Trust in Vehicle Technology

*Guy H. Walker[1], Neville A. Stanton[2] & Paul Salmon[3]

[1]School of the Built Environment, Heriot-Watt University, Edinburgh, [UK]EH14 4AS.

[2]School of Civil Engineering and the Environment, University of Southampton, [UK]SO17 1BJ.

[3]University of the Sunshine Coast Accident Research Centre, Maroochydore DC, Queensland, 4558 Australia.

*Corresponding author: G.H.Walker@hw.ac.uk

Abstract

Driver trust has potentially important implications for how vehicle technology is used and interacted with. In this paper it will be seen how driver trust functions and how it can be understood and manipulated by insightful vehicle design. It will review the theoretical literature to define steps that can be taken establish trust in vehicle technology in the first place, maintain trust in the long term, and even re-establish trust that has been lost along the way. The implication throughout is that trust is a good thing for the acceptance of vehicle technology, and for safe, efficient and enjoyable driving in general. The further implication is that trust is a powerful variable that is available to be favourably manipulated by the vehicle designer to ensure successful implementations of vehicle technology.

Introduction

The modern day automobile continues to be filled with more and more new advanced technologies. As vehicle designers, we are expecting drivers to use these complex forms of new technology even though they may have little idea about the underlying principles and mechanisms behind their function. To use new vehicle technology essentially means putting drivers in a situation of uncertainty and incomplete knowledge, asking them to place their lives in the hands of unknown technologies, potentially, to put themselves “at risk or in vulnerable positions by delegating responsibility for actions to another party” (Lee & See, 2004, p 53). Whether we intend it or not, we are asking drivers to trust the vehicle systems we are designing. If they do not, these vehicle systems will, to use Parasurman’s (1997) words, be disused, misused or even abused, yielding unexpected outcomes with potentially serious cost and safety implications (Merritt et al., 2013).

Trust has been a growing topic of interest in several other applied domains (e.g. Kramer & Tyler 1996; Hoffman et al., 2013; Parasuraman and Wickens, 2008; Tharaldsen, Mearns, & Knudsen, 2010; Stanton et al, 2011; Yagoda & Gillan, 2012; Geels-Blair, Rice & Schwark, 2013; and not least the excellent review by Lee & See, 2004). Studies have also appeared previously in this journal (Kazi et al., 2007). Given this growing body of work it seems appropriate to visit trust from a vehicle design perspective and see in what ways the concept could help us. What is trust? The Oxford English Dictionary describes trust as a *"firm belief in reliability* [in a] *person or thing; confident expectation."* (Allen, 1984). This is a simple definition for a complex, multi-disciplinary, multi-faceted, and multi-level construct (Tharaldsen, 2010). There can be little doubt that: *"perhaps there is no single variable which so thoroughly influences interpersonal and group behaviour as does trust.* [..] *Trust acts as a salient factor in determining the character of a huge range of relationships. Trust is critical in* [..] *task performance."* (Golembiewski & McConkie, 1975, p. 131).

Trust has a number of important aspects. Firstly, to judge by the often value laden adjectives used to describe it, there is an emotive, social-psychological aspect (Merritt, 2011). To be bestowed the attribute of trust-worthiness is good, virtuous and desirable; to be labelled un-trustworthy is negative, for people as well as vehicle systems. Secondly, the establishment of trust enables things to be done and plans to be made, especially in situations of incomplete knowledge and increasing complexity (Beller, Heesen & Vollrath, 2013). It therefore has a behavioural aspect. Thirdly, trust has a cognitive dimension, one bound up with the way in which drivers process information as they drive. Lee and See (2004) rightly allude to the fact that this more ‘mechanistic’ approach to trust is often overstated, when in fact the emotive/affective aspects of it could be just as, if not more powerful. Stanton and Young (2000) proposed that trust was interrelated to other psychological factors in vehicle automation, including vehicle feedback, driver locus of control, driver workload, driver stress, driver situation awareness and mental representations. Understanding these relations is not easy because they are both mediated by, and interactive with, experience and events. Some of this complexity is revealed in the model proposed by Stanton and Young (2000) along with others proposed by , who argue it is necessary to understand the complex interplay of factors within the model if useful design recommendations are to be derived. A useful organising framework for current purposes, one which helps to situate trust as an intervening variable in human/technology systems more broadly, is the Theory of Planned Behaviour (TPB; Ajzen, 1991).

