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Vehicle automation and driving performance

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Vehicle automation is highly likely to be in service by the end of this century. While there are undoubtedly some benefits associated with such systems, there are some concerns also. This paper presents a review of studies addressing adaptive cruise control and active steering systems. These studies suggest that there may be some cause for concern. They show a reduction in mental workload, within a secondary task paradigm, associated with some forms of automation and some problems with reclaiming control of the vehicle in failure scenarios. It is suggested that more research and development effort needs to be spent on looking at vehicle automation and driving performance.

1. Introduction to vehicle automation

The theme of vehicle automation is likely to receive increased attention from ergonomists and psychologists in the coming years, as the gap between concepts, prototypes and production vehicles narrows. Although much is written on ergonomic issues connected with vehicle operation, such as occupant packaging, driver comfort, safety, design of controls and displays (Peacock and Karwowski 1993) little attention is given to vehicle automation. Even texts that address future vehicles tend to concentrate on road traffic informatics and not on automation (Parkes and Franzen 1993). When consideration is given to vehicle automation, it has focused on so-called *intelligent* systems (Michon 1993), in which a model of the driver is compared to the actual driving and performance is corrected if it falls short of the model. A review of the past four years' papers in Contemporary Ergonomics (*The Proceedings of The Ergonomics Society Annual Conference*) reveals that only seven papers address advanced vehicle systems, of which five considered route guidance systems and two considered collision avoidance systems. The present authors are concerned with automated driver functions, such as Adaptive Cruise Control (ACC) and Active Steering (AS), rather than Generic Intelligent Driver Support Systems (GIDS). These systems are only in prototype at present, but it is expected that they are likely to be in production vehicles within the next 5 years. The authors are surprised at how few empirical studies on this topic are in the public domain. This may be due either to commercial confidentiality restricting publication of such studies or, more worryingly, because such studies have not been conducted. The aim of this paper is to introduce the arguments proposing a need for vehicle automation, introduce different types of advanced vehicle systems and review the

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three empirical studies that are known. From these studies the authors will identify what they consider to be the key psychological issues and draw their conclusions for future research that needs to be conducted.

1.1. *The need for vehicle automation*

The need for vehicle automation has been well rehearsed by the engineering community. Stanton and Marsden (1996) introduce three main arguments in favour of vehicle automation. The first argument assumes that driving is an extremely stressful activity and consequently, the suggestion goes, automating certain driving activities could help to make significant improvements to the driver's well-being. The second argument is based upon the fact that human error constitutes a major cause of road accidents, thus it could be reasonably suggested that the removal of the human element from the control loop may ultimately lead to a reduction in accident statistics. The final argument is based on economic considerations and presumes that automation will enhance the desirability of the product and thus lead to substantial increases in unit sales.

There is certainly some suggestion that a section of the population has a dislike of driving (Matthews and Desmond 1995, Matthews *et al*. 1996) and that this group of individuals may be more prone to overload of attentional resources (Wickens 1992). Vehicle automation could advantage the driving performance of this group of people significantly. Reason *et al*. (1990) report data to show the types of errors drivers make in manually controlled cars. It is possible that some of these errors may be reduced through vehicle automation. There is also a considerable body of information on accident statistics. Broughton and Markey (1996) propose that accidents occur primarily because drivers drive too fast, they lack judgement about their own path, or they get distracted. They argue that technological solutions to these problems may include automated systems as well as warnings to the driver.

1.2. *Advanced vehicle systems*

As previously indicated, there are many forms of advanced vehicle systems, some still in early concept stages, others in prototype and others entering service. The authors have chosen to classify these systems into systems that support the driver and systems that replace the driver. It is believed that there are important psychological distinctions between these two types of systems and the authors intend to focus on the latter in this paper. These systems may be considered within the range of driver activities, which are classified as vehicle navigation (such as route planning and route guidance), vehicle control (such as braking, steering, accelerating) and hazard identification. The authors will not be dealing with systems that monitor the driver and intervene (GIDS: Michon 1993).

