.

Initially suggestive of a low level of percentage agreement, only 6 out of the 34 publications received the same first choice coded theme categorization across all three raters. However, randomization functions were used to generate 3 chance response values (i.e., 1-6) for each of the 34 publications and repeated 100 different times. Thus, it was determined that the chance probability of achieving full way agreement for 6 or more publications was less than 1%. In comparison, random chance full agreement was observed for 0 publications to be 40%, for 1 publication to be 37%, for 2 publications to be 15%, for 3 publications to be 6%, for 4 publications to be 1%, for 5 publications to be 1%, and for 6 or more publications to be < 1%. Simulations with up to 1 million repetitions verified such a range of chance performance across 0 to 6 publications: 38%, 37%, 18%, 5%, 1%, < 1%, 0%.

Furthermore, matched categorizations between any 2 rather than all 3 of the raters was considered. As such, 27 out of the 34 publications received the same first choice coded theme categorization between at least 2 raters. As with the preceding full agreement analyses, random chance probabilities of two-way agreement were also computed from 100 sets of 3 random values for each of the 34 publications. The chance probability of achieving two-way categorization agreement for 27 or more publications was also determined to be less than 1%. In comparison, random chance two-way agreement was observed for between 31-34 publications to be less than 1%, for 26-30 publications to be less than 1%, for 21-25 publications to be 5%, for 16-20 publications to be 42%, for 11-15 publications to be 46%, for 6-10 publications to be 7% and for 5 or fewer publications to be less than 1%. Simulations with up to 50,000 repetitions verified such chance performance across the ranges of 31-34, 26-30, 21-25, 16-20, 11-15, 6-10, and 0-5 respectively as 0%, < 1%, 3%, 41%, 50%, 5%, and < 1%.

Theme Frequency

Weighted frequency scores (i.e., from aggregated first and second choice responses across raters) for each theme code and per each publication are listed in reverse chronological order in Table 2. Theme 5 appears to be the most common solution area, followed closely by 2 and 6. In contrast, Theme 1 appears to be the rarest, followed by Theme 3. While the majority of publications received heavy score weightings distributed across several themes, a highest likelihood single theme was recognizable for 28 of the 34 references (82%), as a result of the first and second choice rater aggregation scoring scheme. Theme 2 of objective reduction of amounts of human supervisory control of automation was found to be the most frequent first choice solution area labelled by 2 out of the 3 raters (i.e., AV and CO), whereas TX most often identified Theme 5 pertaining to support of internal cognitive processes and mental models. Theme 5 was also the most frequent second choice for TX and AV. Theme 6 regarding the use of external contexts and task considerations was the most frequent second choice of CO.

All publications of the included thematic analysis set were informally organized into primary operational domain(s) of concern (i.e., what job or service was the human supervisory control of automation investigated in). Most likely solution areas from weighted raters' first and second choice applied theme codes were determined per publication. Domains and most likely themes are combined in reverse chronological order in Table 3. In general, it can be observed that for the included publications, the domain areas have shifted over the decades from more general laboratory and basic research and power processing plants towards more mobile vehicle/missile applications and most recently especially with remotely operated vehicles. Although of limited sample size, some general domain trends might be observed. For example, it appears that uninhabited aerial vehicle (UAV) operations predominately favoured Theme 2 with also some consideration for Theme 6. In contrast, uninhabited ground vehicle (UGV) operations presently indicated only Theme 4. Earlier work with space, power plants, and general basic research showed a mix mostly of Themes 5 and 6. Aviation areas with pilots and air traffic control had a split of Themes 4 and 5. Missile air defence consisted of Theme 4 and Theme 2. Lastly, two automobile studies were present in the returned results: the first involving a fairly abstracted driving decision task (with a resulting likely categorization of Theme 2), and the second evidencing a split categorical rating assignment between Theme 2 and Theme 5.

Discussion

Evolution of Cross Domain Concern

With a proliferation of automation also comes an increase in human supervision of automation (Sheridan,1992) because automation does not simply replace but changes human activity. Such changes often evolve in ways unintended or unanticipated by automation designers and have been predominately regarded in a negative sense as in ‘*misuse*’, ‘*disuse*’, and ‘*abuse*’ (Parasuraman & Riley, 1997) and/or as ‘*ironies*’ (Bainbridge, 1983). Whether or not significant human supervisory problems will manifest in a proliferation commiserate with automation propagation is likely to be a function of the automation’s reliability in the handling of the problems inherent in its’ domain area. Human supervisors of automation are needed not only because a component might fail (e.g., electrical glitch) but also because the situation might exceed the automatic programming. Originally, computers and their programs were physically much larger and constrained to determinable locations within predictable and enclosed environments. As computers have become physically smaller their automated applications could be more practically incorporated into vehicles. Vehicles, however literally move across time and space and hence are subject to many environmental variants. Advances in supervisory control automation have been originally appropriate and suitable to vast expanse domains (outer space, the oceans, the sky) because they are difficult for humans to safely and commonly inhabit. Thus, such domains typically suffer from impoverished infrastructures and are subject to signal transmission latencies where automation must close some loops itself. Such automatic closures are benefited further by the absence of masses of people because compared to machines, people create a lot of noise and uncertainty with many different kinds of unpredictable and/or imprecise behaviours.

Likewise, driving automation was first showcased on highly structured freeways (Ellingwood, 1996), out in the desert and within a staged urban environment on a closed air force base (DARPA, 2014) before progressing towards more open operational design domains. Subsequently, driving automation market penetration has tended to begin first within more closed campus sites and scenarios with lower levels of uncertainty (e.g., interstate expressways) before proceeding into other contexts of increasing uncertainty and/or complexity (e.g., state highways, rural roads, and urban areas). Thus, while the present search terms for keeping attention/engagement in supervisory control returned only two studies in the automotive area, more might be expected in the future to the extent that 1) automated vehicles continue to need human supervisors (e.g., how structured and predictable vs. messy and uncertain are the areas in which they drive) and 2) how much attention/engagement of human supervisors of automated driving might be expected to wane or waver.

Convergence and Contribution

When restricted to a single choice, seemingly few applied theme codes were found to be in common agreement across all three independent raters. However, non-chance agreement was still obtained both in terms of standard inter-rater reliability Kappa statistics and percentage agreement analyses. Furthermore, thematic categorization agreement was enhanced by the allowance of rater second choices, which seems plausible, as empirical research conclusions can of course be of compounding nature. For example, Stanton et al. (2001) address the design of future ADAS by advocating for future research that ‘*could take any of the following forms: not to automate, not to automate until technology becomes more intelligent, to pursue dynamic allocation of* *function, to use technology to monitor and advise rather than replace, to use technology to assist and provide additional feedback rather than replace, to automate wherever possible*'. Saffarian et al. (2012) proposed several design solution areas for automated driving: shared control, adaptive automation, improved information/feedback, and new training methods. Specifically for the topic of SAE Level 2 'partially automated driving', Casner et al. (2016) lament their expectations for vigilance problems in their conclusions that '*Today, we have accidents that result when drivers are caught unaware. Tomorrow, we will have accidents that result when drivers are caught even more unaware'*. Furthermore, they anticipate dramatic safety enhancements are possible when automated systems share the control loop (such as in backup systems like brake-assist and lane-keeping assistance) or adaptively take it as needed from degraded driver states (i.e., distraction, anger, intoxication). Casner et al. (2016) also conclude that designers of driver interfaces will not only have to make automated processes more transparent, simple, and clear, they might also periodically involve the driver with manual control to keep up their skills, wakefulness, and/or attentiveness. Lastly, Seppelt and Victor (2016) suggest new designs (better feedback and environment attention-orienting cues) as well as '*shared driving wherein the driver understands his/her role to be responsible and in control for driving*' and/or fully responsible driving automation that operates without any expectation that the human driver will serve as a fall-back.

The proposed solution areas overlap with many of the compounded review conclusions above from Stanton et al. (2001), Saffarian et al. (2012), Casner et al. (2016), and Seppelt and Victor (2016). From the present literature survey, what is added is a grouping framework that might more fully encapsulate the conclusions of empirical results from both the broad body of human factors, ergonomics, and learning theory as well as human driving automation interaction research. Furthermore, the solution areas were purposefully organized in a hopefully digestible and memorable way. The first three themes describe avoidance either in a hard sense or different versions of a soft stance: objective or subjective reductions. The latter three themes describe solutions under familiar learning theory paradigms in chronological order: behaviourism, cognitivism, and ecological constructivism.

