TO DELEGATE OR NOT TO DELEGATE

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There have been significant advances in technology that will eventually see us viewing the use of autonomous cars as a common occurence. Various systems are already on the market that provide the driver with different levels of decision support. This paper highlights the key human factors issues associated with the interaction between the user and an autonomous system, ranging from assistive decision support and the delegation of authority to the automobile. The level of support offered to the driver can range from traditional automated assistance, to system generated guidance that offers advice for the driver to act upon, and even more direct action as initiated by the system itself. In many of these instances the role of the driver is slowly moving towards one where they are acting as a supervisor of a complex system rather than taking direct control of the vehicle. Different paradigms of interaction are considered and focus is placed on the partnership that takes place between the driver and the vehicle. There is a wealth of knowledge in the aviation literature that examines such technology partnership and this paper will draw on relevant comparisons to assist the community to better understand the underlying issues that have already been witnessed in the cockpit between the human and their interaction with complex systems.

1 Introduction

With an increasingly congested road network the existing road infrastructure is unsufficient at meeting the growing demand placed on it; with resulting economic, sociological and environmental consequences. Alongside this is a strong desire to improve efficiency and safety. This can either be achieved via sociological, economic or political means. Human error involving drivers is at the centre of accident causality and thus advances in autonomous systems[1] are hailed as the harbinger of a technology that can potentially

[1] In the scope of this paper, the term autonomous system will be defined as the quality of being able to perceive information from the environment and then the ability to act upon it.

reduce road fatalities in the future. What better way to reduce human error than by removing the human driver? The impetous behind some of these decisions is directly related to the advances in technology that can assist in the management of the traffic infrastructure (such as intelligent transport systems) or those technologies that can be provided in-vehicle such as driver assistance systems. Several states in the United States (including Nevada, Florida, Michigan and California) have reflected this growing appetite by passing legislation that allows the introduction of autonomous cars onto public highways.

2 Advances in Technology

If we look across the current range of autonomous cars (Google, Toyota, Nissan, BMW, to name but a few) we can see they are all actively researching the integration of autonomous decision making technologies into some vehicle models. Although there are differences across these manufacturers in terms of their approach to integrating autonomous systems, they all have one thing in common – a driver.

With the onset of smaller and cheaper sensors we have seen a migration of such technology transfer from other domains into the automotive community. For example, the development of LiDAR (“Light Radar”) was initially designed for uses in analysisng meteorological conditions (specifically cloud density). Modern LiDAR systems have been used in unmanned ground vehicles for detecting obstacles whilst navigating. Perhaps the best known use of this within a car is the Google (‘Chauffeur’) car, with it’s recognisable spinning LiDAR mounted on the roof. At the moment this technology is expensive but there are already moves to produce a more affordable version of this technology that could be integrated into other cars.

LiDAR is but one of many different sensor technologies currently available to be integrated within an intelligent automotive system. Predominantly ultrasound technology is used in advanced driver assistance systems (ADAS) for parking and proximity/separation. Examples of the number of possible applications that sensors may be integrated into the vehicle are shown in Figure 1.

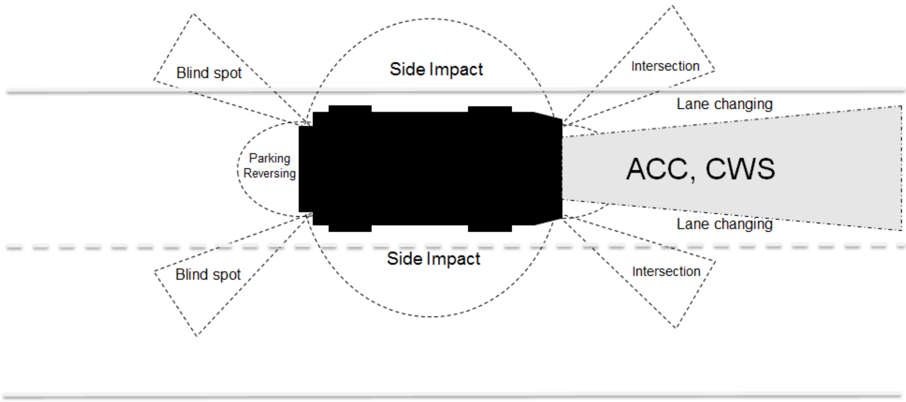

Figure 1: Some available automotive sensor applications

If we therefore assume that systems, such as intelligent collision avoidance, are integrated into the existing traffic network then how would drivers use such a system? There is one of two ways in which the system could be seen to interact with the user. For example, an autonomous car will be able to respond to an event or situation that is perceived by the system (using on-board sensors) as a potential threat and (1) will advise the driver on what action to take and place authority on the driver to respond, or (2) the car will be authorised to take action in order to avoid an accident. The need for a framework of delegating authority between the system and the user would clearly be of benefit.