1.2.1. *Systems that support the driver*: Systems that support the driver are not new, but have typically been associated with vehicle control, such as power-assisted steering. Examples of new vehicle control systems that support the driver include parking aids and vision enhancement systems. Parking aids work through sensors built into the front and rear bumpers of the car that are able to detect, at slow speed, the distance the vehicle is away from other objects. Typically, auditory tones indicate how far the car is away from the object to the driver, using the sonar metaphor. The closer together the tones, the nearer the car is to the object. A continuous tone indicates that the driver should stop as the gap is very small. This device helps the driver to park the car without bumping into other cars. Vision enhancement systems work by employing an infrared camera next to the headlights at the front of the car. The road view captured by the camera is then projected to provide a head-up display to the driver, overlaid on the real world. This image enables the driver to see the road and objects in his path that otherwise might not be seen due to poor illumination. The system enhances night-time vision where objects may be dull even with ordinary headlight illumination. The benefits of vision enhancement become even more obvious when driving in foggy conditions. Under such conditions the driver's range of vision may be reduced to only a few metres. With the vision enhancement system activated the road view becomes greatly enhanced, enabling the driver to literally see through the fog. Examples of vehicle navigation systems that support the driver include route planners (such as 'Route 66', which are typically off-line trip planning aids) and route guidance (such as 'TrafficMaster', which are on-line systems). Route planners work by the driver entering the starting point and destination of the journey and asking the computer for the shortest route or the quickest route to be plotted. Typically these systems provide a printout of the route with a list of road changes. Route guidance systems work in a similar manner, but provide the driver with on-line information about problems with the route (e.g. problems associated with traffic build-ups) and suggest alternative routes. These systems act like driving prostheses, enabling the driver to improve their performance without making any fundamental changes in the driving task. On the other hand, automation may, by removing tasks traditionally performed by the driver, leave the driver with fundamentally different tasks to perform.

1.2.2. *Systems that replace the driver*: There is nothing particularly new about the idea of replacing the driver by providing automated systems in the car. An example of a navigation system that replaces a task traditionally performed by the driver or passenger, is the Global Positioning System (GPS). This system works by satellite triangulation to determine the position of the vehicle and is accurate to within a few yards. Vehicle position is calculated automatically and the driver has no need to pay any heed to their position, only to follow the instructions on the associated vehicle navigation system. Without GPS, the driver is required to determine their position and relate it to the instructions provided by the navigation system.

Automatic transmission is quite a common feature, even in what could be considered ordinary vehicles. Examples of new vehicle control systems that replace the driver include Adaptive Cruise Control (ACC) and Active Steering (AS). ACC controls both speed and headway of the vehicle, slowing the vehicle down when presented with an obstacle and restoring target speed when the obstacle is removed. In this way ACC differs from traditional Cruise Control (CC) systems. In traditional cruise control, the system relieves the driver of foot control of the accelerator only (i.e. relieving the driver of some physical workload), whereas ACC relieves the driver of some of the decision-making elements of the task, such as deciding to brake or change lanes (i.e. relieving the driver of some mental workload), as well as physical demands of accelerator control. Likewise AS replaces the driver by guiding the vehicle along the road and maintaining the vehicle within the lane. This is achieved with the aid of onboard cameras that are able to detect the lane markings and therefore the position of the vehicle within the lane. This system should reduce the incidence of lane sharing (i.e. driving across both lanes) and lane creep (i.e. weaving in and out of lanes). Potentially, then, automation as embodied by ACC and AS are welcome additional vehicle systems that will add comfort and convenience to the driver. However, certain ergonomics issues do arise when considering any form of automation and these need to be properly addressed to improve overall system performance (Stanton and Marsden 1996). It is envisaged that although these systems will behave in exactly the manner prescribed by the designers and programmers, this may lead to some scenarios in which the driver's perception of the situation is at odds with the system operation (Stanton and Marsden 1996). There is also little known about the effects of combining advanced vehicle systems, e.g. the operation of ACC and AS together and the relative merits compared to either system operated alone.

Typical driving patterns in terms of speed and headway suggest that a more constant speed and following behaviour is produced when the ACC system is engaged (Faber 1996). Similarly, AS is expected to lead to more consistency in lane-keeping behaviour. This change in driving pattern produced by ACC and AS is expected to ease traffic flow leading to greater throughput and a reduction in both congestion and accidents, primarily by mis-judgment or distraction of the driver. These represent about 15% of fatal accidents on motorways. Studies in the UK suggests that between 5 and 10% of these motorway accidents could be avoided with the help of automation (Broughton and Markey 1996).