Identifying a 'best' or 'preferred' theme of proactive strategy is not expected to be a discretely resolvable answer. Instead, the relative advantages and disadvantages should probably best be reflected upon in light of contextual considerations. Furthermore, due to their qualitative nature, the themes are not directly orthogonal from one another. Themes 2 and 3 could be conceived of as softer avoidance versions of a stricter skip-over stance of Theme 1. Theme 6 can be seen to expand from Theme 5 not as an opposing contrast but as an elevating extension that can still subsume cognitive and human-centred concepts. Themes 5, 2, and 6 were the top three most common solution areas found in the present survey.

Solution Area (1): Avoid the role of human supervision of automation

For Theme 1, it might be easier to hold close to a viewpoint of avoiding supervisory control of automation in theoretical or laboratory-oriented research. A sizeable body of human factors and ergonomics science literature supports such a standpoint that human bias and error is not necessarily removed via the introduction of automation, but instead, humans can generally be shown to be poor monitors of automation. However, industry examples also exist of both traditional and start-up automotive manufacturers (i.e., Ford and Waymo) opting to skip mid-level driving automation where a human is required to continuously supervise the processes (Ayre, 2017; Szymkowski, 2017). The low coverage of this theme in the present survey (see Table 2) is probably more an artefact of the present survey rather than evidence of its unimportance or non-viability—more discussion is provided in a separate limitations section.

Solution Area (2): Reduce the role along an objective dimension

Regarding Theme 2, temporal restrictions based upon scheduled durations of automation use might be a practical starting place to initially implement mechanisms to reduce the objective amount of human supervision of driving automation. For combatting fatigue associated with conventional driving control during long trips, many modern day vehicles come equipped with timing safety features. Such rest reminders function by counting the elapsed time and/or distance of a single extended trip (e.g., hours of continuous operation since ignition on) and consequently warn/alert the driver for the sake of seeking a break or rest period. Because time on task has been traditionally identified as a major contributing factor to vigilance problems (Mackworth, 1948; Teichner, 1974; Greenlee et al., 2018), time-based break warnings and/or restrictions as with general driving fatigue countermeasures, might be practically worthwhile to apply on scales specific for human supervisory monitoring of SAE Level 2 driving automation. Compared to other contributing components to vigilance decrements (cf. Cabrall et al., 2016), the duration of watch period is expected to be an attractive dimension for human-automation interaction system designers due to its intuitive and simplistic operationalization even in spite of its potential to interact with other vigilance factors.

Solution Area (3): Reduce the role along a subjective dimension

Theme 3 of altering the perception towards increased danger or uncertainty and thus necessitating greater care from end-users could be problematic for automotive manufacturers that would reasonably expect to maintain positive rather than negative attributions of their products and services. However, an altered experience might carefully be crafted to direct attribution of uncertainty away from the vehicle and towards aspects of the environment or others (see Norman, 2007, pp. 83-84). For example, advanced driving automation of SAE Level 2 (simultaneous lateral and longitudinal control) might operate on an implicit level to support a driver who believes that he/she alone has control authority/responsibility (e.g., in line with how previous lower level driver assistance systems such as electronic stability control have been successfully deployed in the background). Discussion of its relatively low amount of coverage in the present survey (see Table 2) is provided in a separate limitations section.

Solution Area (4): Support the role from the behaviourism paradigm

Theme 4 is perhaps the most widely known in the general population and especially that behaviouristic aspect of manipulating or shaping behaviour through rewards and punishments. Caution, however, is warranted, as effects have been previously shown to be limited in lasting power and reach. For example, Parasuraman & Giambra (1991) found that while training and experience can help to reduce vigilance decrements, its benefits were not as observable in older populations: practice alone is insufficient to eliminate age differences. Notably, elderly populations are commonly regarded as primary users and beneficiaries of automated/autonomous ADAS (cf. Hawkins 2018). Furthermore, the practical viability of Theme 4 should be noted with consideration of the fact that a large proportion of the vigilance decrement phenomena exhibited in historic experiments was undertaken by young, highly trained, and motivated operators. By comparison, the present literature survey was concerned with uncovering proactive knowledge further generalizable and applicable to laypeople who might not be used to or amenable to rigours of professional training when it comes to driving (e.g., recurrent training, reading of documentation, attention to help resource media/material, etc.).

Solution Area (5): Support the role from the dyadic cognitivism paradigm

Theme 5 cognitive science approaches have become prominent and favoured over the last few generations. Established human-automation research guideline approaches are on the rise (i.e., information processing models, awareness/attention, user/human centred design, etc.) alongside the popular success of companies like Google that promote their top maxim as '*Focus on the user and all else will follow*' (Google, 2018). With the launch of a subsidiary company called "*Ford Autonomous Vehicles LLC*", the Ford Motor Company is self-reportedly embedding a deeper product-line focus where '*the effort is anchored on human-centered design'* (Ford, 2018).

Solution Area (6): Support the role from the triadic ecological paradigm

Theme 6 pertaining to leveraging and augmenting information in the environment and task itself (e.g., situated, ecological, extended cognition, etc.) is expected to gain traction commensurate with technological progress of increased access to ambient data that might have been previously too cost-prohibitive in previous decades. For example, more recent times have seen an acceleration of accessibility from the miniaturization of recording equipment and availability of ubiquitous sensing and computing power. As automation applications continue to grow into new operational areas and expand beyond closed control system process considerations (especially as with vehicles which by definition move from one place to another), recognition of environmental and task dependencies are also expected to grow.

Limitations

The presently proposed framework to group answers to the potential problems of degraded driver engagement while monitoring driving automation were not derived from a formal and systematic procedure. Instead, the themes were construed in an abductive reasoning manner while trying to organize and relate timely operational concerns (monitoring responsibilities in SAE Level 2 driving automation) with both established and more recently emergent research literature. Assimilation of these solution areas was desirable, considering the long-standing history of general vigilance issues of prolonged human supervisory attention over any automated processes. However, such a framework cannot claim to be the only one conceivable, and the identified themes could be argued to reflect only idiosyncratic knowledge, reasoning, and partial/imperfect readings of a more full body of literature. For example, Themes 1 and 3 were scarcely used categorizations by any of the raters within the present literature survey. Besides clear challenges presented by such a small sample size of only 34 publications, other explanations are also available as to the absence of Themes 1 and

3 among the rater responses. As foreshadowed first by Billings (1991) and repeated by Endsley and Kiris (1995), the rapid release and continual roll-out of automation (then for aviation, now for automotive applications) might obviate a so-called '*too academic*' position of strict avoidance (i.e., Theme 1). Thus, it is conceivable how an approach area as Theme 1 might be under-represented in the literature as being both either too obvious and/or too obsolete. For example, the proactive literature search terms (e.g. of keeping engagement/attention in supervisory control) might reasonably not be expected to return publications that are predominately oriented towards the first solution area of avoiding the supervisory role. In contrast, Theme 3 might be too abstract or unusual (or even arguably unethical as a feature of deception) to be directly arrived at and associated with the terms of '*supervisory control*'. While shared control and backup automation are far from being alien concepts, the logical complement of changing a subjective experience with automation (Theme 3) to that of changing an objective amount of automation (Theme 2) might be for some too unfamiliar as a grouping umbrella perspective. Furthermore, because humans are still humans whether supervising automated processes or performing other kinds of vigilance and/or sustained attention work, it should be noted that, although presently left out of scope, many of the other literature search returns regarding proactive solutions to human attention/engagement in supervisory or monitoring control/work might be expected to transfer interesting lessons learned even if from non-operator domains: educational classrooms, business offices, creative work, medical hospitals, geriatric care, etc.

