From Fly-by-Wire to Drive-by-Wire:

Safety implications of automation in vehicles

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The purpose of this paper is to critically review the current trend in automobile engineering toward automation of many of the functions previously performed by the driver. Working on the assumption that automation in aviation represents the basic model for driver automation, the costs and benefits of automation in aviation are explored as a means of establishing where automation of drivers tasks are likely to yield benefits. It is concluded that there are areas where automation can provide benefits to the driver, but there are other areas where this is unlikely to be the case. Automation *per se* does not guarantee success, and therefore it becomes vital to involve Human Factors into design to identify where automation of driver functions can be allocated with a beneficial outcome for driving performance.

KEYWORDS: Automation, Driving, Driver Behaviour, Allocation of Function.

1. Introduction

The trend to automate driver functions wherever possible appears to be an unstoppable force in modern automotive engineering. Accordingly, most major manufacturers have announced plans for a radical revision of the driver's role, such that in the very near future it is likely that much greater reliance for routine vehicle control tasks will be delegated to automated control systems. Included in the list of possible driver activities likely to be "allocated to the machine" are items such as navigation and route finding, vehicle separation, automatic braking and acceleration, cruise control, and lane following, to name but a few. Presumably the human will be assigned a mainly monitoring role in these high technology automobile designs and this is the vision which is constantly being reinforced in the popular press:

> *COMPUTER CAR 2000*
>
> "*Cars of the future will take the stress out of driving. Cars will be installed with an electronic system, which will enable them to travel at high speed, nose to bumper, without fear of collision. As soon as the car is on the guide track on the centre of the road the driver can sit back and watch an in-car video or snooze. Laser sensors will control the distance from the car in front and respond to underground indicators that replace traffic lights. A computer will ensure the vehicle follows a programmed route to the required destination.*"
>
> *(Quest, 1989)*

The question of establishing whether automation is always a desirable strategy has been considered on a number of occasions (e.g., Fitts, 1951; Swain, 1980; Bainbridge, 1983; Billings, 1991; Marsden and Hollnagel, 1994). However, the issue has only rarely been adequately addressed within the context of driver behaviour (however see Michon, 1993 for a notable exception). The purpose of this paper is to try to redress this imbalance by providing an objective assessment to the trend to automation in Advanced Intelligent Vehicle Design (AIVD) by examining the costs and benefits associated with an automation strategy in relation to the psychology of driver behaviour.

As the title of the paper suggests the discussion is based upon the assumption that the dominant model for AIVD comes from the aviation industry. Certainly many of the motor manufacturing industry's plans bear remarkable similarity to aviation design concepts such as "fly-by-wire" and "glass cockpit" technologies. In a review of future technologies for the automotive industry, Stokes *et al* (1990) drew primarily from the aviation environment. Consequently, the evaluation draws heavily on the experience of automation in these areas as a means of gauging where problems with automobile automation are likely to arise. The paper concludes with the suggestion that automated aids must always be designed with the user in mind and that devices designed for use in cars are no exception to this general rule. Such a conclusion means that on some occasions the optimal solution will be to allocate to the human tasks for which automation appears to be a viable option when viewed in purely engineering terms.

2. Overview of arguments favouring driver automation

The arguments favouring automation of the driver role appear to take at least three forms. The first assumes that driving is an extremely stressful activity and consequently, the suggestion goes, automating certain driving activities could help make significant improvements to the driver's well-being. The second argument is similar. Given the fact that human error constitutes a major cause of road accidents (e.g., United Nations, 1986), 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. Each of these arguments is considered in more detail below.

2.1 *Improving the driver's well being*

This argument can be justified on the basis that in certain situations (e.g. busy roads in bad weather) driving is an extremely stressful activity which can lead first to frustration and subsequently to increased risk taking behaviour. Indeed, there is a growing body of evidence to suggest that many traffic accidents occur either during or shortly following an encounter with heavy, slow moving, traffic. Whereas this does seem to concur with common experience it presupposes that the source of stress comes more from the need to react to such conditions rather than simply the experience of them. If this hypothesis is correct then automation may indeed improve the driver's well being. If not, then automation will at best provide no benefits and at worst may increase the drivers sense of frustration by preventing him or her from driving in a way that helps relieve the tension which has built up. Recently, a phenomenon called 'Road Rage' has been reported by the media in the UK. A recent case cited one driver being attacked by another with an axe. This seems to be an extreme example of driver frustration, and one which automation may, or may not, relieve.