As has already been pointed out, there is little empirical evidence to support these claims, and there is no evidence on the effects of combining these systems, such as activating both ACC and AS together. A car with ACC and AS would be semi-autonomous, i.e. vehicle control would be automated but the driver would still be required to undertake vehicle navigation and hazard identification. If all of the navigation and control systems were integrated the car would be truly autonomous, indeed it would be the driverless car as envisaged in concept 2096 as shown on BBC's *Tomorrow's World*. For the purposes of this paper the authors will only consider semi-autonomy with automation of some aspects of vehicle control. Despite the apparent attraction of automation, Stanton and Marsden (1996) caution that automated systems are not without their problems. Based upon an evaluation of automation in aviation, which they take to be development ground for the concepts that are now entering into land-based transportation, they suggest that automated systems may be less reliable than anticipated when they are introduced into the operational arena. There are three main concerns. First, that drivers will become over-reliant upon the automated systems. Second, that drivers will evoke the systems in situations beyond their original design parameters. Third, that drivers will fail to appreciate that the system is behaving in a way that is contrary to their expectations.

1.3. *Research environment*

All three of the studies to be reviewed have been undertaken in driving simulators. Simulator studies have several advantages for research of this nature (Senders 1991). First, they can be used to put people into situations that would not be ethical in the real environment, such as life-threatening situations. Second, simulators can be used in carefully controlled experimental studies, so that one may be sure that it is the experimental variables being manipulated that result in differences in driver performance, not other confounding variables. Finally, one is able to compress experience, to collect data on a whole range of situations unlikely to be encountered in the natural environment in a short time frame. The use of simulation in research environments is not without controversy. In a recent review of the literature Stanton

(1996) identified the main issues surrounding the simulator use were focused upon the level of fidelity encapsulated within the simulated environment. These issues are apparently domain-independent and certainly apply to driving simulators. Two major issues can be identified as physical (i.e. the degree to which the simulated environment looks like the real environment) and functional (i.e. the degree to which the simulated environment behaves like the real environment) fidelity. Simulators appear to have been used with some success in research on driving (Michon 1993, Nilsson 1995, Bloomfield and Carroll 1996). The research evidence seems to suggest that functional fidelity is of greatest importance to transfer effects, i.e. the degree to which behaviour in the simulator transfers to the real operational environment (Senders 1991, Stanton 1996). Physical fidelity may help to convince the experimental participant that the task should be taken seriously, which would be less convincing in a more abstract environment. It is much harder to simulate the consequences of driver outcomes, for example the consequences of an accident in the 'real-world' might lead to personal injury, the inconvenience of being without a car while it is being repaired and an increase in insurance premiums. Movement fidelity is possible with moving-base simulators. Some argue that lack of movement detracts from the generalizability of data from driver simulators. In this review, study I was undertaken in a moving-base simulator whereas studies II and III were undertaken in a fixed-base simulator. Comparison of the data generated from these studies should help one to gauge the benefits of research conducted in moving-base over fixed-base driving simulators as well as the performance effects of driver automation.

2. Three studies of the effects of vehicle automation upon driving performance

To our knowledge, there are only three empirical studies in the public domain that report upon the effects of vehicle automation on driving performance. The authors review these studies in this section.

2.1. *Study I: Comparing manual driving and adaptive cruise control in three critical traffic situations*

The first study to be considered was conducted by Nilsson (1995) who sought to compare driver behaviour and workload in critical scenarios in manual and ACC conditions. Twenty drivers aged between 26 and 46 years (10 males and 10 females) were assigned to the experimental groups: in the first group participants drove the simulator under manual control and in the second group with ACC engaged. The driving simulator was a moving-base Saab 9000 with automatic gear box. Nilsson claims that the simulator was able to evoke 'impressions, reactions and actions which are very close to those experienced by the driver in real driving' (Nilsson 1995: 1255). Full details of the simulator set-up may be found in Nilsson (1995). Nilsson compared driver's behaviour between the manual and ACC conditions in critical traffic situations: approaching a stationary queue of traffic (the participant approaches a stationary queue but the ACC system fails to detect the cars therefore requiring the participant to intervene and assume control of the vehicle), a car pulling out in front of the participant's vehicle (while overtaking cars in a row, a car from within the row pulled out in front of the participant — intervention was required in the ACC condition as the braking required exceeded the maximum braking capacity of the automatic system) and hard braking by the lead vehicle (the participant approached the lead car which braked and was also being overtaken by another car to prevent the participant from simply overtaking — intervention was again required in the ACC condition as the braking required exceeded the maximum braking capacity of the automatic system). All of these scenarios required intervention by the participant. Workload was measured using the NASA Task Load Index (Hart and Staveland 1988, Hendy *et al.* 1993), which is a subjective rating scale. Nilsson found that only in the first scenario (i.e. approaching a stationary queue of traffic) did some of the drivers fail to intervene in a timely manner. Four participants in the ACC group were involved in a collision (i.e. when the ACC system failed to detect the vehicles in front of the participant), whereas only one of the participants in the manual condition collided with the stationary queue. Nilsson suggests that this is likely to be due to the expectation of the drivers that the ACC system would cope with the situation effectively. The only other statistically significant difference in driving behaviour between the two groups was in the increased duration that the ACC group spent in the overtaking lane. Interestingly, Nilsson found no statistical differences in the level of mental workload between the ACC and manual conditions. One might, intuitively, associate reduced levels of workload with automation. However, the task of monitoring the automate system may be as demanding as driving without automation. Nilsson also suggests that automation will be readily accepted by drivers, based upon subjective ratings on driver opinion scales.