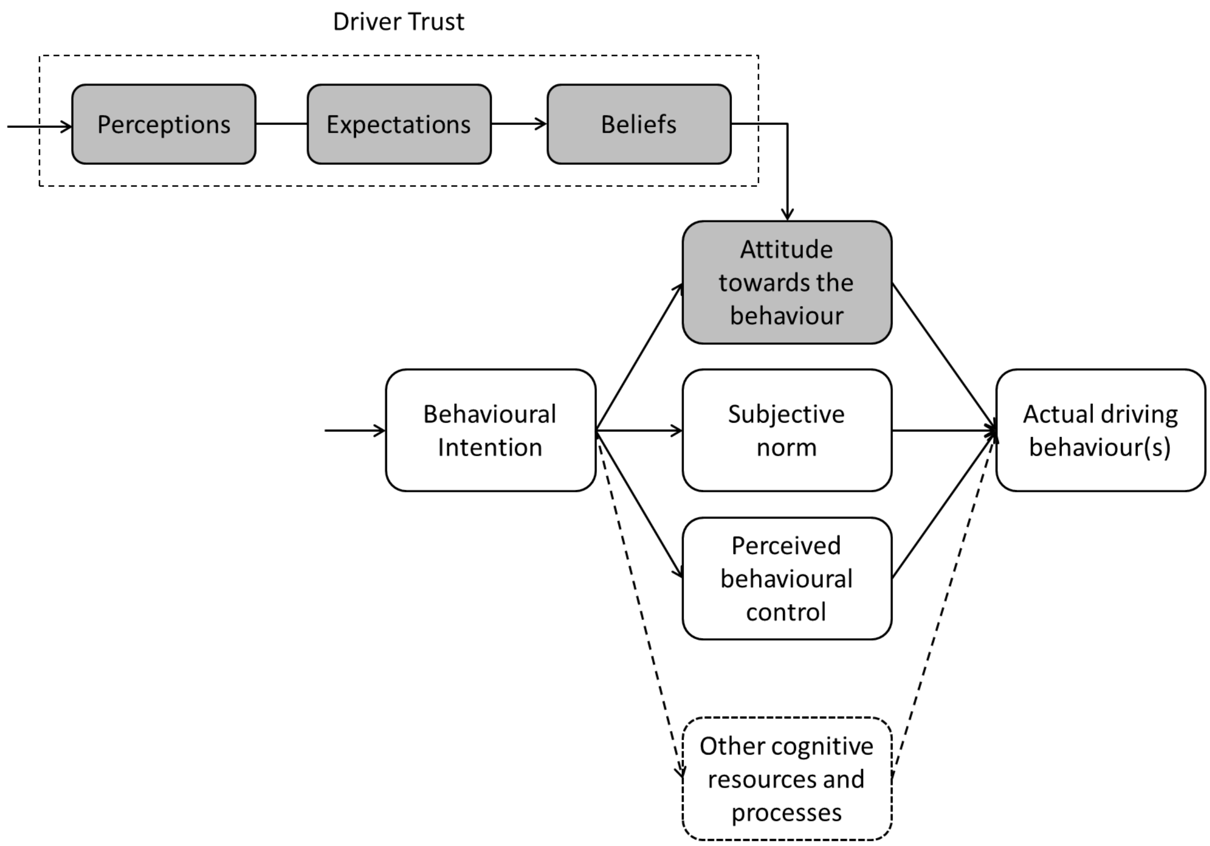

Figure 1 – The Theory of Planned behaviour can be used as a simplified behavioural model within which to situate trust and its effects on behaviour.

Under this rubric the main determinant of actual driver behaviour is an intention to perform it. Of course, drivers do not carry out every behaviour they intend to perform because of the modifying influence of other cognitive, social psychological and emotional/affective factors. The cognitive element is captured by the various information processing activities that are performed, including issues around disposition (Merritt & Ilgen, 2008), the degree of behavioural control (Rotter, 1966) and decision-making biases (Rice, 2009), amongst others. The social-psychological component is captured in the intended behaviour being situated within a set of socially defined norms governing whether a behaviour is normal/acceptable

(Lewandowsky, Mundy & Tan, 2000). Finally, and importantly for trust, is the emotional/affective component captured under the various attitudes the driver has about the behaviour (Merritt et al., 2013). Attitudes describe a negative or positive evaluation of the intended behaviour, informed by beliefs and expectations that certain positive or negative outcomes will arise in the future. Beliefs and expectations are an integral part of trust.

The TPB has been used in numerous transportation contexts (e.g. Effrat & Shoham, 2013; Elliot, Armitage & Baughan, 2005; Palat & Delhomme, 2012; Paris & Van den Broucke, 2008 etc.) and is premised on the idea that in order to elicit the driver behaviours we want, a worthwhile strategy is to understand the underlying beliefs and target them, rather than the behaviour itself. According to the TPB, therefore, trust can have a significant effect on the attitudinal component of behaviour, and whether something is performed at all. This experience is common. In many cases the physical 'engineering' properties of vehicle systems remain constant, but some people like automatic gears, others do not, some react with horror at the prospect of drive by wire, others with enthusiasm. Trust is an important intervening variable because drivers do not have complete in-depth knowledge of the system they are using, and are basing their decision to make use of it on more than its objective 'engineering' performance (e.g. Lewandowsky et al., 2000). Individual drivers are bringing something much more complex and subtle than a rational cost-benefit analysis to the driving scenario, and trust provides valuable insight into exactly what (Muir, 1994).