2.2 *Enhancing road safety*

The validity of the road safety hypothesis hinges upon the issue of whether automation can and will lead to an overall reduction of the driver errors which are implicated in accident causation. Undoubtedly, the desire to automate is based upon the (correct) assumption that drivers are responsible for most of the vehicle accidents. A recent "Cutting Edge" programme (BBC Television in the UK) entitled "A is for Accident" suggested that 95% of automobile accidents in the UK involve driver error. 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 negated through automation as proposed in table 1. As table 1 shows, most, if not all, of these errors have a technological solution that could reduce the likelihood of the errors by relieving the driver's workload. Whilst studies of mental and physical workload have produced unequivocal evidence to show that if persons are overloaded their task performance does degrade (e.g. Wickens, 1992), there is little evidence to demonstrate that the driver is anywhere near this point of overload in all but exceptional circumstances. Therefore, perhaps automation is meant for exceptional circumstances. If this is so, then driver automation does not clearly follow the aviation model, where automation is an operational necessity rather than an optional extra.

TABLE ONE ABOUT HERE

2.3 *Increasing unit sales*

A final justification for automation can be made on economic grounds. Automation can help provide manufacturers with a means of differentiating from similar products. Undoubtedly automation would enhance the already dazzling list of options and standard items to be offered with a product range. Automation as a feature may well be the salesman's edge over rival products. We must accept that there are many factors that influence the purchasers decision and good human factors/ergonomics may not be the most persuasive feature

3. The Psychology of Driver Behaviour

Potentially, automated systems could relieve the driver of tasks that are too complex, too dangerous and require reactions too quick to be performed by humans. These proposals suggest that automation relieves the driver of excessive demands. A systems model of the driver and vehicle subsystems is illustrated in figure 1. This illustrates the context of the driver and automated systems within the vehicle.

FIGURE ONE ABOUT HERE

Figure 1 shows the way in which information flows between the driver and machine subsystems. Automated systems assume control of the vehicles' sensors and actuators severing the drivers input into the control loop. There seem to be 3 main principles which operate in relation to driver psychology, these are: driving as skilled behaviour, driving as shared resources and driving as risk optimisation.

3.1 *Driving as skilled behaviour (Barber, 1988)*

Driving requires the driver to possess a large set of skills, e.g.: perceptual-motor skills (for steering, changing gear, operating the pedals and other controls) and cognitive skills (decision making, prediction, selective attention and fault diagnosis). The primary task of the driver is to steer the vehicle along an appropriate course to the desired destination. This is a highly skilled task in experienced drivers, but still requires a good deal of attention. Automaticity offers an important explanation in the development of driving skills. The driving tasks (control of the vehicle) will occupy much of the novice driver's conscious attention. This may leave little spare capacity for attending to other associated tasks, such as perceiving hazards. Therefore, hazard perception and the level of driving skill may be interrelated, to some extent. With extended practice, as more of the driving tasks are subsumed to automatic processes, the driver has more attentional resources available for hazard perception. Researchers have demonstrated dramatic improvements in task performance with increased automaticity, and these changes are directly related to practice (Anderson, 1990). Driving as a skill-based activity (in the Rasmussian sense) is in the domain in which humans are generally considered to perform quite well and errors are minimal. Accidents resulting from driver errors stem mainly from risk taking behaviour (see principle 3: *Driving as utility optimisation*), influence of alcohol and violations of traffic rules.

3.2 *Driving demands on limited attentional resources (Wickens, 1992)*

The driver frequently has to deal with several sources of information concurrently, for example, the manoeuvres of other road users, traffic signals, road signs and the local road environment in combination with information from inside the vehicle. It is noteworthy that when traffic conditions worsen, particularly in an emergency, the driver will often allow conversation with the passenger to lapse so that more attentional resources can be devoted to controlling the vehicle. The concept of limited pools of attentional resources (Wickens, 1992) is central to this proposal. The basic premise of this argument is that allocation of attentional resources to one task will result in fewer resources available for another. For example, attentional resources focused on the operation of in-car devices will mean that there are fewer resources available for the task of controlling the vehicle.

Attention may be described using the metaphor of a searchlight (Barber, 1988): the direction of the drivers attention is like the beam of the searchlight and everything that falls within the beam of the searchlight is processed. The limits of human attention can cause problems in the driving task in three ways. First, the driver's attention may be focused on an in-car device and fail to notice that the vehicle is encroaching on a vehicle in front. Second, the driver may fail to focus attention on vehicle control due to the presence of a distraction within the car (e.g. an audible warning). Third, the driver's attention may be divided between too many tasks (e.g. control of the vehicle, route guidance and navigation, operation of in-car devices, control of passengers, avoiding hazards, etc.), which presents problems due to limitations in the driver's ability to time-share between multiple tasks.

Therefore, we argue that there are two main factors to be investigated: attentional resources and direction of visual focus. These factors offer the investigators two performance variables with which to measure the attentional demand placed upon the driver. Driving involves three main tasks of vehicular control, route navigation and hazard avoidance. The demands of route navigation and hazard avoidance can be subtracted from the demands of vehicular control, on the premise that resources utilised will not be available for the primary task. Mental workload is a concept much discussed in the literature on cognitive psychology and human performance. Under certain conditions, the driver may find the demands of performing multiple concurrent tasks overwhelming (Schlegel, 1993). Automation potentially has much to offer in relieving the driver of excessive workload. Overload occurs when the driver is called upon to perform beyond the limits of his or her resources. Task difficulty is obviously a major variable in affecting mental workload (Stokes *et al*, 1990).