2.2. *Study II: Comparing manual driving and adaptive cruise control in a car following scenario*

This study sought to examine the ability of drivers to reclaim control under an ACC failure scenario (where the ACC system fails to detect a vehicle in its path), and compare the level of mental workload with that under manual control of the vehicle (Stanton *et al.* 1996). A fixed-base driving simulator based on a Ford Orion with automatic gear box was used (the Southampton Driving Simulator). Figure 1 shows the forward field of view presented to the driver. The driver was presented with a view of the road ahead, the rear view in the mirror (centre top of the picture), a rotated figures task (bottom left of picture) and vehicle instrumentation (bottom centre and bottom right of picture). Manual control of the vehicle was affected by using the brake and accelerator pedals and steering wheel.

On the basis of study I, it might be reasonable to expect that drivers might have some difficulty in detecting ACC failure. Twelve drivers with the mean age of 21 years (six males and six females) participated in this study and all drivers were exposed to both the manual and ACC conditions. Measures were collected of all primary driving task performance data and secondary task (using the rotated figures task: Baber 1991) data were collected to provide a measure of driver workload to compare task demand in manual and ACC scenarios. In addition, the automated condition was designed to present a failure situation that is anticipated in ACC operation. The most malignant failure scenario for ACC is unexpected accelerating by the ACC system when there is a vehicle in its path. This could occur owing to a technical malfunction and would require the driver to reclaim manual control of the vehicle. Participants were instructed to follow a lead vehicle at a speed and distance that felt comfortable, so that driving demands could be held constant in the manual and automated conditions. The results showed no statistically significant differences in driver's position on the road, distance from lead vehicle and speed in the automated and manual conditions. Workload demands were significantly greater in the manual condition, as measured by a secondary task. Four of the twelve

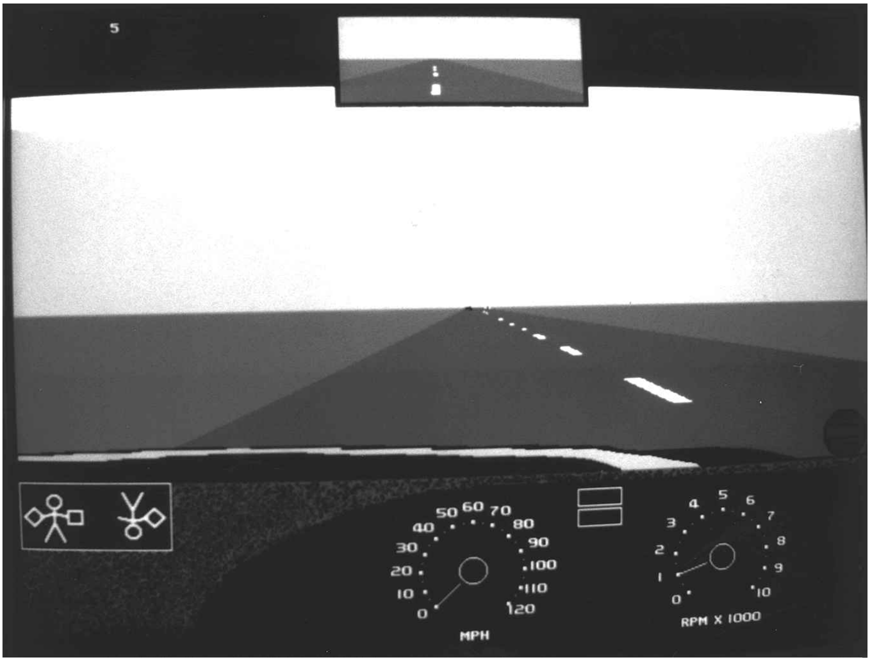

Figure 1. The driver's forward field of view.

participants in the ACC condition failed to reclaim control of the vehicle in an effective manner before it crashed into the lead vehicle. Of the eight participants in the ACC condition who responded effectively (i.e. avoided the collision when the ACC system failed), two participants steered out of trouble and six participants employed the strategies of steering and braking together.