Conclusions

A wealth of literature suggests categorical approaches to proactive strategies for addressing potential degradation of driver monitoring performance in human supervisory control of driving automation. A qualitative framework of six themes to group solutions have been presently proposed in order to answer a research question of '*how do we keep people engaged while supervising (driving) automation*'. These themes were motivated from human factors and psychological learning theory literature and found to be recognizably applied by raters to categorize empirically grounded human automation interaction research recommendations. The present themes were devised as short-hand formulations that might be easy to remember. Such abstracted organization frameworks are expected to be useful in order to more easily draw comparisons both within and across domains. For example, as a sort of lay of the land overview, the solution areas might serve like a map for automation research/design practitioners to locate where their present approaches (i.e., to human vigilance in supervising driving automation) currently reside and what other alternative areas might be interesting to explore. Additionally, underlying concepts can also thus be more easily entertained to provide common groundwork benefits across seemingly disparate themes.

General Lessons Learned

The body of literature has much to say regarding supervisory control of automation. We encourage readers towards broader review work in general (Sheridan, 1992), for unmanned robot-vehicle systems (Chen et al., 2011), and for evolving driving roles specifically (Merat & Lee, 2012). Across these review works (and across the six presently identified themes), a consensus benefit would appear to be meta-information requirements to combat uncertainty regarding human involvement in supervising automation (e.g., information about control utility, situated automation capability, performance predictions, etc.). Specific findings from these publications are highlighted below to substantiate this position.

Sheridan (1992) provides a definitive reference for supervisory control that brings together a variety of theories and technologies across decades of his experimental research within the area. In his concluding chapter, he warns of alienation of operators from their work/responsibilities as an underlying cause and concern to be combatted through designs that allow an operator to retain her/her sense of responsibility and accountability. He considers the future of supervisory control in relation to the task entropy (i.e., the complexity or unpredictability of task situations to be dealt with). He offers a way forward through an assumption that humans know best when the automation should apply based on how readily the required information can be modelled.

> ‘*The human decision maker is necessary for the information that is not explicitly modelable … Some, perhaps most, decision situations the human operator will encounter require only information that is modelable. She will make mistakes in such decisions, and can benefit from a decision aid for these cases, and in such cases the decision aid can be validated … Assume the human can properly decide when the situation includes elements the decision aid can properly assess, and for which elements the decision aid should be ignored*’ (p. 359).

Chen et al. (2011) cover a multitude of related research concerning human performance issues (e.g., multitasking performance, trust in automation, situation awareness, and operator workload) and innovative technologies designed to reduce potential performance degradations surrounding human supervisory control of automated robot-vehicles. They review interface/tool design developments of multimodal display/controls, planning, visualization, attention management, trust calibration, adaptive automation, and intelligent agent and human-robot teaming. Chen et al. (2011) relay sub-roles within supervisory tasks from Sheridan (2002) that append aspects of planning and learning to bookend monitoring and intervening. Such surrounding aspects of gaining experience with when/where to moderate attention strategies in the application of supervisory control echoes those discussed above by Sheridan (1992).

Complicating interactive challenges reviewed by Chen et al. (2011) include inaccuracies in meta-knowledge that contribute to issues of both automation disuse and over-reliance. On the one hand, humans commonly overestimate the cognitive/perceptual abilities of themselves and others (e.g., metacognitive errors such as change blindness blindness, verbal and visual hindsight bias, self-confirmation bias, cognitive dissonance, etc.) which inflate their sense of necessity for human involvement. On the other hand, to the extent that operators anthropomorphize hardware/software into human-like teammates could then likewise exacerbate expectations of capability, encourage complacency and produce over-reliance on automated processes. At the heart of the issue is the concept of trust calibration (i.e., during a supervisory control task, operators intervene only when they have reason to believe their own decisions are superior to the automation system’s decisions). Within their review of calibrating human trust of automation, Chen et al. (2011) suggest that the capabilities and limitations of the automation should be conveyed to the operator whenever feasible because previous research has shown that awareness of context-related nature of automation reliability has significantly increased a rate of correct human detection of automation failures.

Beyond aspects of proneness towards false alarms or misses, they suggest additional dimensions of trust: utility, predictability, and intent.

Merat and Lee (2012) include a review of driver automation interaction research to guide future designs. Their results include identification of two general design philosophies for automation: substitution vs. support. They conclude that assumptions towards substitution are not seamlessly simple to meet and instead argue that successful designs will depend on recognizing and supporting the new roles for drivers. Merat and Lee (2012) provide scenario-based warnings both of conflicting timescales: '*Automation may require drivers to intervene on a scale of milliseconds, but reentering the control loop may take seconds*' (p. 683), as well as of ironies of automation that '*…can accommodate the least demanding driving situations—encouraging drivers to disengage from driving—but then calls on the driver to address the most difficult situations … Periods when drivers are most likely to fully rely on automation—highway driving—also require the most rapid re-entry of drivers into the control loop.*' (p. 683-684). In consideration of such scenarios, it becomes apparent that interactive meta-information (of humans, vehicles/automation, and the driving task environments) would be essential for forming expectations of how well drivers will perform their monitoring duties.

In summary, a general lesson for common benefit to all solution areas would appear to be further characterizations of driving situations towards understanding which are more complex from those that are more routine (i.e., for both humans and for machines). Such kind of information would support designers and end-user expectations in meta-supervisory mental model knowledge of when/where the automation they are tasked with supervising might better/worse perform and why (and likewise for the monitoring performance/requirements of the human supervisor). To the extent that the driving is able to be handled entirely within perfectly formulated sets of rules and logic, then automated processes should excel and consequences for human oversight would reasonably be diminished. On the other hand, to the extent that driving involves complex socio-cultural norms and violations that are not mathematically well-described and highly interactive with un-modelled context dependencies, then human engagement in monitoring becomes more crucial. For example, as relayed by Merat and Lee (2012): '*Even now, the role of the person behind the wheel is often not that of a driver but that of an office worker on a conference call, a mother caring for a child, or a teen connecting with friends* (Hancock, 2017b)'. As more mutually informed tests are conducted of SAE Level 2 driving automation, between laboratory and on-road research and development, such experiences should serve to provide clearer details, specifics, and evidence in place of assumptions. Positive progress towards specific details relevant for human monitoring of driving automation can be recognized from the California Department of Motor Vehicles. The CA DMV has begun to publically share documentation of annual collision and disengagement reports from autonomous vehicle (test) operations within its jurisdiction (California DMV, 2018) — 95 collision reports are available between 2015-2018, and 2308 disengagements for the 2017 reporting period. More than just a requirement to enumerate problems, the disengagement documentation also begins an attempt to standardize a communication of circumstances (e.g., who initiated the disengagement, on what kind of road, with a description of facts causing the disengagement). Future research might make use of such details to further inform targeted studies surrounding the topic of human attention in supervision of driving automation. As more information becomes available, such information can be used in line with the first three of our presently identified solution area themes to avoid (1) and/or reduce (2-3) the operational design domains of partial automation that requires human supervision, or by the last three solution area themes to support its operations via e.g., enhanced training (4), feedback and mental models (5), and/or task environment relations (6).

References

Note: References marked with a hash # indicate publications included in the present literature survey categorization analysis.

#Ackerman, W., & Block, W. (1992). Understanding supervisory systems. *Computer Applications in Power*, 5(4), pp. 37-40.

Ayre, J. (2017). Ford: Skip level 3 autonomous cars – Even engineers supervising self-driving vehicle testing lose "Situational Awareness". *Clean Technica*. Available at: https://cleantechnica.com/2017/02/20/ford-skip-level-3-autonomous-cars-even-engineers-supervising-self-driving-vehicle-testing-lose-situational-awareness/

Bainbridge, L. (1983). Ironies of automation. *Automatica*, 19(6), 775–779. http://dx.doi.org/10.1016/0005-1098(83)90046-8.

Banks, V.A., Eriksson, A., O'Donoghue, J., & Stanton, N.A. (2018). Is partially automated driving a bad idea? Observations from an on-road study. *Applied Ergonomics*, 68, pp. 138-145.

#Banks, V.A., & Stanton, N.A. (2016). Keep the driver in control: Automating automobiles of the future. *Ergonomics*, 53, pp. 389-385.

Banks, V.A., Stanton, N.A., & Harvey, C. (2014). Sub-systems on the road to vehicle automation: Hands and feet free but not 'mind' free driving. *Safety Science*, 62, pp. 505-514.

Beggiato, M., Hartwich, F., Schleinitz, K., Krems, J.F., Othersen, I., & Petermann-Stock, I. (2015). What would drivers like to know during automated driving? Information needs at different levels of automation. *7th conference on driver assistance*. Munich, Germany.