3.3 *Driving as utility optimisation (Wilde, 1976)*

This principle is based upon Risk Homeostasis Theory (RHT) as proposed by Wilde (1976, 1988, 1995). RHT makes the controversial assumption that people seek to maintain a target level of risk despite changes in environmental risk. This means that if the environment becomes safer (e.g. the introduction of seat belt laws) drivers will engage in riskier behaviours and conversely, if the environment becomes more dangerous (e.g. poor road conditions due to ice) drivers will engage in more cautious behaviours. This restoration of risk to previous levels, prior to environmental change (e.g. seat belts or ice) is thought to have a homeostatic effect. RHT proponents argue that levels of accident loss return to levels prior to the intervention within 2 years of the change. This theory has major, negative implications for the introduction of automation based upon a safety case. RHT would predict that the introduction of automation to make the driving safer would lead to drivers engaging in more risky behaviours to restore target risk levels. This restoration of risk occurs primarily through a utility optimisation process, RHT asserts that to make driving safer one needs to adjust the level of target risk and this can only occur if environmental changes affect the utilities. The utilities are made up of the costs and benefits of engaging in risky and cautious behaviours.

3.4 *Summary of likely influence of automation on driver psychology*

Psychology's hardest problems often involve the simplest things because they engage mental processes that are so efficient we are unaware of them (Minskey, 1988, cf, Norman, 1988). In particular, we arrive at the following conclusions:

(a) Automation will be relatively ineffective in relation to improvement of driver skills.

(b) Automation could be of assistance in relation to reducing attentional demands.

(c) Automation would make effects of risk homeostasis worse.

Some research has suggested that generic intelligent driver support systems (GIDS) may be able to monitor both the driver and vehicle to improve overall performance (see Michon, 1993, for a report of these systems). Whilst the research community is optimistic about the potential for GIDS, we tread a cautious path to so-called 'intelligent' automation. Whilst it may be technically feasible for computing systems to make some valid comparisons of driver performance against an 'ideal' model of driving, it is questionable whether we would wish to allow automatic systems to intervene if a mismatch in the comparison occurs. There are some occasions when we may intentionally drive in a seemingly erratic manner, for example we may swerve to miss an obstacle that we anticipate will be in our path if we stayed on our existing course. As will be argued, experience gained in other areas suggests that automation does not necessarily hold the key to safer operation of technological systems.

4 Experience of Automation in Aviation

Given, as we suggested at the beginning of the paper, many of the concepts for vehicle automation owe much to automation in aviation, much could be learned from the experiences of automation in aviation. These experiences have led us to identify 4 principal negative outcomes: shortfalls in expected benefits, problems with equipment reliability, problems with skills maintenance and error inducing designs.

4.1 *Shortfalls in expected benefits*

A major problem associated with automated aids arises when the system in question fails to deliver the expected benefits. Performance shortfalls can take a number of forms. For example, one common problems is that automated systems are frequently less reliable than anticipated when introduced into the operational arena. They can also sometimes prove more costly to operate than originally envisaged by the design teams. In yet other situations, automation can have detrimental effects on human performance due to increases (or reductions) in the amounts of information which must be monitored and processed by the user.

To pursue this latter theme one stage further, there is now good evidence available to suggest that automation in aviation has occurred quite rapidly in areas of work where pilot workload demands are already quite low, for example, routine in-flight operations. Automation here has led to increased boredom of flight crews. Conversely, the allocation to automation in areas with inherently high pilot work rates, for example, take-off and landing, can contribute greatly to cognitive strain and team stress due to the need to process ever increasing amounts of information (Billings, 1991; Weiner, 1985; 1989). Indeed, there are several well documented case histories in which automation induced cognitive stress contributed to the occurrence of a serious accident.

Inattention to flight instruments was cited as a probable cause of an accident involving an Eastern Air Lines L-1011 at Miami, Florida on the 29th December, 1972. The crash was thought to have occurred following an accidental autopilot disconnect which went undetected for a considerable amount of time. The crew also failed to notice an unexpected descent in sufficient time to prevent impact with the ground in the Florida Everglades. The accident report noted that the three crew members plus an additional jumpseat occupant were preoccupied with the diagnosis of a minor aircraft malfunction at the time the accident occurred.

Cognitive strain was identified as a factor in an accident which occurred at Boston's Logan Airport in 1973. In this incident, a Delta Air Lines DC 31 struck the seawall bounding the runway killing all 89 persons on board. The cockpit voice recorder indicated that the crew had been experiencing difficulty with the Sperry Flight Director while attempting an unstabilised approach in rapidly changing meteorological conditions. The accident report concluded that the accumulation of minor discrepancies deteriorated in the absence of positive flight management in a relatively high risk manoeuvre. Specifically, the crew were preoccupied with the information being presented by the flight director to the detriment of paying attention to altitude, heading and airspeed control.