2.3. *Study III: Comparing manual driving, adaptive cruise control, active steering and semi-autonomous control in a car-following scenario*

The study was devised to investigate the driver behaviour and workload demanded by the driving task in manual and automated scenarios (Young and Stanton 1997). The automated scenarios were Active Steering (AS), Adaptive Cruise Control (ACC) and combined automation (AS and ACC together). Studies I and II only considered the implementation of a single system, whereas study III considered the effects of combining systems. Study III used the Southampton Driver Simulator (as used in study II). Thirty drivers with the mean age of 25.3 years participated in this study (17 males and 13 females) and were instructed to follow a vehicle at a comfortable distance for each of the experimental trials. They were also asked to attend to the secondary task whenever they could (the figure rotation task). After completing each trial, participants were asked to complete a workload questionnaire (the NASA-TLX) and Nilsson's (1995) driver opinion scales.

The results showed differences in driver behaviour, workload and driver opinion between the manual and automated conditions. First, there were significant differences in the position of the vehicle on the road. Drivers in the AS and ACC+ AS conditions drove much closer to the centre of their lane than drivers in the manual and ACC conditions. This result might be expected as the active steering system would ensure good lane-keeping behaviour. There were also significant differences in the headway of the vehicles. Drivers in the ACC and ACC+ AS conditions drove much closer to the lead vehicle than drivers in the manual and AS conditions. This might also be expected as headway judgements were automated in the ACC and ACC+ AS conditions. There were significant differences in the speed of vehicles in the experimental conditions. Drivers in the ACC and ACC+ AS condition drove more consistently at the target speed in following the lead vehicle than drivers in the manual and AS conditions. Again, this is most likely to be due to the effects of automation. Second, both the secondary task and the NASA-TLX showed significant differences between the manual and automated conditions. Greatest workload was experienced in the manual and ACC conditions (there were no statistically significant differences between these two conditions). Less workload was experienced in the AS condition and least workload was experienced in the ACC+ AS condition. It seems that automation of steering and combined automation leads to reductions in driver workload. Finally, the driver opinion scale, developed by Nilsson (1995) revealed statistically significant differences on three of the scales: predictability (drivers rated the AS and the ACC+ AS conditions as more predictable than the manual and the ACC conditions), stressfulness (drivers in the manual and ACC conditions rated driving as more stressful than drivers in the AS and ACC+ AS conditions), and smoothness (drivers in the ACC, AS and ACC+ AS conditions rated driving as smoother than drivers in the manual condition). This suggests that automation leads to greater predictability and smoothness of the vehicle handling, which is accompanied by reduced driver stress.

2.4. *Comparison of the three studies*

It was thought that it would be both useful and interesting to compare the results of the three studies along the dimensions of driver behaviour, workload, collisions and driver opinion. This contrast should help to highlight some of the trends in the results and indicate the way forward for further research. It should be noted that studies I and II only compare manual with ACC, whereas study III compares manual, ACC, AS and ACC+ AS. It should also be noted that study I comprised 20 participants (10 in the manual condition and 10 in the ACC condition), study II comprised 12 participants (all participants were exposed to both the manual and ACC conditions) and study III comprised 30 participants (all participants were exposed to manual, ACC, AS and ACC+ AS conditions). In addition, not all of the same data were collected in all three studies, as indicated by a dotted line in the tables.

2.4.1. *Driver behaviour*: One common feature to all three studies is that they all collected data on vehicle headway, as shown in table 1.

Studies II and III show that there were no differences in road position for manual and ACC, but study III also shows that there were differences in road position for conditions that included AS. Studies I and II show no difference in vehicle headway associated with ACC use, but study III shows that when ACC is used the participant’s vehicle is closer to the lead vehicle. Finally, there is some disagreement with the results found in studies II and III as the data from study III suggest that when ACC is used the speed of the vehicle is more consistent with the target speed.