3 Automation and Human Performance

The implication of incorporating an element of autonomy or automation predicates the delegation of authority, by the human, to the system.

There are many theories of automation that suggest that the human should always have the final say in any decision involving safety [1] [2]. Such a stance represents a human-centred approach to automation, whereby the human always has authority over the decision-making elements within the system. However, delegation of control authority has been outlined in thoeries of adaptive automation [3] [4] whereby the system is authorised to make certain decisions on behalf of the human. An existing example of this is the demonstration of automotive collision avoidance braking systems [5] [6]. The application of automation can be viewed in most domains as an attempt to reduce the workload burden of the operator whilst also offering a higher level of safety and efficiency. This is particularly valid in the aerospace domain, where over the last thirty years we have witnessed a revolution in automated flight decks [7]. Of course, while there is a great deal of literature citing the benefits of increasing automation, there is evidence that points to its possible drawbacks. What we can conclude form the literature is that by increasing the level of automation in an attempt to mitigate instances of human error, it does not eliminate it altogether. In fact what we are confronted with is a different type of human error. Again, we can look at examples in aerospace where incidents of automation bias [8] and automation surprise [9] have been regarded as a confounding factor in many accidents. For example, the tragic flight of Air France 447 in 2009 is testament to how a highly skilled flight crew can suddenly lose situation awareness when a system is under automatic control. While cases such as these are rare, we are compelled to learn from them in order to assure that the same mistake is not made again. The importance of providing the human with a good understanding of what the system is doing (and why) is essential – especially in instances where a system failure or change in situation is presented. Much like humans, systems can fail and are fallable. Therefore it is important that we do not stand in awe of such advanced systems but rather try to optimise the relationship in a safe and effective manner.

4 Frameworks for Delegating Control Authority

Autonomous cars are sometines referred to as ‘driverless’, which is misleading. It is not about taking control from the driver, but allowing them to delegate authority to the system. To facilitate the interaction between the human and the system a framework is required that defines the delegation of authority under a variety of different circumstances.

The traditional model for defining the levels of automation was put forward by Sheridan & Verplank (1978), and later revised by Parasuraman, Sheridan & Wickens (2000) [10,11]. This framework offers ten levels of automation between the human and the system, ranging from the human making all decisions (Level 1) to the system making all decisions on behalf of the human (Level 10), as in Table 1.

Table 1: Levels of Automation (Sheridan & Verplanck, 1978).

LOA	DESCRIPTION
10	Fully Autonomous: The automation system decides everything; act autonomously, yet collaborating with other automation systems, ignores the human.
9	The automation system informs the human supervisor only if the system decides to.
8	The automation system inform the human, only if asked.
7	The automation system executes autonomously and then necessarily inform the human supervisor.
6	The automation system allows the human supervisor a restricted time to veto before automatic execution.
5	The automation system executes that suggestion if the human supervisor approves.
4	The automation system suggests one decision action alternative.
3	The automation system narrows the decision choice selection down to a few.
2	The automation system offers a complete set of a decision/action alternatives.
1	The computer offers no assistance, human must take all decisions and actions

It is possible to view this scale as a progressive change in delegation from the human to the system. There are various iterations of delegated authority between these two extremes and it thus provides us with a useful understanding of the type of interaction required.

Within the aerospace domain there is a variation of this, whereby a pilot may delegate authority to the aircraft to perform some preordained tasks. This is referred to as the PACT (Pilot Authorisation and Control of Tasks) framework, as shown in Table 2. Bonner, Taylor, Fletcher & Miller (2000) outline the different levels of delegated authority that can exist between a user (in this instance a pilot) and a system that may be either highly automated or autonomous [12].

Table 2: The PACT Framework (Bonner, Taylor & Miller, 2000).

Mode	Level	Operational Relationship	Computer Autonomy	Pilot Authority
AUTOMATIC	5	Automatic	Full	Interrupt
ASSISTED	4	Direct support	Advised action unless revoked	Revoking action
	3	In support	Advice, and if authorised, action	Acceptance of advice and authorising action
	2	Advisory	Advice	Acceptance of advice
	1	At Call	Advice only if required	Full
COMMANDED	0	Under Command	None	Full

The PACT framework offers three basic modes of automation: (1) fully automatic, (2) assisted, and (3) under human command. This provides a framework that can assign different levels of autonomy to different tasks; ranging from routine processes to safety critical events.