Establishing Driver Trust

Trust is necessary to reduce complexity, save time and the amount of physical and mental energy expended on a task. Trust, however, is not simply present or absent. It is a dynamic phenomenon, moving along a continuum, spiralling upwards or downwards based on perceptions of how the vehicle system operates, beliefs about what those perceptions mean, and the positive or negative attitudinal attribution that arises. Distrust, therefore, can just as easily evolve when perceptions do not conform to beliefs (Zand, 1972). From the vehicle designer's point of view the key question is how trust builds and grows, and how can vehicle technology be designed to facilitate it? Lee and Moray (1992), Muir (1994), and Muir and Moray (1996) offer some of the most interesting foundational work on trust in automation. A primary feature of this work is the deployment of Rempel, Holmes and Zanna's (1985) classifications of predictability, dependability and faith. These are not the only trust classifications by any means (e.g. see review by Lee & See, 2004; Zuboff, 1988; Barber,

1983) but they are a convenient organising framework to discuss how driver trust is constructed and de-constructed.

Predictability

In a recent meta-analysis (Hancock et al., 2011) system performance had the biggest effect on the development of trust (with a medium to large effect size of d = 0.71, p 522). A number of vehicle design issues are relevant here. The first is that drivers can be extremely sensitive observers of vehicle performance and capability (Horswill & Costa, 2002). Hoffman and Joubert (1968), for example, obtained just noticeable difference data on a number of vehicle-handling variables and discovered “a very high differential sensitivity to changes of [vehicle] response time, and reasonably good ability to detect changes of steering ratio and stability factor”. Joy and Hartley (1953 – 54) describe this level of sensitivity as corresponding roughly to “the difference in feel of a medium-size saloon car with and without a fairly heavy passenger in the rear seat”. This level of sensitivity places the onus on the designer to make the function of new technology transparent to the user (see Beller, Heesen & Vollrath, 2013), perhaps despite the temptation to do the opposite (e.g. Loasby, 1995; Norman, 1990; Walker et al., 2006).

The second design issue relates to the wider context in which the vehicle operates. According to Social Learning Theory (e.g. Rotter, 1971, 1980) “expectations for a particular situation are determined by specific previous experiences with situations that are perceived to be similar” (Lee & See, 2004, p. 56). What this means in practice is that vehicle performance can become sub-optimal without the implication of an inherent failure, but only in cases where the environment in which previous failures has occurred is perceived to be different. It is a subtle distinction, but it means that trust is not just about the ‘quantity’ of failures but also the context (perceived and actual) in which they occur. However, just as failure in one part of the system may, depending on the context, not be attributed to an inherent system-wide failure, the reverse can also be true.

The third design issue refers to ‘functional specificity’ (Lee & See, 2004). Predictable performance describes the case of high functional specificity, whereby trust is linked to particular observable components or parts. Keller and Rice (2010) call this ‘component specific trust’. Most trust research tends to focus on this rather than multiple systems working in tandem. The assumption is often tacitly made, incorrectly, that failure of one component will not impact trust in another part of the system but Geels-Blair, Rice and Schwark (2013), among others, shown this not to be the case. Component failures have impacts beyond the component in question, with automatic systems that provide a lot of false alarms being more 'contagious' in their trust effects than other types of error. Findings such as these support Keller and Rice's systems view of trust and the issues associated with Dependability.

Dependability

Trust can be derived from viewing the overall dispositional traits of the vehicle, shifting the emphasis away from highly functionally specific 'component' behaviours (Muir, 1994) to lower levels of functional specificity whereby "the person's trust reflects the capabilities of the entire system" (Lee & See, 2004, p. 56). This describes a more recent innovation called System-Wide Trust theory (SWT; Keller & Rice, 2010). The theory puts forward a continuum of possibilities: at one end of the continuum users would adjust their trust levels depending on the performance of individual sub-systems. At the other end of the continuum people would integrate these component views to form a system-wide dispositional trust judgement. The key issue is the extent to which component failures will 'pull down' trust for the system as a whole, or indeed, how the overall dispositional traits of the system protect it against localised failures. Studies have begun to explore this (e.g. Geels-Blair, Rice & Schwark, 2013) and some early trends have been discovered (e.g. false alarms are more contagious than other types of automation error) but because trust is so context dependent further work is required.