A less dramatic example of an instance where automation has failed to meet prior expectation can be illustrated with reference to the case of Ground Proximity Warning Systems (GPWS) which produced a high level of spurious alarms when first introduced into the cockpit environment. The experience of GWPS is similar to many other instances where the implementation of first-generation automation has had detrimental effects on the performance of flight crew due to problems inherent in the prototype design, for example, Traffic Collision Avoidance Systems such as TCAS-II (cf, Billings, 1991).

4.2 *Equipment Reliability*

The question of equipment reliability is clearly an important consideration in the automobile automation debate. Equipment reliability appears to significantly affect human performance in a number of circumstances.

Perhaps the most obvious way that the reliability of automation might effect the quality of human performance arises when the automated system in question consistently malfunctions. In this case, one would expect that the user would, over time, lose confidence in the device to the extent that they prefer to operate in the manual mode wherever possible. Such a hypothesis is supported in a number of scientific publications , conference proceedings and incident reports (see for example, Weiner and Curry, 1980) and need not be considered further in detail here.

Similarly, loss of faith in the reliability of automated aids will occur where devices are prone to faults of an intermittent nature. Intermittent failures in automated aids are potentially more serious for human cognition because they can frequently go undetected for long periods of time only to manifest themselves at a critical phase of operation. Witness the case of Delta flight 1141 which crashed shortly after take-off from Dallas Fort Worth Airport in 1988. The accident was attributed in part to an intermittent fault in the aircraft's take-off warning system which should have alerted the flight crew to the fact that the aircraft was wrongly configured for the operation being performed (National Transport Safety Board, 1989).

Perhaps the most surprising way in which the reliability of automation can cause serious problems for users comes not from system deficiencies, but rather from equipment which has a well proven reliability record accumulated over many years of operation. In this situation, flight crews often come to over depend on automated aids when they are operating in conditions beyond the limits of their designs. Billings (1991) has discussed this aspect of automation at length and suggested that there are many examples where:

> "*...automated systems, originally installed as backup devices have become de facto primary alerting devices after periods of dependable service. These devices were originally prescribed as a "second line of defence" to warn pilots when they had missed a procedure or checklist item. Altitude warning devices and configuration warning devices are prime examples*"

Over-reliance of technology was a factor in an incident involving a China Airlines B747-SP which occurred 300 miles north-west of San Francisco in February, 1989. Towards the end of an uneventful flight, the aircraft suffered an in-flight disturbance at 41,000 feet following loss of power to its Number 4 engine. The aircraft, which was flying on autopilot at the time, rolled to the right during attempts by the crew to relight the engine, following which, it subsequently entered into an uncontrolled descent. The crew was unable to restore stable flight until the aircraft had descended to an altitude of 9,500 feet, by which time it had exceeded its maximum operating speed and had sustained considerable damage. In conducting its enquiry, the NSTB concluded that a major feature of this incident was the crew's over dependence on the autopilot during the attempt to relight the malfunctioning engine, and that the automated device had effectively masked the onset of the loss of control of the aircraft.

A similar conclusion was obtained for another incident which in this case involved a Scandinavian Airline DC-10-30. In this incident, the aircraft overshot the runway at JFK Airport, New York by some 4700 feet. The pilot was, however, able to bring the plane to a halt in water some 600 feet beyond the runway's end. A few passengers sustained minor injuries during the evacuation of the aircraft. The enquiry noted that again the crew had placed too much reliance upon the Autothrottle Speed Control System while attempting to land. It was also noted that use of the autothrottle system was not a mandatory requirement for a landing of the type being performed.

4.3 *Training and Skills Maintenance*

A third way in which automation has been found to have detrimental effects on the quality of human operator performance concerns the knock-on effects which automated aids can have on the knowledge and skills of an individual. The tendency for humans to rapidly lose task related knowledge and skills in partially automated environments is a well documented psychological phenomenon. In the aviation domain the accident involving the collision between two B747's at Tenerife appears to be particularly relevant. In this accident, a highly experienced KLM Training Officer with considerable operational experience, failed to ensure that adequate runway clearance had been given prior to commencing take-off. The findings of the Spanish Commission set up to investigate this incident part attributed causality to the fact that the KLM pilot had insufficient recent experience of route flying with the 747.

While the problems of deskilling are well known, much less understood are the strategies whereby the knowledge and skills possessed by an individual can be developed or maintained such that they can regain control of the system in the event of a malfunction. Barley (1990) has suggested that flight crews often have to deal with the problem of skill maintenance by periodically disengaging the automated systems to refresh their flying skills and/or relieve the boredom of a long-haul operation. One would expect, however, that more effective methods of refresher training could be implemented to ensure the retention and development of automated tasks which rely on human intervention following failure of the technology.