Within the automotive sector there has been a similar push to address the levels of autonomy for driver-vehicle interaction. In the United States of America the National Highway Traffic Safety Administration (NHTSA), a Government Agency concerned with writing and enforcing regulatory standards for the highways, has defined several levels of autonomous driving (see Table 3). Using this classification we can clearly see that the majority of autonomous cars (such as the Google system) may be viewed as adopting a system that is closer to Level 3.

There is a need for a better understanding of how a driver interacts with an intelligent vehicle. This must allow for different modes of autonomy that allows the driver the flexibility to delegate different levels of control to the system at different times.

Table 3: NHTSA classification of vehicle automation.

Level	Function	Description
0	No automation	Driver in control
1	Function-specific automation	One or more specific primary control system utilises automation
2	Combined function automation	At least two primary control systems are automated in order to assist the driver
3	Limited self-driving automation	Driver is able to cede all safety-critical functions to the vehicle in some instances
4	Full self-driving automation	Vehicle able to perform all safety-critical driving and monitor external conditions

There may be instances that dictate the driver having full control of the vehicle (simply to allow the individual to choose when they want to drive) or as a system that offers opportunities for the vehicle to be controlled by the autonomous system. This would either be seen as a benefit in the reduction of frustration or workload of the driver, or even have the potential to let the autonomous system act as the supervisor of the driver (basically as safety mechanism). The model in Figure 2 highlights the relationship between the car and driver in terms of control, and the delegation of authority.

By examining the three levels it is possible to categorise manual (Driver Authority), semi-autonomous (Adaptive Assistance), and fully autonomous (Car Authority) modes. The shift in terms of control is seen as the balanced interaction between the driver and the car and the dynamic changes based on what level of control (direct/indirect) is delegated.

It is important to remember that in all instances the driver will always be responsible for the safe operation of the car, regardless of what level of assistance is engaged.

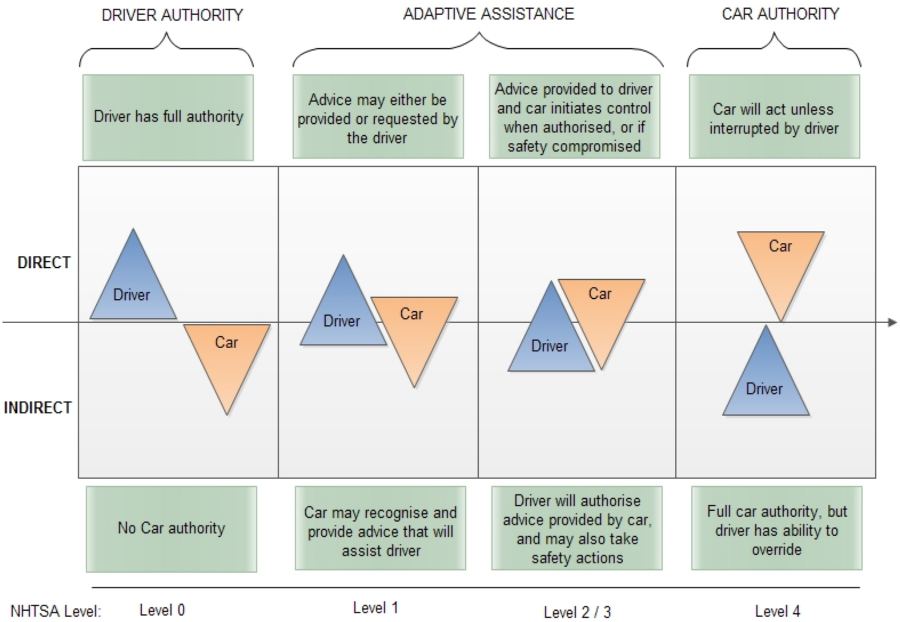

Fig. 2 Model of control delegation between driver and car

5 Cognitive Aspects of Supervisory Control

It may be argued that the more automation or decision support the user is provided then it is more important to provide the user with a better understanding of what the system is doing. The active monitoring of a highly automated system is cognitively demanding [13] and requires a high degree of vigilance on behalf of the user [14]. In order to reduce the likelihood of human error it is important that the individual attains a sufficient level of situation awareness pertaining to their situation and context [15]. Mental workload has also been cited as having a detrimental effect on human performance and safety [16]. However, if mental workload is reduced and situation awareness is maintained then the issue monitoring the system suddenly becomes a critical aspect in using the system [17]. The lack of vigilance has often been linked to a number of accidents that have ranged in severity [18]. The mental model that the user possesses is not only important in terms of evaluating when a mode error is made in automated systems [19], but also in terms of the change in perceived control that the user has over the system.