Robust System-Wide Trust can, however, be aided by a range of design decisions, such as making underlying processes or chains of cause and effect obvious, or allowing the vehicle to offer desirable performance beyond what may be considered its normal performance envelope (Muir, 1994). This latter point is particularly salient. Research on where drivers typically operate within the performance envelope has found they use only around 30 to 50% of a vehicle's total dynamic capabilities, leaving around 50 to 70% spare vehicle capability (Lechner & Perrin, 1993). With this much spare capability in hand, modern vehicles are unlikely to ever exhibit anything but entirely dependable behaviour in normal use. Even well beyond the normal limits of operation vehicles can pleasantly surprise their drivers and give rise to the (emotionally laden) 'dispositional traits' encountered more widely in the motoring press (see Curtis, 1983 for the relationship between subjective reviews and objective vehicle handling criteria). It is only with recourse to historical examples that we can see the inverse situation and a stark illustration of the component versus system-wide perspectives:

The component view:

"The basic flaw with a simple swing axle suspension system as fitted to the [..] *is that, when cornering, centrifugal force levers the car upwards about the more heavily loaded outside wheel which then tucks under, drastically reducing grip and cornering power.* [..] *The result is handling that, even at modest cornering speeds, can only be described as nasty, with strong oversteer* [which] *can be quite violent."* (Motor, 1978, p. 40).

The system view:

"…when other liabilities […] *are added to the nasty handling and steering, the overall picture is depressing. The* […] *is not a car we can recommend."* (Motor, 1978, p. 45).

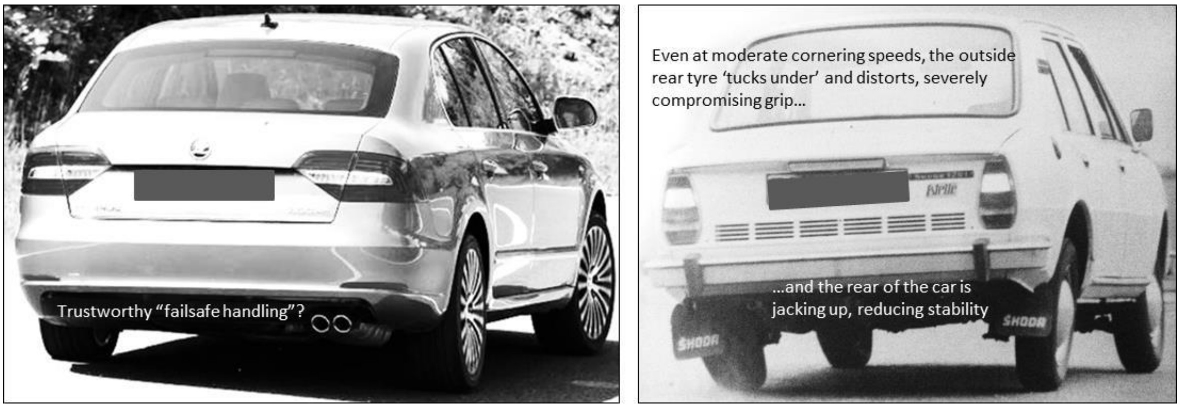

Figure 2 – Trust can arise from dependability which in turn can arise from a generous 'performance envelope', which is something modern vehicles now provide (Lechner & Perrin, 1993)

Faith

Whether it is something as fundamental as a vehicle's dynamic character, or the functioning of a driver aid, expectancy based upon predictability saves on the driver's cognitive effort. They no longer have to sample, observe or 'worry about' the behaviour of the vehicle in a functionally specific way. They can begin to depend on it. Trust can also be derived from how generalizable past predictability and dependability is for future situations (Rempel, et al. 1985; Muir, 1994). The defining feature of faith, as distinct from predictability and dependability, is its firm orientation to the future (Rempel, et al. 1985). Indeed, in the case of new technology it is often not possible to observe its behaviour prior to using it, predictable or otherwise, nor is it possible to develop a feel for wider dispositional traits. In many cases the driver has to make a 'leap of faith'. This is complex for a number of reasons.

The first reason is that some drivers will be inherently more likely to trust than others (Merritt & Ilgen, 2008). Studies have shown how the intrinsic ‘propensity to trust’ is independent from the more situationally specific attitude toward the piece of technology that requires trust (Merritt et al., 2012). Merrit and Ilgen (2008) state: “The implication is that individuals with a greater disposition toward trusting others will demonstrate greater levels of trust in another entity upon initial contact with that entity.” (p. 195). However, it was also found that pairing those people with an unreliable form of automation gave rise to significantly poorer outcomes as trust expectations were not met. Even when paired with reliable automation, these people ran the risk of over-inflated trust (Merrit & Ilgen). So, while it is the case that the two can combine: attitudes can override propensity and vice versa, the relationship is a complex and sometimes counter-intuitive one.