Bennett, K.B., & Flach, J.M. (2011). *Display and interface design: Subtle science, exact art*. CRC Press, Taylor & Francis Group. Boca Raton, FL, USA.

Billings, C.E. (1991). Human-centered aircraft automation; A concept and guidelines (NASA Tech. Memorandum 103885). Moffet Field, CA: NASA Ames Research Center.

Black Tesla (2016). Tesla v8.0 Autopilot – Warning Interval & Autosteer Unavailable. Available at: https://www.youtube.com/watch?v=isZ3fSbE_pg

#Blasch, E.P., & Plano, S. (2002). JDL level 5 fusion model 'user refinement' issues and applications in group tracking. *Signal Processing, Sensor Fusion, and Target Recognition XI*, pp. 270-290.

BMW (2017). 7 series, 750i xDrive Owner's Manual. Steering and lane control assistant. Available at: https://www.bmwusa.com/owners-manuals.html

#Breda, L.V. (2012). Supervisory control of multiple uninhabited systems: Methodologies and enabling human-robot interface technologies. NATO Research and Technology Organization. Technical Report. Neuilly-Sur-Seine, France.

Broadbent, D.E., & Gregory, M. (1965). Effects of noise and signal rate upon vigilance analysed by means of decision theory. *Human Factors*, 7(2), pp. 155-162.

Brooks, R. (1991). Intelligence without representation. *Artificial Intelligence*, 47, pp. 139-159.

Cabrall, C.D.D., Goncalves, J., Morando, A., Sassman, M., de Winter, J.C.F., & Happee, R. (2017). HFAuto D3.1 Driver-state monitor. Human Factors of Automated Driving, Initial Training Networks, FP7-PEOPLE-2013-ITN, Grant agreement no.: 605817

Cabrall, C.D.D., Happee, R., & de Winter, J.C.F. (2016). From Mackworth's clock to the open road: A literature review on driver vigilance task operationalization, *Transportation Research Part F: Traffic Psychology and Behaviour*, 40, 169-189.

California DMV (2018). Testing of Autonomous Vehicles with a Driver. State of California Department of Motor Vehicles, Vehicle Registration. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing

Card, S.K., Moran, T.P., & Newell, A. (1983). *The psychology of human-computer interaction*. Lawrence Erlbaum Associates. Hillsdale, New Jersey.

Casner, S.M., Hutchins, E.L., & Norman, D. (2016). The challenges of partially automated driving. *Communications of the Association for Computing Machinery (ACM)* , 59(5), pp. 70-77

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

#Chen, J.Y.C., & Barnes, M.J. (2012). Supervisory control of multiple robots in dynamic tasking environments. *Ergonomics*, 55, pp. 1043-1058.

Chen, J.Y.C., Barnes, M.J., & Harper-Sciarini, M. (2011). Supervisory control of multiple robots: Human-performance issues and user-interface designs. *IEEE Transactions on Sysmtes, Man, and Cybernetics- Part C: Applications and reviews.*, 41(4), pp. 435-454

Chiappe, D., Strybel, T.Z., & Vu, K.L. (2015). A situated approach to the understanding of dynamic systems. *Journal of Cognitive Engineering and Decision Making*, 9(1), pp. 33-43.

Clark, A., & Chalmers, D. (1998). The extended mind. *Analysis*, 58, pp. 10-23.

#Clauss, S., & Schulte, A. (2014). Implications for operator interactions in an agent supervisory control relationship. *International Conference on Unmanned Aircraft Systems (ICUAS)*. Orlando, FL, USA.

Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement*, 20, pp. 213-220.

Craig, A. (1984). Human engineering: The control of vigilance. In J. Warm (Ed.), *Sustained attention in human performance* (pp. 247–291). Chichester, UK:Wiley.

#Cummings, M.L., Bruni, S., Mercier, S., & Mitchell, P.J. (2007). Automation architecture for single operator-multiple UAV command and control. *International Command and Control Journal*, 1(2), pp. 1-24.

#Cummings, M.L., & Guerlain, S. (2007). Developing operator capacity estimates for supervisory control of autonomous vehicles. *Human Factors*, 49(1), pp. 1-15.

#Cummings, M.L., Mastracchio, C., Thornburg, K., & Mkrtchyan, A. (2013). Boredom and distraction in multiple unmanned vehicle supervisory control. *Interacting with Computers*, 25(1), pp. 34-47.

#Cummings, M.L., & Mitchell, P.J. (2007). Operator scheduling strategies in supervisory control of multiple UAVs. *Aerospace Science and Technology*, 11(4), pp. 339-348.

#Cummings, M.L., & Nehme, C.E. (2010). Modeling the impact of workload in network centric supervisory control settings. In S. Kornguth, R. Steinberg, & M.D. Matthews (Eds.) *Neurocognitive and physiological factors during high-tempo operations*. Ashgate. Surrey, UK. pp. 23-40.

DARPA (2014). The DARPA Grand Challenge: Ten Years Later. Defense Advanced Research Projects Agency, News and Events. Available at: https://www.darpa.mil/news-events/2014-03-13

De Waard, D., Van der Hulst, M., Hoedemaeker, M., & Brookhuis, K.A. (1999). Driver behavior in an emergency situation in the automated highway system. *Transportation Human Factors*, 1(1), pp. 67-82.

De Winter, J.C.F., & Dodou, D. (2011). Why the Fitts list has persisted throughout the history of function allocation. *Cognition, Technology and Work*, 16(1), pp. 1-11.

Diewald, S., Moller, A., Roalter, L., Stockinger, T., & Kranz, M. (2013). Gameful design in the automotive domain – Review, outlook, and challenges. *Proceedings of the 5th International Conference on Automotive UI*, Oct. 28-30, Eindhoven, The Netherlands.

Ellingwood, K. (1996). Project begins to test ‘driver-less’ freeway system. Los Angeles Times. Available at: http://articles.latimes.com/1996-06-28/news/mn-19436_1_highway-system

Elliot, M.A., McColl, V.A., & Kennedy, J.V. (2003) Road design measures to reduce drivers’ speed via “psychological” processes: A literature review. (No. TRL Report TRL564). Crowthorne, UK: TRL Limited.

Endsley, M.R. (1995). Toward a theory of situational awareness in dynamic systems. *Human Factors*, 37(1), pp. 32-64.

#Endsley, M.R., & Kiris, E.O. (1995) The out-of-the-loop performance problem and level of control in automation. *Human Factors*, 37 (2), pp. 381-394.

Endsley, M.R., Bolte, B., & Jone, D.G. (2003). *Designing for situation awareness: An Approach to User-Centered Design*. CRC, Taylor & Francis Group. Boca Raton, FL, USA.

*Eriksson, A., *Petermeijer, S.M., Zimmerman, M., De Winter, J.C.F, Bengler, K.J., & Stanton, N. (in press). Rolling out the red (and green) carpet: Supporting driver decision making in automation to manual transitions. *IEEE Transactions on Human-Machine Systems*. THMS-17-02-0061. *- Joint first author

Fitts PM (ed) (1951) Human engineering for an effective air navigation and traffic control system. National Research Council, Washington, DC.

Flach, J.M. (1990). Control with an eye for perception: Precursors to an active psychophysics. *Ecological psychology*, 2(2), pp. 83-111.

Flach, J.M. (2018). Situated cognition. Professional communication via LinkedIn posting, June 2018. Available at: https://www.linkedin.com/feed/update/urn:li:activity:6413792059702022144

Flemisch, F., Abbink, D., Itoh, M., Pacaux-Lemoine, M-P., & Wessel, G. (2016). Shared control is the sharp end of cooperation: Towards a common framework of joint action, shared control and human machine cooperation. *International Federation of Automatic Control (IFAC) PapersOnLine*, 49(19), pp. 72-77.

Ford (2018). Ford creates ‘Ford Autonomous Vehicles LLC’: Strengthens global organization to accelerate progress, improve fitness. Ford Media Center. Available at: https://media.ford.com/content/fordmedia/fna/us/en/news/2018/07/24/ford-creates-ford-autonomous-vehicles-llc.html

Frankmann, J., & Adams, J. (1962). Theories of vigilance. *Psychological Bulletin*, 59(4), 257–272. http://dx.doi.org/10.1037/h0046142.