Despite the assumption that skills can be developed through standard proficiency training programmes, there are many examples which can be taken from accident and near-miss reports, which indicate that the human in an automated environment only rarely receives adequate training and exposure to manual task performance. The poor quality of Air Traffic Controller training, for example, was cited as an important factor in two aircraft separation incidents which were investigated at Atlanta Hartsfield Airport on the 10th July, 1980. The investigators concluded that the collisions were the result of inept traffic handling on the part of controllers, and that the ineptitude was due in part to the inadequacies in training, procedural deficiencies, and the poor design of the physical layout of the control room.

Similar criticisms have been made in relation to the standards of preliminary and refresher training received by flight crews, and more than one accident has been attributed in part to mistaken actions made by trainee officers flying unfamiliar aircraft. An example, here is provided by the case of the Indian Airlines A320 (a reduction from an aircrew of 3 to 2 persons accompanied the introduction of automation into the airbus) which crashed short of the runway at Bangalore on February 2nd, 1990 killing 94 of the 146 persons on board. In this incident the primary cause was attributed to the failure of the trainee pilot to disengage the flight director which was operating in an incorrect mode, and the failure of the crew to be alert to the problem in sufficient time to prevent the accident. All members of the flight crew were killed in the accident which may, in retrospect, have been prevented by more effective training in the use of fly-by-wire technology.

4.4 *Error Inducing Equipment Designs*

It has already been suggested that many prototype automated systems are introduced with inherent design flaws which can compromise the effectiveness of the human-machine combination. In the majority of cases, residual design faults are rapidly identified in the operational arena and rectified in second generation technology. In some cases, however, identification of system shortcomings leads not to redesign, but rather to an engineering fix in which a system is, to a greater or lesser extent, patched up.

In their account of cockpit automation, for example, Boehm-Davies *et al* (1983) discuss a case in which a proposal to rectify problems inherent within air traffic control-flight crew voice transmissions by means of a CRT cockpit data link would increase the propensity of the flight crew to make reading errors, rather than the errors of hearing which appeared to be occurring at that time. Furthermore, they suggested that the adoption of such methods of communication would have the effect of depriving flight crews of important information regarding the location of other aircraft within the vicinity. One possible consequence of such a transition could be an increase in the number of air traffic separation incidents.

The experience with Inertial Navigation Systems (INS) would seem to offer a more concrete example of automation with a propensity to induce (or indeed amplify) pilot errors. In this system, developed for flight management purposes, pilots are required to enter way-point co-ordinates by means of a computer console. Incorrect data entry can have catastrophic consequences. It is now widely believed that the aberrant flight of the Korean Air Lines B-747, which was destroyed by air-to-air missiles over Soviet airspace in 1983, was due to the incorrect entry of one or two waypoints into the INS prior to its departure from Anchorage. In less dramatic fashion, the near collision over the Atlantic between a Delta Air Lines L-1011 and a Continental Airlines B-747, was also attributed to incorrect waypoint entry in this case in the Delta aircraft. At the time of the incident the L-1011 had strayed some 60 miles away from its assigned oceanic route.

4.5 *Summary*

It is commonly assumed that automation confers many benefits on complex and dynamic real-world systems (such as automobile designs) and that the advantages of its use far outweigh any disadvantages. While this may be true, it is also the case that automation can create special problems for the human component of a highly automated system. The review indicates that there are a number of important limitations to the design and implementation of automated aids.

5 Allocation of System Function

The question of allocating function to humans or machines has been of interest to Human Factors for over 4 decades. It is highly appropriate to apply the paradigm to the problem of determining which function to allocate to the driver a which functions to allocate to the automated systems. The process for allocation of function for driving tasks is summarised in figure 2, which shows the main steps. Singleton (1989) argues that optimal allocation depends upon technological capability and the feasibility of human tasks.

FIGURE 2 ABOUT HERE

The first step is to separate driver function into discrete categories. This serves as a basis for allocation. Functions are either allocated to the driver or to automation. These allocations may be validated by task analysis (see Kirwan & Ainsworth, 1992, for details of methods) and technological assessment. If the validation outcomes are satisfactory, the functions are transformed into design activities.

There are a number of methods for allocating function, including Tables of Relative Merit (TRM), psychometric approaches, computational aids and the Hypothetical-Deductive Model (HDM). The TRM approach is perhaps in its most well known form as the Fitts' List (1951). This list is continually being updated, for example the Swain list (1980). The TRM method employs the task dichotomy approach: tasks that machines are good at humans are poor at and vice versa. Essentially all of the approaches characterise the differences in abilities between humans and machines. When these differences have been determined, decisions can be made to form prescriptions for the design of systems. In an extensive review, Marsden (1991) concluded that more formal and balanced approaches to allocation of function (such as HDM) offer a significant advance on the TRM approach. The HDM (Price, 1985) consists of five main stages: specification (in which the system requirements are clarified), identification (in which system functions are identified and defined in terms of the inputs and outputs which characterise the various operations), hypothesise solutions (in which hypothetical design solutions are advanced by various specialist teams), testing and evaluation (in which experimentation and data gathering is undertaken to check the utility of functional configuration for the overall design) and finally optimisation of design (in which design iterations are made to correct errors).