The second reason for ‘faith’s’ complexity is that it relates strongly to the intentions of the vehicle system, whether actual, perceived or implied: is the technology benign, intrusive, designed to control behaviour, or some other attribution? Vehicle systems present a ‘system image’ to the users (e.g. Norman, 1998) and this system image may be perceived as intended by the designer, or else a ‘gulf of evaluation’ may open up, leading to incorrect attributions whereby the user does not fully understand the state of the system and what it is doing. In cases like these a benign technology could be perceived as malign, an assistance system could be perceived as a controlling system, and so on. This is important because trust is a form of social exchange, one that evolves between humans quite differently to how it evolves between drivers and vehicle systems (e.g. Lee & See, 2004; Lewandowsky et al., 2000). Interpersonal trust (between humans) requires the trustee to behave in such a way as to elicit trust from a trustor, and vice versa. For this to happen, an awareness of each party’s intentions is required (Deutsch, 1960). The design challenge then becomes one of how to communicate the ‘intentionality’ of a vehicle system, particularly as these systems become more sophisticated, autonomous and more human-like in certain respects. A well-known study by Lewandowsky et al (2000) demonstrates the issues in play. In their experiment participants had to delegate a particular task to either an automatic system or to a human. When delegating to the human, operators used their decisions to trust to manage a social process around how they thought they were being perceived to the person they were delegating too. No such social process was observed when delegating to automation, and under various conditions it was used less frequently. What the participant's did not know was that both processes were run identically by automation. For trust in vehicle technology Lewandowsky's study tells us a) that trust in automation often means faith coming before predictability and dependability, b) that to do so relies on attributions of intentionality, and c), humans do not care how they are perceived in the eyes of automation so the social antecedents of trust which designers might assume are present are in fact absent.

Mini Case Studies in Vehicle Technology and Driver Trust

The ultimate purpose behind the vehicle designer's interest in trust is to ensure that new vehicle's, vehicle systems and technologies are accepted by users, and used in ways that maximise benefits in accordance with the designer's predictions. If the examples above, which are orientated around driver trust at the present level of driver/vehicle interaction, provide evidence for the processes underpinning trust and the correct way to achieve it, then the following case studies show some of the unexpected trust pitfalls.

Anti-lock Braking and Trust Calibration

The introduction of Anti-Lock Braking (ABS) systems is the test case for behavioural adaptation as exemplified in Wilde's (1994) Munich Taxicab experiment. According to Wilde's Risk Homeostasis Theory (RHT: 1994), if we assume driver behaviour remains the same with a new form of technology like ABS then the vehicle will be intrinsically safer. It has, however, been shown that driver behaviour does not stay the same. A principle of sociotechnical systems design is that people (drivers) "[…] change their characteristics; they adapt to the functional characteristics of the working system, and they modify system characteristics to serve their particular needs and preferences." (Rasmussen, Pejtersen & Goodstein, 1994). In the case of Wilde's study, drivers discovered certain behaviours that ABS seemed to afford, specifically, harder and more consistent braking regardless of road conditions, therefore, closer following distances and higher speeds. The results showed that, contrary to engineering expectations, the ABS equipped cars were involved in more accidents and braked more sharply than the non-ABS equipped cars (Wilde, 1994). For Risk Homeostasis Theory it meant that drivers had an 'in-built' target level of risk, and if you changed the environment with a new technology like ABS, behaviour adapted in order to regain the target level. For trust we have a situation where the driver is 'over-trusting' the vehicle system. "Excessive trust can lead operators to rely uncritically on automation without recognizing its limitations" (Parasuraman, 1997, pp. 238-239) and this mismatch, to use Muir's (1994) original terminology, describes poorly calibrated trust. Calibration is "the process of adjusting trust to correspond to an objective measure of trustworthiness" (Muir, 1994, p. 1918) and it can be conceptualised in the manner shown in Figure 3.