Gallagher, S. (2005). *How the body shapes the mind*. Oxford University Press. Oxford.

Gao, P., Hensley, R., & Zielke, A. (2014). A roadmap to the future for the auto industry. McKinsey Quarterly, October.

#Gaushell, D.J., & Darlington, H.T. (1987). Supervisory control and data acquisition. *Proceedings of the IEEE*, 75(12), pp. 1645-1658

#Gersh, J.R., & Hamill, B.W. (1992). Cognitive engineering of rule-based supervisory control systems: Effects of concurrent automation. *Proceedings of the IEEE Conference on Systems, Man, and Cybernetics*. Chicago, IL, USA. pp. 1208-1213.

Gibson, J.J. (1979). *The ecological approach to visual perception*. Houghton Mifflin. Boston, MA, USA.

Google (2018). Ten things we know to be true. Available at: https://www.google.com/about/philosophy.html

Gopher, D. (1991). The skill of attention control: Acquisition and execution of attention strategies. In D. Meyer and S. Kornblum (Eds.), *Attention and Performance XIV*, Hillsdale NJ: Erlbaum.

Greenlee, E.T., DeLucia, P.R., & Newton, D.C. (2018). Driver vigilance in automated vehicles: Hazard detection failures are a matter of time. *Human Factors*, 60(4), p. 465-476.

Groh, F. (2012). Gamification: State of the art definition and utilization. *Proceedings of the 4th Seminar on Research Trends in Media Informatics*, Ulm University, Germany, pp. 39-46.

Gunn, D.V., Warm, J.S., Nelson, W.T., Bolia, R.S., Schumsky, D.A., & Corcoran, K.J. (2005). Target acquisition with UAVs: Vigilance displays and advanced cuing interfaces. *Human Factors*, 47(3), pp. 488-497.

Hancock, P.A. (2017a). On the nature of vigilance. *Human Factors*, 59(1), pp. 35-43.

Hancock, P.A. (2017b). Driven to distraction and back again. In M.A. Regan, J.D. Lee, & T.W. Victor (Eds.). Driver Distraction and Inattention: Advances in Research and Countermeasures. Surrey, UK: Ashgate.

#Hart, C.S. (2010). Assessing the impact of low workload in supervisory control of networked unmanned vehicles. Master's Thesis, The Massachusetts Institute of Technology. Available at: http://web.mit.edu/aeroastro/labs/halab/papers/Hart-Thesis-2010.pdf

Hawkins, A.J. (2018). Senior citizens will lead the self-driving revolution. The Verge: Transportation, Autonomous Cars. Available at: https://www.theverge.com/2018/1/10/16874410/voyage-self-driving-cars-villages-florida-retirement-communities

Hawley, J.K., Mares, A.L., Giammanco, C.A. (2005). The human side of automation: Lessons for air defense command and control. Army Research Laboratory, Report No. ARL-TR-3468.

#Hawley, J.K., Mares, A.L., Giammanco, C.A. (2006). Training for effective human supervisory control of air and missile defense systems. Army Research Laboratory, Report No. ARL-TR-3765.

#Hoc, J.M. (2000). From human-machine interaction to human-machine cooperation. *Ergonomics*, 43, pp. 833-843.

Hutchins, E., Weibel, N., Emmenegger, C., Fouse, A., & Holder, B. (2013). An integrative approach to understanding flight crew activity. *Journal of Cognitive Engineering and Decision Making*, 7(4), pp. 353-376.

Janssen, N.M. (2016). Adaptive automation: Automatically (dis)engaging automation during visually distracted driving. Master's Thesis. Retrieved from TU Delft repository: http://resolver.tudelft.nl/uuid:dd4cbcc5-f99e-4986-9f82-ab15c621ddc5

Johnson, J. (2010). *Designing with the mind in mind: Simple guide to understanding user interface design rules*. Morgan Kauffmann Publishers, Elsevier. Burlington, MA, USA.

#Johnson, R., Leen, M., & Goldberg, D. (2007). Testing adaptive levels of automation (ALOA) for UAV supervisory control (AFRL-HE-WP-TR-2007-00682). Wright-Patterson Air Force Base, OH: Air Force Research Laboratory.

Kircher, K., & Ahlstrom, C. (2017). Minimum Required Attention: A human-centered approach to driver inattention. *Human Factors*, 59(3), pp. 471-484.

Kyriakidis, M., van de Weijer, C., van Arem, B., & Happee, R. (2015). The deployment of advanced driver assistance systems in Europe. *22nd Intelligent Transportation Systems World Congress*. Bordeaux, France.

Landis, J.R., & Koch, G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33, pp. 159-174.

Lee, J.D., & See, K.A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, 46(1), pp. 50-80.

Lee, J.D., & Seppelt, B.D. (2009). Human factors in automation design. In S.Y. Nof (Ed.) *Handbook of Automation*. Springer. Berlin, Heidelberg. pp. 417-436.

Li, L., Wen, D., Zheng, N-N., & Shen, L-C. (2012). Cognitive cars: A new frontier for ADAS research. *IEEE Transactions on Intelligent Transportation Systems*, 13(1), pp. 395-407.

#Lockhart, J.M., Strub, M.H., Hawley, J.K., & Tapia, L.A. (1993). Automation and supervisory control: A perspective on human performance, training, and performance aiding. *Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society*. Seattle, WA, USA.

Lowry, R. (2018). Kappa as a measure of concordance in categorical sorting. VassarStats: Website for Statistical Computation. Available at: http://vassarstats.net/kappa.html

Lutteken, N., Zimmermann, M., & Bengler, K. (2016). Using gamification to motivate human cooperation in a lane-change scenario. *IEEE 19th International Conference on Intelligent Transportation Systems (ITSC)*, Rio de Janeiro, Brazil, Nov 1-4.

#Manly, T., Robertson, I.H., Galloway, M., & Hawkins, K. (1999). The absent mind:

Further investigations of sustained attention to response. *Neuropsychologia*, 37, pp. 661-670.

Mackworth, N.H. (1948) The breakdown of vigilance during prolonged visual search. *Quarterly Journal of Experimental Psychology*, 1(1), 6-21, DOI: 10.1080/17470214808416738.

Mackworth, N.H. (1950). Researches on the measurement of human performance. Medical Research Council Special Report Series No. 268. London, UK: HMSO.

Merat, N., Jamson, A.H., Lai, F.C.H., Daly, M., & Carsten, O.M.J. (2014). Transition to manual: Driver behaviour when resuming control from a highly automated vehicle. *Transportation Research Part F*, 27, pp. 274-282.

Merat, N., & Lee, J.D. (2012). Preface to the special section on human factors and automation in vehicles: Designing highly automated vehicles with the driver in mind. *Human Factors, 54(5),* pp. 681-686.

MercBenzKing (2016). 2017 Mercedes S Class Head up display Drive Pilot Nightvision assist Distronic Plus Lane Keeping. YouTube demonstration video. Available at: https://www.youtube.com/watch?v=RjvI57BIDp0

Mercedes-Benz (2017). S-Class Operator's Manual. Part no. 2225849405. Available at: https://www.mbusa.com/mercedes/service_and_parts/owners_manuals#!year=2017&class=S-Sedan

#Miller, C., & Parsuraman, R. (2007). Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control. *Human Factors*, 49(1), pp. 57-75.

Molloy, R. & Parasuraman, R. (1996). Monitoring an automated system for a single failure: Vigilance and task complexity effects. *Human Factors*, 38(2), p. 311-322.

Moray, N. (1982). Subjective mental workload. *Human Factors*, 24(1), pp. 25-40.

Mosier, K.L., Fischer, U., Morrow, D., Feigh, K.M., Durso, F.T., Sullivan, K., & Pop, V. (2013). Automation, task, and context features: Impacts on pilots' judgments of human-automation interaction. *Journal of Cognitive Engineering and Decision Making*, 7(4), pp. 377-399.

Mulder, M., Abbink, D., & Boer, E. (2012). Sharing control with haptics: Seamless drive support from manual to automatic control. *Human Factors*, 54(5), pp. 786-798.

Neisser, U. (1978). Perceiving, anticipating, and imagining. In W. Savage (Ed.). Perception and cognition: issues in the foundations of psychology (pp. 89 – 105). Minneapolis: University of Minnesota Press.