The central part of the approach is the third stage (hypothesise solutions), in which the role of the Engineering team is to hypothesise primarily technological solutions and the Human Factors team take responsibility for hypothesising people-based solutions. Following this, the two teams interact to produce solutions involving human-machine combination. Those functions which have no acceptable allocations re-iterate back to stage 2 (identification). This re-iteration continues until an acceptable allocation can be made.

Integral to this process is the determination of which tasks are best performed by humans, machines, both humans and machines or neither humans or machines. This allocation requires some formalisation of a decision matrix (see figure 3).

FIGURE 3 ABOUT HERE

The decision matrix is divided into six regions, labelled Uh, Ua, Uah, Ph, Pa and Pha (where U = unacceptable, P= preferable, a = automatic systems and h= humans). To take a hypothetical example of driving, it is important to develop an understanding of what the driver is attempting to do in order to determine what to automate and at what level to automate. A taxonomic analysis of driving has led to seven categories of driver tasks (Webster *et al*, 1990 cited by McLoughlin *et al*, 1993). These categories are: signalling, steering, accelerating, waiting, yielding, stopping and calculating. Some, if not all, of these tasks are potential candidates for automation. In figure 3 we have plotted points on the decision matrix where we feel that these might be placed by a design teams (where 1 = signalling, 2 = steering, 3 = accelerating, 4 = waiting, 5 = yielding, 6 = stopping, 7 = calculating). This is intended for the purposes of an example only, not a fully validated allocation of function. However, it does support the principle that any task can be plotted against both axes and relative to other tasks.

We suggest that for most driving tasks dynamic allocation of function (see the decision matrix shown in figure 3) is likely be optimal (i.e. the co-operative automation indicated in table 2). Automation differs in the degrees of control, from no control to partial control to full control (Meister, 1989) as illustrated in table 2. Automation can be classified into at least 2 categories, automation that replaces driver performance and automation that assists driver performance. This dichotomy is illustrated in table 2, denoted as "Full" and "'Co-operative" automation respectively.

TABLE 2 ABOUT HERE

This approach would avoid the problems of restricted operation. Thus we are not calling for an end to the automation race, rather the consideration and involvement of the driver in the automation of tasks.

6 Conclusions

In learning the lessons from automation in aviation we may anticipate at least 4 potential types of problem for automation in automobiles: (i) shortfalls in expected benefits, (ii) problems with equipment reliability, (iii) training and skills maintenance, and (iv) error inducing equipment designs. Conclusions for these are drawn.

(i) Automatic systems seem to have shortfalls in expected benefits when introduced into the operational arena. In terms of vehicular automation, this could mean that they turn out to be less reliable (e.g. the collision avoidance system fails to detect approaching object), more costly (e.g. the automated systems add substantially to the purchase price of the vehicle) and have an adverse impact upon human performance (e.g. automation seems to make the easy tasks boring and the difficult tasks even more difficult).

It is also worth noting that alarms generated by the automated and non-automated systems can be a source of confusion to the human operators of the system. It is a particular irony that alarms seem to be of least use when thay are most needed. Some research has called for the need for clear priorities in situations of high demand, but unfortuately most alarm information is context dependent. What may be a high priority in one context could well be a low priority in another. This adaptive context-dependent prioritisation calls for a level of intelligence not yet technically feasible. Argueably more effort should be directed at improving the alarm interface (Stanton, 1994).

(ii) Automatic systems can have problems related to equipment reliability. In terms of vehicular automation, this could mean that drivers lose their trust in the automated systems (e.g. the driver prefers to choose the manual alternative), intermittent faults could go undetected until the context becomes critical (e.g. the failure reveals itself immediately prior to the vehicle impacting at high speed into another vehicle) and the driver becomes so dependent upon the automated systems that they operate them beyond design limits (e.g. invoking Automatic Intelligent Cruise Control in non-motorway situations).

(iii) Automatic systems seem to lead to problems related to training and skills maintenance. In terms of vehicular automation, this could mean that driving skills could be stripped away through lack of practice by automation being in control. This is likely to make the driver even more dependent upon the automated systems. If drivers are not performing a function, how can they be expected to take it over adequately when the automated systems fail to cope?

(iv) Finally, automatic systems seem to induce errors in users. In terms of vehicular automation, this could mean that design flaws lead to driver errors when interacting with the automated systems, for example specifying the wrong target speed and distance with Automatic Intelligent Cruise Control. Of particular concern is the possible introduction of mode errors (i.e. the driver believes the system to be in one mode when it is actually in another). Mode errors are most likely when controls have more than one function and the mode the system is not transparent.