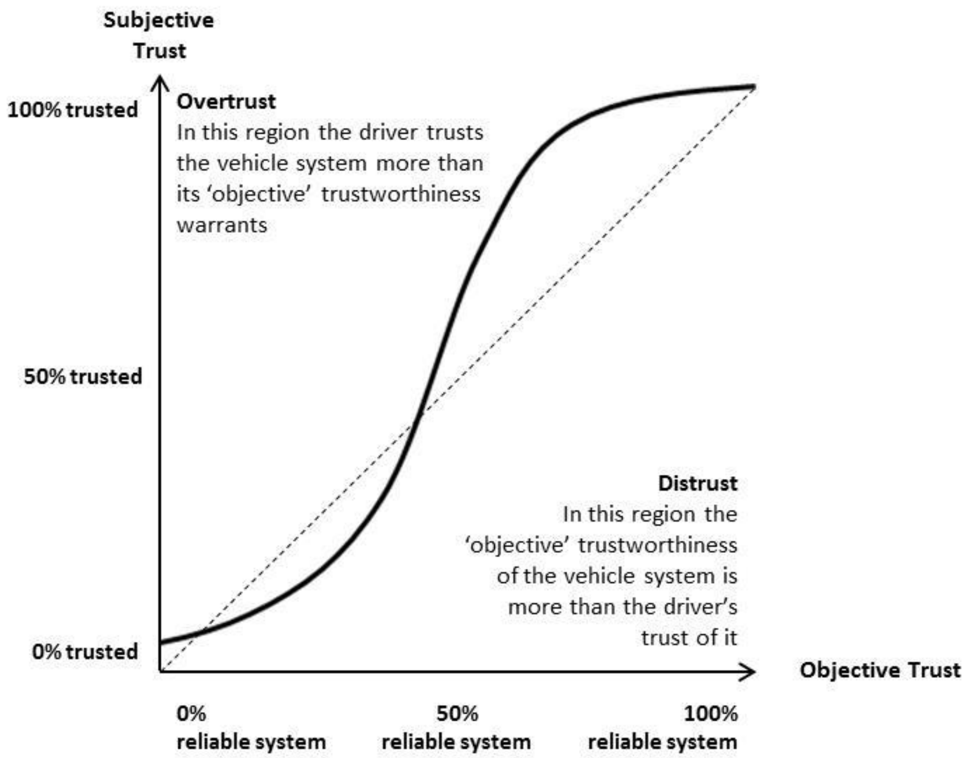

Figure 3 – Trust curves and the relationship between objective system reliability and driver trust. The dotted line is a theoretical trust continuum, whereas the solid curved line is an approximate one based on empirical studies (e.g. Kantowitz, Hanowski & Kantowitz, 1997 & Kazi, Stanton & Walker, 2007).

When the driver's trust in a vehicle system exceeds its objective trustworthiness (in terms of reliability, performance, capability etc.) then a situation of over-trust and technology misuse arises. When the driver's trust in a vehicle system is lower than the objective trustworthiness of the technology then a situation of distrust and disuse arises. The dotted diagonal in Figure 3 represents trust that is 'theoretically' matched (i.e. calibrated) to trustworthiness.

Navigation Systems and Reliability

Designers of in-vehicle navigation systems have already been grappling with the idea of user acceptance and trust (e.g. Kantowitz, Hanowski & Kantowitz, 1997; Ma & Kaber, 2007; Reagan & Bliss, 2013). This is hardly surprising, as the keystone of any route guidance system is reliable, objectively trustworthy route information. But how reliable does it have to be? Is the theoretical trust calibration diagonal in Figure 3 a continuum as shown, or is it a curve? Experiments with the reliability of navigation systems provide some insight.

From the start it can be assumed that 100% reliability is the most objectively trustworthy route guidance, but also the most expensive. What are the limits of trust? Can it be lower and cheaper? How low can system reliability go and still be trusted and accepted by drivers? The answer, in the case of route guidance at least, seems to be about 70% accuracy (Kantowitz, Hanowski & Kantowitz, 1997). In this particular study the driving simulator allowed three discreet levels of route guidance reliability. One hundred percent reliability gave rise to the best driver performance and the best driver subjective ratings of the system, followed reasonably closely by 71% system accuracy. As accuracy broached the 43% level, however, large decrements in performance started to occur (Kantowitz, et al.). What this and similar research (e.g. Kazi et al., 2007) shows very clearly is that rather than a diagonal continuum as shown in Figure 3, trust is perhaps more like a phase-transition or s-curve. This means trust is potentially fragile but it also means small, user-centred interventions can have disproportionately large effects. In other words, the cost/benefit of going from 40 to 70% reliability could be far greater than going from 70 to 100%. In addition, the technical challenges of going from 40 to 70% reliability are likely to be much less punitive than the challenges of going from 70 to 100%.

Muir and Moray (1996) go further to say that trust is fragile but not brittle. Kantowitz, et al. have shown this to be the case, because although unreliable navigation information can quickly damage trust levels, they do recover gradually when the driver is presented with accurate information again, although not always to full prior levels (see also Stanton & Pinto, 2000; Beggiato & Krems, 2013). According to System-Wide Trust (SWT) theory as trust starts to be lost in a particular sub system this can sometimes become generalized across other related sub systems, sometimes not (Muir & Moray, 1996; Lee & Moray, 1992; Keller & Rice, 2010). Lee and See (2004) refer to this property as resolution. The literature does not assist us at this point, but it is possible to speculate that trust founded on dependability and faith, that which refers to system-wide traits and dispositions, will apply across a much wider range of system reliability and be more resilient to localised failures. Trust founded on predictability, in which a narrow range of system capability will map on to a much wider range of trust, will be more brittle and less resilient. Fortunately, there is evidence to suggest that even completely unreliable systems may, in some circumstances, still not be totally abandoned (e.g. McFadden, Giesbrecht, & Gula, 1998).