Nelson, J.T., McKinley, R.A., Golob, E.J., Warm, J.S., & Parasuraman, R. (2014). Enhancing vigilance in operators with prefrontal cortex transcranial direct current stimulation (tDCS). *NeuroImage*, 85, pp. 909-917.

NHTSA (2008). National motor vehicle crash causation survey. Report to Congress. *Report No. DOT HS 811059*. Washington, D.C.: National Highway Traffic Safety Administration.

NHTSA (2017). Automated driving systems 2.0: A vision for safety. Washington, D.C.: National Highway Traffic Safety Administration.

Norman, D. (2007). *The Design of Future Things*. New York: Basic books. See esp. chap 3, ‘Natural Interaction’, section ‘Natural Safety’, pp. 77-85.

#Norman, D., & Shallice, T. (1986). Attention to action: Willed and automatic control of behavior. In R.J. Davidson, G.E. Schwartz, & D. Shapiro (Eds.) *Consciousness and self-regulation (vol. 4): Advances in Research and Theory*. Plenum Press. New York. pp. 1-18.

Ogden, G.D., Levine, J.M., & Eisner, E.J. (1979). Measurement of workload by secondary tasks. *Human Factors*, 21(5), pp. 529-548.

Olson, W.A., & Wuennenberg, M.G. (1984). Autonomy based human-vehicle interface standards for remotely operated aircraft. *Proceedings of the 20th Digital Avionics Systems Conference,* Daytona Beach, FL, USA.

O’Regan, J.K. (1992). Solving the ‘real’ mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology,* 46, pp. 461-488.

Panou, M.C., Bekiaris, E.D., & Touliou, A.A. (2010). ADAS module in driving simulation for training young drivers. *13th International IEEE Conference on Intelligent Transportation Systems*. Madeira Island, Portugal.

Parasuraman, R. (1979). Memory load and event rate control sensitivity decrements in sustained attention. *Science,* 205(4409), pp. 924-927.

Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, 39(2), pp. 230-253.

Parasuraman, R., Kidwell, B., Olmstead, R., Lin, M.K., Jankord, R., & Greenwood, P. (2014). Interactive effects of the COMT gene and training on individual differences in supervisory control of unmanned vehicles. *Human Factors,* 56 (4), pp. 760-771.

#Parasuraman, R., Galster, S., & Miller, C.A. (2003). Human control of multiple robots in the RoboFlag simulation environment. *Proceedings of the IEEE Conference on Systems, Man, and Cybernetics.* Washington, DC.

#Parasuraman, R., Galster, S., Squire, P., Furukawa, H., & Miller, C.A. (2005). A flexible delegation interface enhances system performance in human supervision of multiple autonomous robots: Empirical studies with RoboFlag. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans,* 35, pp. 481-493.

Parasuraman, R., Mouloua, M, & Molloy, R. (1996). Effects of adaptive task allocation on monitoring of automated systems. *Human Factors*, 38 (4), pp. 665-679.

Parasuraman, R., Sheridan, T.B., & Wickens, C.D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics*, 30(3), pp. 286-297.

Pijnenburg, J. (2017). Naturalism: Effects of an intuitive augmented reality interface property in the display of automated driving status. Master's Thesis. Available at: http://resolver.tudelft.nl/uuid:92d6b140-56f7-440a-b9ba-ff997c00ab4b
#Pop, V.L., Stearman, E.J., Kazi, S., & Durso, F.T. (2012). Using engagement to negate vigilance decrements in the NextGen environment. *International Journal of Human-Computer Interaction*, 28, pp. 99-106.

#Pope, A.T., Bogart, E.H., & Bartolome, D.S. (1995). Biocybernetic system evaluates indices of operator engagement in automated task. *Biological Psychology*, 40, pp. 187-195.

Posner, M.I. (1978). *Chronometric explorations of mind*. Lawrence Erlbaum. Hillsdale, NJ, USA.

Price, M.A., Venkatraman, V., Gibson, M., Lee, J., & Mutlu, B. (2016). Psychophysics of trust in vehicle control algorithms. SAE Technical Paper 2016-01-0144, doi: 10.4271/2016-01-0144.

Rasmussen, J., Pejtersen, A.M., & Goodstein, L.P. (1994). *Cognitive systems engineering*. John Wiley & Sons. New York.

Rudin-Brown, C.M., & Parker, H.A. (2004). Behavioural adaptation to adaptive cruise control (ACC): Implications for preventative strategies. *Transportation Research Part F: Traffic Psychology and Behaviour*, 7(2), pp. 59-76.

#Ruff, H.A., Narayanan, S., & Draper, M.H. (2002). Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles. *Presence*, 11, pp. 335-351.

SAE (2014). Surface vehicle information report: Taxonomy and definitions for terms related to on-road motor vehicle automated driving systems. Standard J3016. On-Road Automated Vehicles Standards Committee, SAE International. Available at: https://www.sae.org/standards/content/j3016_201401/

SAE (2018). Surface vehicle recommended practice: Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. Standard J3016. On-Road Automated Vehicles Standards Committee, SAE International. Available at: https://www.sae.org/standards/content/j3016_201806/

Saffarian, M., De Winter, J.C.F., & Happee, R. (2012). Automated driving: Human-factors issues and design solutions. *Proceedings of the Human Factors and Ergonomics Society 56th Annual Meeting*. Boston, MA, USA.

#Sarter, N.B., & Woods, D.D. (1992). Mode error in the supervisory control of automated systems. *Proceedings of the Human Factors and Ergonomics Society 36th Annual Meeting*. Atlanta, GA, USA.

#Sarter, N.B., & Woods, D.D. (1993). How in the world did we ever get into that mode? Mode error and awareness in supervisory control. *Human Factors*, 37(1), pp. 5-19.
Scallen, S.F., Hancock, P.A., & Duley, J.A. (1995). Pilot performance and preference for short cycles of automation in adaptive function allocation. *Applied Ergonomics*, 26 (6), pp. 397-403.

Schutte, P. (1999). Complemation: An alternative to automation. *Journal of Information Technology Impact*, 1(3), pp. 113-118.

#Scott, S.D., Mercier, S., Cummings, M.L., & Wang, E. (2006). Assisting interruption recovery in supervisory control of multiple UAVs. *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting*. San Francisco, CA, USA.

See, J.E., Howe, S.R., Warm, J.S., & Dember, W.N. (1995). Meta-analysis of the sensitivity decrement in vigilance. *Psychological Bulletin*, 117(2), pp. 230-249.

Seppelt, B.D., & Lee, J.D. (2007). Making adaptive cruise control (ACC) limits visible. *International Journal of Human-Computer Studies*, 65, pp. 192-205.

Seppelt, B.D., & Victor, T.W. (2016). Potential solutions to human factors challenges in road vehicle automation. In G. Meyer & S. Beiker (Eds.) *Road Vehicle Automation 3, Lecture Notes in Mobility*. Springer International Publishing. Switzerland.

#Shaw, T., Emfield, A., Garcia, A., De Visser, E., Miller, C.A., Parasuraman, R., & Fern, L. (2010). Evaluating the benefits and potential costs of automation delegation for supervisory control of multiple UAVs. *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting*. San Francisco, CA, USA.

#Sheridan, T.B. (1986). Human supervisory control of robot systems. *Proceedings of the IEEE International Conference on Robotics and Automation*, 2, pp. 808-812.

Sheridan, T.B. (1992). *Telerobotics, automation, and human supervisory control*. MIT press. Cambridge, MA, USA.

Sheridan, T.B., Charny, L., Mendel, M., & Roseborough, J.B. (1986). Supervisory control, mental models, and decision aids. U.S. Office of Naval Research, contract report no. N00014-83-K-0193

#Sheridan, T.B., & Hennessey, R.T. (1984). *Research and modelling of supervisory control behavior*. National Academy Press. Washington, DC.