2.4.2. *Driver workload*: There is an anomaly in the comparison of workload in the ACC conditions in studies I and II. However, study III confirms the results from study I, that there is no reduction in workload in the ACC condition over the manual condition. With hindsight, the authors suspect that this apparent anomaly can be explained by reference to the driving context. Study II required drivers to control the vehicle along a straight road, consistent with motorway driving, whereas studies I and III put greater load on the vehicle control task by requiring the driver to steer around bends. Matthews *et al*. (1996) have shown that greater workload is associated with driving on winding roads when compared to straight roads.

Study III also shows a reduction in workload associated with the use of AS and a further reduction when AS and ACC are used together, despite the fact that ACC alone does not lead to a reduction in workload.

2.4.3. *Collisions*: A comparison of collisions associated with the failure of the ACC device shows a remarkable similarity in the outcome for studies I and II (there was no failure scenario in study III) as shown in table 3.

From these studies it seems reasonable to suggest that up to 40% of drivers in this study may encounter problems associated with ACC failure in malignant scenarios.

2.4.4. *Driver opinion*: The participants were asked to complete an eight item, 7-point Likert scale, where 1 represented negative response and 7 represented a positive response. The data for study I related to ACC only (table 4).

Visual comparison of the mean rating between studies I and III indicates some possible points of disparity on the scales of safety (where a higher score indicates that the driver felt safer), responsiveness (where a higher score indicates that the driver felt that the system was more responsive) and compatibility (where a higher score indicates that the driver felt that the system was more compatible with how they

Table 1. Comparison of driver behaviours over the three studies.

Behaviours	Study I	Study II	Study III
Road position	–	NS	$p < 0.0001$
Headway	NS	NS	$p < 0.01$
Speed	–	NS	$p < 0.0001$

Table 2. Comparison of workload over the three studies.

Workload	Study I	Study II	Study III
Secondary task	–	$p < 0.0001$	$p < 0.0001$
NASA TLX	NS	–	$p < 0.0001$

Table 3. Comparison of collisions over the three studies.

Collisions	Study I	Study II	Study III
Manual	1 out of 10	0 out of 12	–
ACC	4 out of 10	4 out of 12	–

Table 4. Comparison of driver opinions over the three studies.

Scales	Study I	Study II	III: ACC	III:AS	III:ACC+ AS
Acceptability	5.4	–	4.2	5	4.3
Predictability	5.4	–	5.6	6	6.2
Stressfulness	5.6	–	3.5	4.8	4.8
Pleasantness	5.4	–	4.1	4.6	4.7
Safety	5.4	–	3.8	4.3	4.0
Responsiveness	3.9	–	5.2	5.1	4.9
Smoothness	5.4	–	5.1	5.3	5.5
Compatibility	4.1	–	3.0	3.3	2.8

normally drive). In study I, drivers rate that they feel safer with the ACC system than drivers in study III. This is ironic given that drivers in study I encountered failure scenarios. In study III drivers rate the ACC system as more responsive than drivers in study I. This may be due to the failure scenarios encountered in study I. Finally, in study I, drivers rate the driving as closer to their way of driving than do drivers in study III. This may be an artefact of the fixed-base simulator in study III compared to the moving-base simulator in study I.

2.4.5. *Summary of comparison of the three studies*: Taken together, the three studies seem to show that automation will have an impact upon driving performance. First, automation seems to make sure that the parameter under automated control (e.g. speed or road position) is held at a more consistent value than when it is under manual control, for example ACC holds the target speed of a vehicle more constant than manual accelerating and braking, and AS keeps the vehicle more consistently in the centre of the lane than manual steering. Second, for some functions (e.g. AS and combined ACC and AS) automation is accompanied by reductions in driver workload. Third, some drivers fail to intervene effectively in automation failure scenarios. Finally, subjective judgements on the Likert scales suggest that the drivers in the present sample perceived automated systems in a fairly positive manner.

3. Psychological issues

There are a number of psychological issues pertinent to vehicle automation, which the authors feel could help to guide future empirical studies. These will be discussed briefly. First is the issue of locus of control, the extent to which removal of control from the driver affects performance of the vehicle. Second is the issue of trust that the driver has in the automated systems. Third is the situational awareness of the driver about the operational status of the technological system and the driving context. Fourth, and connected to the third issue, is the issue of mental representation that the driver builds up of the automated systems. Fifth, is the issue of mental and physical workload associated with automation. Sixth the issue of feedback will be discussed, comparing human and automated intervention. Finally, driver stress and its implications for vehicle automation will be discussed.