Adaptive Cruise Control and Perceived Behavioural Control

Research into trust and system reliability with vehicle navigation reveals a further aspect of trust that vehicle designers need to be aware of: driver confidence. Driver confidence has been the topic of much research (e.g. Marottoli & Richardson, 1998) where it seems the tendency for drivers to over-estimate their abilities is a strong one. This has some important implications for trust and the subsequent use of advanced vehicle systems (Adams-Guppy, Guppy, 1995). The relationship can be stated as follows: if confidence exceeds trust, then the system will not be used regardless of how predictable or dependable it is. If the driver feels they can perform the job better than the vehicle system then they generally will (Kantowitz, et al., 1997). This is certainly a problem for a broad class of telematics and Intelligent Transport System (ITS) interventions targeted at familiar journeys such as commuting (e.g. Lyons et al., 2008).

The concept of Locus of Control links well to driver confidence, and in turn to issues encountered with Adaptive Cruise Control (ACC). Locus of Control relates to the perceived source of behavioural control (Montag & Comrey, 1987; see also Theory of Planned Behaviour above). The perceived source of behavioural control has been shown to emerge from two dimensions: internality and externality. Drivers' with an internal locus of control will have high levels of perceived behavioural control. An illustration of this is provided with reference to Montag and Comrey's MDIE locus of control questionnaire (1987). An internally disposed driver will respond positively to questions that the driver themselves can do many things to avoid accidents, and are in control and responsible for the safety of the journey. On the other hand, a driver who measures highly for external locus of control perceives the source of behavioural control as residing more 'out in the world' rather than internally to them. Such drivers will agree with MDIE question items along the lines that accident involvement is a matter of fate, and there is not a lot that they can actively do to prevent this. It can be speculated that an 'external' is much more likely to place their trust in a given system. The dimension of externality has been shown by prior research to be negatively correlated with perceived skill level (Lajunen & Summala, 1995). If skill level is perceived to be low, then it is likely that confidence will be correspondingly low. If confidence is low then trust is more likely to predominate. An internally disposed driver, on the other hand, might be predicted to prefer manual control. Montag and Comrey (1987) have found the dimension of internality to be favourably implicated in attentiveness, motivation, and a greater ability to avoid adverse road situations and accidents. If this is the case then self - confidence is more likely to exceed trust.

In summary, 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. It could be the case that a driver who measures highly for external locus of control will tend to over trust and therefore misuse a given vehicle system, whereas an internal locus of control might be given to being more distrustful therefore disusing, or even perhaps 'abusing' the system. As for the technology itself, ironically, it has been found that *"a less-than-perfect system forces the driver to reclaim control from time to time, allowing him/her to get back into the loop intermittently.* [..] *it seems that the system's intrinsic fallibility may help the driver to stay in the loop"* and avoid over-confidence (Larrson, 2012). Episodes such as these have been shown to feed into a tactical level of control, with drivers anticipating situations the automation will not cope with, and disengaging it before a potentially hazardous situation arises (Kircher, Larsson & Hultgren, 2014). This once again foregrounds the vehicle design issues around allocation of function, transparent system operation, feedback, behavioural control and the continuing evolution of the driving task in the face of new technology.

Beyond Trust

So far we have argued that trust is a useful and relevant concept for vehicle designers. It is possible to go further. It flows from trust that the concepts of mistrust, distrust and even revenge might be equally useful. The following sections explore these ideas further.

Mistrust and Distrust

Muir (1994) defines errors in trust calibration as mistrust. Mistrust comprises false trust and false distrust, or errors connected with misuse and over trusting in the former case, and disuse and lack of trust in the latter. Mistrust can be regarded as a functional alternative to trust wherein a particularly interesting relationship becomes apparent. The ultimate role of trust is to decrease uncertainty and to reduce sampling and cognitive effort. In cases of complete trust the system does not have to be sampled in order to 'check' its behaviour, thus sampling will be zero (or near zero). At the other extreme, total distrust will give rise to sampling behaviours that outweigh the technology benefits, at which point the technology is disused. In this condition the sampling behaviour will also be zero (or near zero), simply because there is no behaviour for the vehicle system to exhibit and therefore to be observed and sampled. Between full trust and full mistrust is a middle area in which sampling behaviours change rapidly for only moderate changes in objective/subjective trust. Muir (1994) proposes an inverted U relationship but the evidence for vehicle systems appears different, as **Figure 4** demonstrates.