The introduction of an interactive cognitive task has been shown to counteract the effect of mental underload both in terms of physiological measures of arousal and subjective assessment of alertness [20]. By providing a degree of cognitive effort, in terms of a secondary task, it is possible to maintain a degree of attention that facilitates a degree of *functional vigilance*. Traditionally adaptive decision support systems have been used to provide assistance to users who need to make timely (and sometimes) safety-critical decisions whilst under great task demand or mental overload. For example, if we consider an adaptive automation system on the flight deck the pilot would welcome a decision support system that would monitor user physiological indices for symptoms of mental overload. However, similarly an adaptive system could also monitor for signs of metal underload and provide cognitive cues (akin to an interactive cognitive task) in order to maintain levels of vigilance and alertness.

6 Discussion

We are seeing a shift in the traditional role of the driver, but this does not diminish the driver's responsibility; it merely changes how the driver interacts with the system. The majority of use cases for autonomous cars place the user in the traditional driving seat in front of a steering wheel, but in essence 'hands free'. However, that is not to say that the driver requires less opportunity to interact with the vehicle; in some instances we could argue that the driver requires more information. As soon as the driver delegates control authority to the vehicle then this is more than a simple task shift, but a a more complex interaction of trust, reliability and safety. In autonomous mode the driver no longer requires the traditional control interface with the vehicle. The placement of hands on the steering wheel and feet situated above pedals seems superfluous to the act of delegation. Indeed, when the vehicle is within autonomous mode the steering wheel and pedals act as means by which the driver may take control back from the system – much like the way in which ADAS currently operates. However, there will still be a requirement for the driver to be supplied with appropriate cues for effectively monitoring and supervising the autonomous system.

Taking examples from the highly automated flight deck there have been many instances of human error routed within vigilance and situation awareness. There are a number of psychological phenomenen that have been cited as occurring in automated systems. These range from Mode confusion, automation bias to automation surprise.

Providing an increased level of support to the user by introducing automation and decision support has obvious benefits in terms of reducing cognitive load and reducing some elements of human error. However, Kantowitz & Sorkin (1987) observed that increasing automation can also leave the human as a simple monitor of automation and possibly requiring specific training. Humans are poor at monitoring systems due to the nature of vigilance and situations with low perceptual stimuli [21].

Some results have already suggested that users are willing to accept certain levels of delegated authority when it comes to safety. For example, Itoh, Horikome, & Inagaki (2013) found drivers approved of a semi-autonomous collision avoidance system that would present the driver with an auditory tone before performing a safety manoeuvre [22]. The technology that will facilitate the introduction of the autonomomus car has entered a phase of demonstration, with the Technology Readiness Levels (TRL) getting closer to market introduction. What is less mature is the associated understanding of how drivers will adopt to this new style of driving. We often view these systems as being intelligent and in some cases out-performing the human, with little regard for the implicit nature of the sharing of the primary task and objective that in essence represents a shared goal between human and system [23]. On the occasion that the human is happy to delegate control to the system, thought is needed as to how to keep the user in-the-loop in terms of maintaining situation awareness. Good situation awareness is essential not just for monitoring the system in terms of ensuring it is safe, but more so for predicate events that suddenly occur when there is a system failure or the system recommends the human take control. In such instances human trust in the system may very well lead to a dangerous degree of complacency. As we have seen in other domains this is all too common and can lead to tragic consequences. This is why, for the foreseeable future, a driver of an autonomous car will be legally required to be paying attention to the road at all times (as is legally required in some of the US States that have alredy passed legislation).

7 Conclusion

The use of an autonomous car is not about taking control away from the driver, but allowing him/her to delegate authority to the system. This changes the nature of the driving role with the driver adopting a more supervisory approach to monitoring an intelligent system. In order for this interaction to be effective it is important to design the system that allows the user to understand not only what the system is currently doing (and plans to do), but what the system *cannot* do also. This builds a partnership of honesty between the user and the system that recognises not just human limitations, but instances whereby the system will not be able to cope.

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