3.1. *Locus of control*

One of the biggest unknowns in ACC and AS operation is the reaction of the driver to the apparent loss of some of their driving autonomy. The idea that locus of control might have an effect upon performance is not new. Locus of control is determined by the extent to which drivers attribute their own activities as responsible for the behaviour of the vehicle (an internal locus of control) or whether the behaviour of the vehicle is due to the automated system (an external locus of control). The authors think that some drivers may perceive that they are in overall control of the vehicle when it is in automated mode whereas others may not. Research in other domains suggests that people with an internal locus of control generally perform better than individuals with an external locus of control (Rotter 1966, Krause and Stryker 1984, Parkes 1984). This finding might be attributed to the degree of task engagement for the individual. An external locus of control might lead an individual to assume a passive role with the automated system, whereas an internal locus of control may lead individuals to assume an active role. This might explain why some individuals failed to intervene when the automated system failed (the *passive* drivers) whereas other individuals took control of the situation (the *active* drivers. Anecdotal reports from participants in studies II and III suggest that some drivers feel that the ACC system forces the pace of their driving rather than them feeling in control of the ACC system.

3.2. *Trust*

There is little written on trust in machines, but Muir (1994) puts forward the notion based upon research on trust in humans. This identifies three main factors: predictability, dependability and faith. The relationship between predictability, dependability and faith in humans is supposed to be temporal, i.e. dependability is based upon predictability, which leads to a leap of faith. If experience with a machine provides predictable outcomes, then an individual may start to depend upon that system. The increase in dependency may be observed by a decrease in sampling behaviour as the outcome proves to be predictable. Increased dependency may lead the individual to impart a degree of trust on the machine that implies qualities beyond those directly observed. The extent to which trust in machines can be based upon trust in humans is debatable. The basis of the model may not be unfounded, however. Muir and Moray (1996) show that subjective ratings of ‘predictability, dependability and faith accounted for high proportions of variance in trust over time’ (Muir and Moray 1996: 443). However, they question the temporal nature of the stage-based model. Their research shows that the expectations about the operational equipment (the *faith* factor) that the participants bring to the experimental task may interfere with this temporal relationship. Muir and Moray (1996) also show that their participants would rather do the task manually than leave it to an automatic system that they do not trust and it is much harder to dispel distrust than to establish trust in the first place. This work has implications for vehicle automation. Drivers will only use ACC and AS in situations where it can be trusted to operate effectively and if the system fails to meet these expectations they may not use it at all.

3.3. *Situational awareness*

Research on situational awareness in other fields shows that the separation of perceived machine state from actual machine state leads to operational problems. Automation raises the issue of locus of control. If automation takes away control of the vehicle from the driver, it is questionable how well prepared the driver will be to intervene when required (Nilsson 1995, Stanton *et al.* 1996). Woods (1988), in particular, discusses the separation that occurs between what the human operator thinks the technical system is doing and what the technical system is actually doing. This separation, he argues, is one possible cause for errors in system operation. In addition, this situation may be exacerbated by the driver attending to other stimuli, such as the in-car audio system or conversation with other passengers. These postulations are rather speculative at the moment, but are ones that the authors intend to investigate further.

In a series of experiments aimed at investigating fault detection in manual and automatic control systems, Wickens and Kessel (1981) concluded that automating the system does not necessarily reduce the mental workload of the human controller. First, they noticed a paradox of task operation. In manual control, operators are able to continually update their 'model' of the system, but are also required to perform two tasks: control and detection. However, in automatic control they had only the detection task, but were not 'in-loop' to update their 'model'. This means that removing the human from the control loop may reduce the attention paid to the system state. Wickens and Kessel (1981) suggest that whether the manual or automatic control task performance was superior would depend largely upon the relative workload, i.e. under some conditions workload might favour manual control and in other workload might favour automatic control. Automation shifts the locus of the information processing demands. This might suggest that some form of dynamic allocation of function would be appropriate, where vehicle control would be undertaken by the driver except where demands exceed resources, at which point control is passed to the automated systems until the driver is able to cope again.