Sheridan, T.B. (2002). Supervisory control. In Humans and Automation: Systems Design and Research Issues. New York: John Wiley and Santa Monica, CA: Human Factors and Ergonomics Society, p. 115-129

Sherman, D. (2016). 2016 BMW 750i xDrive: Second place: Semi-autonomous cars. Car and Driver. Available at:

https://www.caranddriver.com/features/semi-autonomous-cars-compared-tesla-vs-bmw-mercedes-and-infiniti-feature-2016-bmw-750i-xdrive-page-4

Stanton, N.A. & Young, M.S. (2005). Driver behaviour with adaptive cruise control. *Ergonomics*, 48(10), pp. 1294-1313.

Stanton, N.A., Young, M.S., Walker, G.H., Turner, H., & Randle, S. (2001). Automating the driver's control tasks. *International Journal of Cognitive Ergonomics*, 5(3), pp. 221-236.

Sternberg, S. (1969). Memotry-scanning: Mental processes revealed by reaction-time experiments. *American Scientist*, 57(4), pp. 421-457.

Strand, N., Nilsson, J., MariAnne Karlsson, I.C., & Nilsson, L. (2014). Semi-automated versus highly automated driving in critical situations caused by automation failure. *Transportation Research Part F: Traffic Psychology and Behaviour*, 27, pp. 218-228.

Suchman, L.A. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge University Press. New York.

Super Cars (2017). What Happens If You Leave Tesla Autopilot on FOREVER Terrible Idea. Available at: https://www.youtube.com/watch?v=C7xV9rMajNo

Szymkowski, S. (2017). Waymo found drivers asleep, so it dumped partial self-driving feature. *Motor Authority*. Available at: https://www.motorauthority.com/news/1113654_waymo-found-drivers-asleep-so-it-dumped-partial-self-driving-feature

Teichner, W.H. (1974). The detection of a simple visual signal as a function of time of watch. Human Factors, 16(4), p. 339-353

Terry (2011). The 'Rattomorphism' of gamification. CGP: Critical Gaming Project, University of Washington. Available at: https://depts.washington.edu/critgame/wordpress/2011/11/the-rattomorphism-of-gamification/

Tesla (2017). Model S Owner's Manual, 8.0. Driver Assistance Features. Available at: https://www.tesla.com/sites/default/files/model_s_owners_manual_north_america_en_us.pdf

Treat, J., Tumbas, N., McDonald, S., Shinar, D., Hume, R., Mayer, R., Stanisfer, R., & Castellan, R. (1979). Tri-level study of the causes of traffic accidents. *Report No. DOT-HS-034-3-535-77* (TAC).

Vicente, K.J., & Rasmussen, J. (1990). The ecology of human-machine systems II: Mediating "direct perception" in complex work domains. *Ecological Psychology*, 2, pp. 207-249.

Wickens, C.D. (1980). The structure of attentional resources. In R. Nickerson (Ed.). *Attention and Performance VIII*. Erlbaum. Hillsdale, New Jersey, USA. pp. 239-257.

Wickens, C.D. (1984). Processing resources in attention. In R. Parasuraman & Davies (Eds.). *Varieties of attention*. Academic Press. New York. pp. 63-101.

Wickens, C.D., & Carswell, C.M. (1995). The proximity compatibility principle: Its psychological foundation and relevance to display design. *Human Factors*, 37(2), pp. 473-494.

Wickens, C.D., & Kessel, C. (1979). The effect of participatory mode and task workload on the detection of dynamic system failures. *IEEE Transactions on Systems, Man and Cybernetics*, SMC-9, 24-34.

Wiener, E.L, & Curry, R.E. (1980). Flight-deck automation: Promises and problems. *Ergonomics*, 23(10), pp. 995-1011.

Wilson, R.A. (2004). *Boundaries of the mind*. Cambridge University Press. Cambridge.

Young, M.S., & Stanton, N.A. (2002). Malleable Attentional Resources Theory: A new explanation for the effects of mental underload on performance. *Human Factors*, 44(3), pp. 365-375.

Table 1

Partially automated driving releases (~2017) [#]

Make	Model	System	Terms for driver state of engagement	Engagement Input[a] modality	Engagement Output[b] modality	Inattention escalation intervals
Volvo Cars	XC90 S90, V90	Pilot Assist II	attention, judgment	VLa VLn VMsc	AU VI TOC	0
GM, Cadillac	CT6	Driver Attention System (Super Cruise)	attention, awareness, supervision, engagement	VI	AU VI TA TOC	>1
Tesla	Model S Model X	Autopilot Tech Package v. 8.0	alert, safely, in control, hands-on, mindful, determine appropriate, be prepared	VLa	AU VI TOC	5
Audi	A4, Q7	Traffic Jam Assist	be in control, ready, responsible, assessing, attention	VLa VMsc	AU VI TOC	>1
BMW	750i 7 series	Active Driving Assistant Plus	be in control, responsible, correctly assess traffic situation, adjust the driving style to the traffic conditions, watch traffic closely, actively intervene, attentively	VLa	AU VI (TA) TOC	1
Infiniti	Q50S	Active Lane Control	be alert, drive safely, keep vehicle in traveling lane, control of vehicle, correct the vehicle’s direction	(VLa)	(AU) (VI)	-1
Daimler, Mercedes-Benz	S65 AMG	Distronic Plus with Steering and Active Lane-Keeping Assist	adapt, aware, ensure, control, careful observation, be ready, maintain safety	VLa VMsc	AU VI (TA) TOC	1

[a] Input modalities (vehicle from driver):

- VLa = vehicle lateral, steering, etc.
- VLn = vehicle longitudinal, brake, gas, etc.
- VMsc = vehicle misc., seat buckle, wait, door lock, etc.

[b] Output modalities (vehicle to driver):

- AU = audio
- TA = tactile/haptic/vestibular
- VI = visual
- TOC = transition of control, change in functionality/level, etc.

[#] sources of information

- Volvo Cars
  - http://volvornt.harte-hanks.com/manuals/2017/S90_OwnersManual_MY17_en-US_TP22301.pdf
  - http://volvo.custhelp.com/app/answers/detail/a_id/9769/~/new-features-available-as-of-november-2016
- GM, Cadillac
  - http://media.gm.com/media/us/en/cadillac/news.detail.html/content/Pages/news/us/en/2017/apr/0410-supercruise.html
  - https://www.youtube.com/watch?v=Shm3GY_JG-w
- Tesla
  - https://www.tesla.com/sites/default/files/model_s_owners_manual_north_america_en_us.pdf
- Audi
  - http://ownersmanual.audiusa.com/
  - http://www.audi.com/en/innovation/piloteddriving/assistance_systems.html
  - https://www.youtube.com/watch?v=T8ESfICGnAc
  - https://www.youtube.com/watch?v=RMj4H4ybEkc
- BMW
  - https://www.bmwusa.com/owners-manuals.html
  - http://www.bmw.com/en/topics/fascination-bmw/connected-drive/driver-assistance.html
  - https://www.youtube.com/watch?v=RKAE-ANKIBY
  - https://www.youtube.com/watch?v=7fqXJcscjzw
- Infiniti
  - https://owners.infinitiusa.com/content/manualsandguides/Q50/2017/2017-Q50-owner-manual-and-maintenance-info.pdf
- Daimler, Mercedes-Benz
  - https://www.mbusa.com/mercedes/service_and_parts/owners_manuals#!year=2017&class=S-Sedan
  - http://techcenter.mercedes-benz.com/en/distronic_plus_steering_assist/detail.html
  - http://techcenter.mercedes-benz.com/en_ZA/steering-pilot/detail.html
- Unofficial demonstration/review reports
  - https://www.youtube.com/watch?v=RjvI57BIDp0
  - https://www.caranddriver.com/features/semi-autonomous-cars-compared-tesla-vs-bmw-mercedes-and-infiniti-feature-2016-bmw-750i-xdrive-page-4
  - https://www.youtube.com/watch?v=isZ3fSbE_pg
  - https://www.youtube.com/watch?v=C7xV9rMajNo

Table 2

Weighted frequency scores for aggregated first and second choices by each inter-rater for each publication reference. Lower/higher weights are lighter/heavier shaded. Highest weights per publication are outlined.