From our analysis of automation in the context of aviation, we see the need for caution in the pursuit of automation of driver functions. This need for caution is also voiced by pilots in their own domain in discussing the A320 Airbus, as the following quote indicates:

"*I love this aeroplane, I love the power and the wing, and I love this stuff* [pointing to the high-technology control panels] *but I've never been so busy in my life...and someday it* [automation] *is going to bite me*"   (Anon, 1991)

This observation makes two problems with automation very clear: the problem of increased workload and the anticipated problem of lack of co-ordination.   We propose that allocation of function needs to explicitly examine co-ordination and co-operation between human and automated sub-systems if the problems of automation in aviation are not to be replicated through automation in automobiles. Automation can have beneficial effects upon system performance, but automation for its own sake can have unforeseen risks which can only be determined by a structured evaluation.

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ERROR	AUTOMATED SOLUTION
Get into wrong lane	Navigation system
Forget which gear	Automatic gear shift
Only half an eye on the road	Fully automated driving system
Distracted, need to brake hard	Anti-lock Braking System
Plan route badly	Route planning & navigation system
Fail to recollect recent road	Navigation system
Wrong exit from roundabout	Navigation system
Intended lights, switched wipers	Daylight sensor and automatic lights
Forget light on main beam	Automatic lighting
Usual route taken by mistake	Navigation system
Misjudge speed of oncoming vehicle	Collision avoidance system
Queuing, nearly hit car in front	Collision avoidance system
Driving too fast on dipped lights	Vision enhancement system
Turn left into cars path	Collision avoidance system
Miss motorway exit	Navigation system
Manoeuvre without checking mirror	Collision avoidance system
Fail to see pedestrian crossing	Collision avoidance system
Brake too quickly	Anti-lock Braking System
Hit something when reversing	Collision avoidance system
Overtake without using mirror	Collision avoidance system
Misjudge gap in car park	Collision avoidance system
Turning left, nearly hit road user	Collision avoidance system
Misjudge interval turning right	Collision avoidance system
Try to pass vehicle turning right	Collision avoidance system
Fail to see pedestrian stepping out	Collision avoidance system
Attempt to drive off in third	Automatic gear shift
Try to drive without starting car	Automatic start-up

Table 1. Driver errors (from Reason et al, 1990) and possible automated solutions.

Functions	None	Co-operative	Full
Gear shift	Driver shifts gear	Automatics shift gear if driver does not: driver can override	Automatics shift gear
Steering	Driver steers	Automatics steer if driver does not: driver can override	Automatic steer
Braking	Driver brakes	Automatics brake if driver does not: driver can override	Automatics brake