3.4. *Mental representations*

It has been argued that people build up internal mental representations in order to understand and predict the behaviour of systems with which they interact (Norman 1983). Mental models are theoretical constructs developed by individuals to account for, and predict the behaviour of, physical systems (Gentner and Stevens 1983). Eysenck and Keane (1990) identify four key aspects of mental models as: they constitute the individual's causal understanding of the system, they are incomplete, they can simulate the behaviour of the physical system and they are unscientific. In a classic study on mental models by Kempton (1986), it was demonstrated that people operate their central heating systems using one or two models: a feedback model or a valve model. Both models are incomplete and lead to some inefficiencies in operating the system. These two models lead users to make different predictions about how the system works and how energy may be saved. In another study, Payne (1991) found that people have different models of how a cashpoint machine works. Payne found that some users constructed a distributed model of the system, with a locally intelligent machine, whereas other constructed a centralized model, with a local dumb terminal. It is likely that drivers will construct mental models of the automated systems (such as ACC and AS), which will lead them to either make correct or incorrect predictions about the performance of the system. The beliefs the driver has, and inferences the driver makes, about these systems will be based upon the design of the system and their experience with it. These beliefs and inferences will lead the driver to expect the system to behave in a particular way and will largely determine actions of the driver in particular situations, for example if they should decide to reclaim control or not. Therefore it is important that the driver develops the appropriate model of system functionality. It is proposed that knowledge elicitation techniques be used to determine the representations drivers build up during their interaction with the system. The ACC and AS systems will not cater for every potential traffic scenario, hence it is essential that the driver has clear understanding of the system operation, and also the points at which they will need to intervene in the automatic operation of the vehicle.

3.5. *Workload*

It is interesting to note that the use of ACC did not lower levels of workload found in all of the automation conditions. The degree of workload may indicate the extent to which the driver was out of the vehicle control loop. It is felt that there is an interesting relationship between the level of workload and the driver's ability to reclaim control from the vehicle. In other areas of research on human supervisory control it has been suggested that reduced levels of attention associated with lower levels of workload may affect the ability of the human operator to maintain an awareness of the status of the system that they are monitoring (Woods 1988, Sheriden 1987). Young and Stanton (1997) argue that optimizing the workload demand for drivers presents a challenge to driver automation. There may be some situations where lower workload leads to decrements in driving performance and other situations where an increase in workload has the same effect.

3.6. *Feedback*

Designers of automated systems need to effectively communicate the status of the system to drivers to help them determine when intervention is appropriate. In none of the reported studies did the automation present any additional information to the driver to indicate its status. Norman (1990) presents two *thought* experiments, to assist an understanding of the problems with automation in aviation. This may be adapted to driving. In the first case, consider handing vehicle control over to the automated system. The automatic system guides the car and maintains the speed and headway of the vehicle on behalf of the driver. The driver has to monitor the automatic system to check that it behaves as expected, and is required to intervene if it doesn't. This becomes a vigilance task, for which humans are generally considered to be poor. The studies in this paper show that drivers are not particularly good at intervening in a timely manner. However, consider the case where the driver hands over driving to another driver, essentially this is the same as the first case as another person guides the car and maintains the speed and headway of the vehicle on behalf of the driver. The major difference being that if the car does not respond in the way in which the new driver expects it to, this is likely to be communicated to the driver. This is the crux of Norman's argument; he suggests that the problem with automation is that it does not communicate its status to the driver, which would help to keep the driver in the control loop. Therefore feedback from the automated system is required to keep the driver up-to-date.

3.7. *Stress*

Driver stress has become a subject of much research in recent years. This research suggests that it is the fatigue from the lack of stimuli that drivers find most stressful, i.e. task underload rather than task overload (Matthews and Desmond 1995, Matthews *et al.* 1996). Matthews *et al.* (1996) report that when the driving task is relatively difficult fatigued drivers perform significantly better than when the driving task is easy. Matthews and Desmond (1995) suggest that in-car systems should be designed to create more attentional demand, not less. This seems to be counter to the research and development effort in vehicle automation, which is aimed at reducing driver workload.

4. Conclusions

While these latter arguments are rather speculative at present, and there is clearly much more research effort required, the authors do hope to indicate pertinent issues for predicting and explaining the results of the research. It is felt that the studies presented show that the simulator environment is ideal for this research, as it provides an environment that is both safe and repeatable. It is also felt that the data from the moving-base simulator looks comparable to that from the fixed-base simulator. This suggests that the data from the fixed-base simulator may be equally valid. The studies do suggest that there are some effects of automation that impact upon driving performance that need exploring further. Most notable is the reduction in workload associated with the automated conditions and the inability of some of the drivers to reclaim control. It is felt that these issues need to be resolved before vehicle automation can be recommended to manufacturers.

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