Ref ID	**Weight of Theme 1**	**Weight of Theme 2**	**Weight of Theme 3**	**Weight of Theme 4**	**Weight of Theme 5**	**Weight of Theme 6**
1	0.0	2.0	0.0	0.0	2.0	0.0
2	0.0	1.0	0.0	0.0	0.5	2.5
3	0.0	2.0	0.0	1.0	0.5	0.5
4	0.0	1.5	0.0	0.0	0.5	2.5
5	0.0	0.0	0.0	2.0	1.5	0.5
6	0.0	0.5	0.0	1.5	1.0	1.0
7	0.0	0.0	0.0	3.0	0.5	0.0
8	0.0	2.0	0.0	0.5	1.0	0.0
9	0.0	2.5	0.0	0.5	1.5	0.0
10	0.0	2.5	0.0	0.0	1.0	0.0
11	1.0	1.0	0.0	0.0	1.0	0.0
12	0.0	2.0	0.0	0.0	0.5	1.0
13	0.0	0.0	0.0	1.0	1.5	2.0
14	0.0	2.5	0.0	0.0	0.0	2.0
15	0.0	3.0	0.5	0.0	0.0	0.5
16	0.0	0.0	0.0	3.0	0.0	0.5
17	0.0	0.0	0.0	0.5	1.0	3.0
18	0.0	2.0	0.0	0.0	1.0	0.5
19	0.0	1.0	0.0	0.0	1.0	1.0
20	0.0	0.0	1.0	0.0	1.0	2.0
21	0.0	2.0	0.5	0.0	1.0	0.5
22	0.0	0.0	1.5	0.0	1.0	1.5
23	0.0	1.0	0.0	2.0	0.5	0.0
24	2.0	2.5	0.0	0.0	0.0	0.0
25	0.0	1.0	0.0	2.0	0.5	0.0
26	0.0	0.0	0.0	0.5	2.0	1.5
27	0.0	0.0	0.0	3.0	0.5	0.5
28	0.0	0.0	0.0	0.0	1.0	2.5
29	0.0	0.0	1.0	0.0	0.5	2.0
30	0.0	0.0	0.0	1.0	3.0	0.0
31	0.0	0.0	1.0	0.0	1.5	1.0
32	0.0	1.0	0.0	0.0	1.5	1.5
33	0.0	0.0	0.0	0.0	2.0	1.5
34	0.0	0.5	0.0	2.0	2.0	0.0
Total:	3.0	33.5	5.5	23.5	34.0	32.0

Table 3

Primary operator domains of publications with identified likely thematic solution category from aggregate inter-rater first and second choice weighted scores.

U(x)V = uninhabited vehicles, robots; UAV = uninhabited aerial vehicles; UGV = uninhabited ground vehicles; USV = uninhabited surface vehicles, ships; UUV = uninhabited underwater vehicles; Pilot = flight-deck, cockpit; ATC = ground-based air traffic control; Missile = air defense command and control; Automobile = automotive cars, trucks, etc.; Naval vessel = battleship, aircraft carrier, etc.; Space = spacecraft, satellites, etc.; Power plant = hydro, nuclear, electric, gas, oil, etc.; General = laboratory, basic research; Radar = military asset defence of airfield, ship, etc.; ComCon = general military command/control, tactical operations.

Ref ID	**U(x)V**	**UAV**	**UGV**	**USV**	**UUV**	**Pilot**	**ATC**	**Missile**	**Auto-mobile**	**Naval Vessel**	**Space**	**Power Plant**	**General**	**Radar**	**ComCon**
1									2/5						
2		6													
3	2	2			2										
4	6														
5			4												
6			4												
7							4								
8	2	2		2											
9	2	2			2										
10		2													
11		1/2/5													
12								2							
13		6													
14		2													
15		2											2		
16								4							
17		6													
18	2	2													
19	2/5/6														
20															6
21	2	2													
22							3/6						3/6		
23													4		
24									2						
25						4									
26						5									
27								4							
28												6			
29							6			6				6	
30						5									
31												5	5		
32													5/6		
33											5				
34													4/5		

Appendix A

Inclusion set of categorized human-automation literature conclusions from search for keeping engagement/attention in supervisory control.

Ref ID	Year	First Author	Title
1	2016	Banks	Keep the driver in control: Automating automobiles of the future
2	2014	Clauss	Implications for operator interactions in an agent supervisory control relationship
3	2013	Cummings	Boredom and distraction in multiple unmanned vehicle supervisory control
4	2012	Breda	Supervisory Control of Multiple Uninhabited Systems-Methodologies and Enabling Human-Robot Interface Technologies (Commande et surveillance de multiples …
5	2012	Chen	Supervisory control of multiple robots: Effects of imperfect automation and individual differences
6	2012	Chen	Supervisory control of multiple robots in dynamic tasking environments
7	2012	Pop	Using engagement to negate vigilance decrements in the NextGen environment
8	2010	Cummings	Modeling the impact of workload in network centric supervisory control settings
9	2010	Hart	Assessing the impact of low workload in supervisory control of networked unmanned vehicles
10	2010	Shaw	Evaluating the benefits and potential costs of automation delegation for supervisory control of multiple UAVs
11	2007	Cummings	Operator scheduling strategies in supervisory control of multiple UAVs
12	2007	Cummings	Developing operator capacity estimates for supervisory control of autonomous vehicles
13	2007	Cummings	Automation architecture for single operator-multiple UAV command and control
14	2007	Johnson	Testing adaptive levels of automation (ALOA) for UAV supervisory control
15	2007	Miller	Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control
16	2006	Hawley	Training for effective human supervisory control of air and missile defense systems
17	2006	Scott	Assisting interruption recovery in supervisory control of multiple UAVs
18	2005	Parasuraman	A flexible delegation-type interface enhances system performance in human supervision of multiple robots: Empirical studies with RoboFlag
19	2003	Parasuraman	Human control of multiple robots in the RoboFlag simulation environment
20	2002	Blasch	JDL Level 5 fusion model: user refinement issues and applications in group tracking
21	2002	Ruff	Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles
22	2000	Hoc	From human-machine interaction to human-machine cooperation

23	1999	Manly	The absent mind: further investigations of sustained attention to response
24	1995	Endsley	The out-of-the-loop performance problem and level of control in automation
25	1995	Pope	Biocybernetic system evaluates indices of operator engagement in automated task
26	1995	Sarter	How in the world did we ever get into that mode? Mode error and awareness in supervisory control
27	1993	Lockhart	Automation and supervisory control: A perspective on human performance, training, and performance aiding
28	1992	Ackerman	Understanding supervisory systems
29	1992	Gersh	Cognitive engineering of rule-based supervisory control systems: Effects of concurrent automation
30	1992	Sarter	Mode error in supervisory control of automated systems
31	1987	Gaushell	Supervisory control and data acquisition
32	1986	Norman	Attention to action: Willed and automatic control of behavior
33	1986	Sheridan	Human supervisory control of robot systems
34	1984	Sheridan	Research and modeling of supervisory control behavior. Report of a workshop

Appendix B

First and second choice (where applicable) thematic category as identified by each rater for each publication reference. First choice overlap agreement by at least 2 raters is shaded and full agreement is outlined.

Ref ID	AV 1st Choice	TX 1st Choice	CO 1st Choice	AV 2nd Choice	TX 2nd Choice	CO 2nd Choice
1	5	5	2	2	2	-
2	6	6	2	-	5	6
3	2	2	4	-	5	6
4	6	6	2	5	2	6
5	4	5	4	5	6	-
6	6	5	4	4	2	-
7	4	4	4	-	5	-
8	2	5	2	-	4	-
9	2	5	2	4	2	5
10	2	5	2	-	2	-
11	1	5	2	-	-	-
12	2	2	6	-	5	-
13	5	6	4	6	5	6
14	2	6	2	6	2	6
15	2	2	2	3	6	-
16	4	4	4	-	6	-
17	6	6	6	5	4	5
18	2	5	2	-	6	-
19	6	5	2	-	-	-
20	3	6	6	5	5	-
21	2	5	2	6	-	3
22	5	6	3	6	3	-
23	2	4	4	-	5	-
24	2	1	2	1	2	1
25	2	4	4	-	5	-
26	5	5	6	6	-	4
27	4	4	4	5	6	-
28	5	6	6	6	-	-
29	6	6	3	-	5	-
30	5	5	5	4	-	4
31	6	5	3	5	-	-
32	6	5	2	5	6	-
33	6	5	5	-	6	-
34	5	5	4	4	4	2
Mode:	2	5	2	5	5	6

View publication stats