Table 2. Degrees of automation for driver tasks

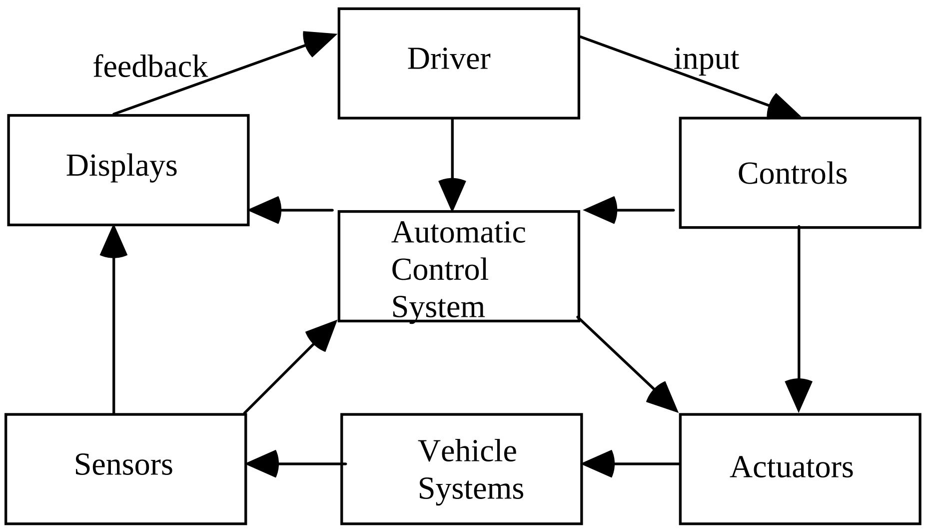

Figure 1. Information flow between driver, automatics and vehicle sub-systems

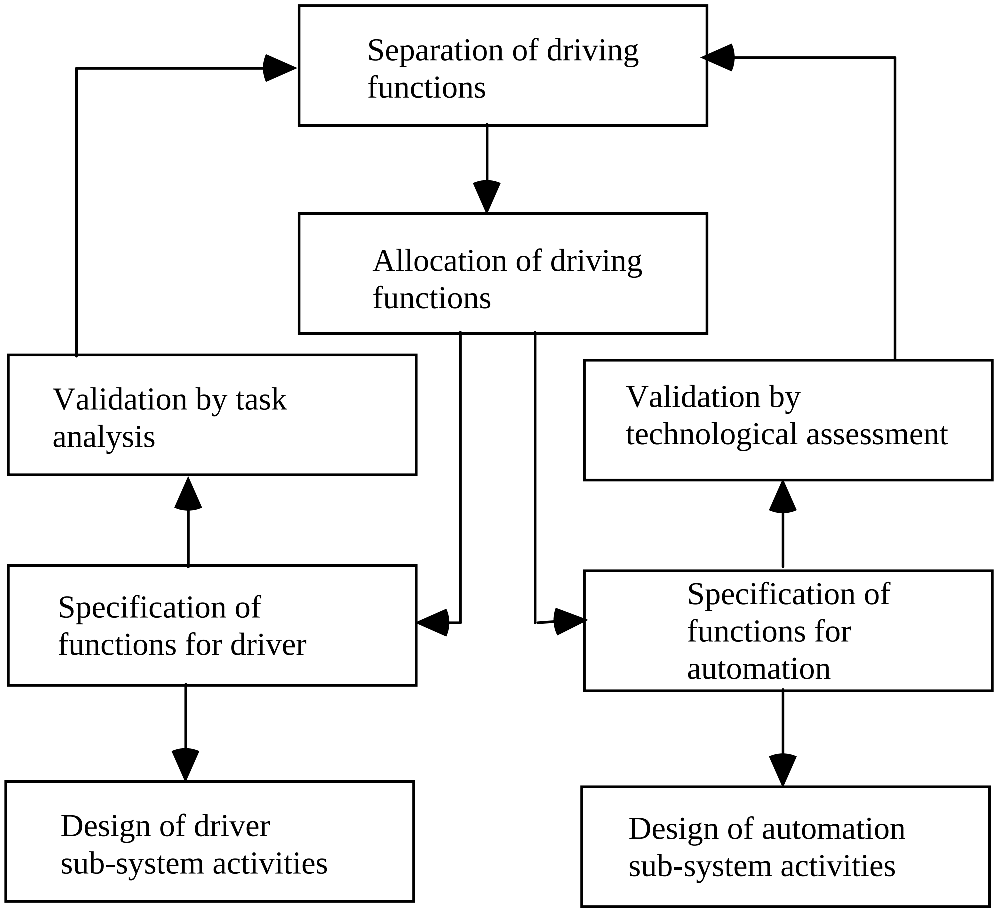

Figure 2. Allocation of Function concept (adapted from Singleton, 1989)

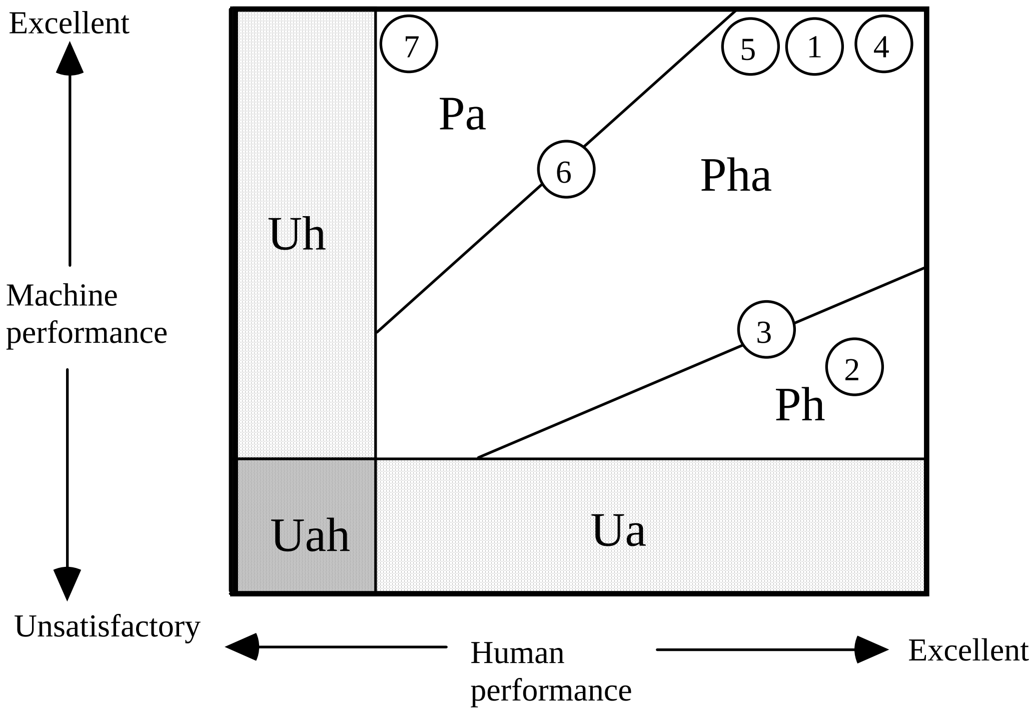

Figure 3.   Example of a decision matrix for allocating function in the HDM