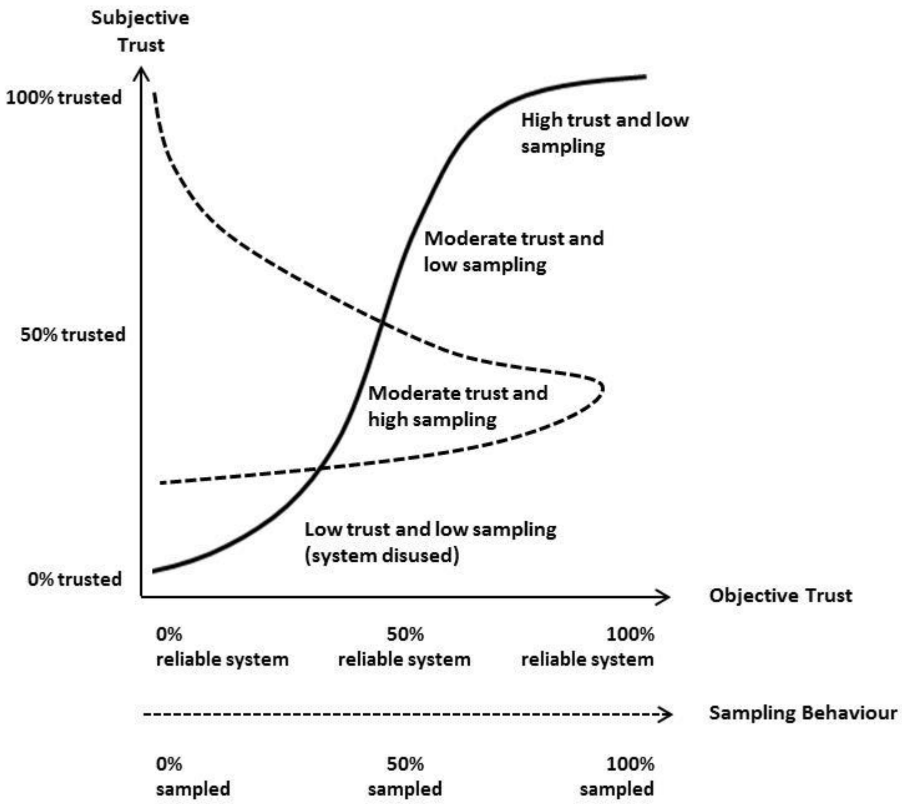

Figure 4 – Indicative trust calibration curve overlain across sampling behaviour curve to reveal an important intermediate region where sampling and trust changes rapidly

Moving along the horizontal axis away from a situation of trust it can be seen how sampling ramps continually upwards until a sharp cut-off; the precise point at which the driver will take manual control (where possible). Research has found that trust dynamics possesses something akin to a logarithmic function, with initially small increases followed by a gradually exploding level of trust (Muir & Moray, 1996). This is evident in Figure 4 and is a key theme. Trust is non-linear which means small design issues can have big effects, both positive and negative. Trust is highly context dependent but it is certainly the case that two very similar levels of trust and system reliability can foster very different sampling behaviours. Moreover, a small design change could be all it takes to shift the interaction in a new direction.

Revenge

It is possible to go even further than mistrust and discuss the complete antithesis of trust; revenge. There is no literature that directly examines this phenomena as it relates towards system trust (or trust in vehicles), so only an analogy drawn from writings about the processes underpinning revenge in interpersonal situations can be provided. The overlaps are nonetheless revealing and potentially important for future research.

Like trust, revenge is underpinned by expectations, but unlike trust, expectations that are violated. Hints of this were seen above when talking about drivers with a high disposition to trust but who have their (high) expectations violated by an unreliable technology. Revenge goes further. Often the technology (or vehicle) becomes viewed as an 'abusive authority' with drivers seeking to re-establish equity in their role as a customer, a user, or the dominant partner in a human/technology relationship they perceive has become distorted (Stillwell, Baumeister & Del Priore, 2008; Walster, Walster & Berscheid, 1978). A process of cognitive appraisal is involved in the development of revenge. The appraisal relies on attributional processes (Bies & Tripp, 1996) in which the 'objective' behaviour is seen as arising from an individual (or technical) trait. It is thus an extreme case of 'anti-System-Wide Trust' in that global traits are bestowed upon the vehicle (more than an individual sub-system) by the human user. In this respect revenge is again similar to trust in that perceived intentionality is important.

This gives rise to separate information processing stages comprised of initial and retrospective revenge cognitions. Initial cognitions are about expectancy violations and are known as 'hot cognitions', for example anger and outrage, and retrospective cognitions involving rumination. It is through these cognitive processes that a number of revenge types can be defined. Far from being an irrational and largely out of control response, revenge actually represents a complex and surprisingly rational means of doing what the driver considers the 'right thing'. Unfortunately for the vehicle designer revenge has a powerful moral imperative; justice must be done (Bies & Tripp). The problem is that justice for the victim is considerably different in magnitude compared to justice for the perpetrator, something Baumeister (1997) refers to as a ‘magnitude gap’. Expressed in trust terms, revenge, by its nature, is poorly calibrated and subject to biases arising from the ‘hot’ nature of the initial cognitions and the ruminating passage of time. What this means is the revenge act can be excessive, as was seen in 2011 when a wealthy Chinese entrepreneur, who was frustrated by persistent engine faults, ordered men to smash his Lamborghini with sledgehammers. A clue to the rational moral imperatives underpinning this act of revenge is that a) the act was conducted in public and b) on World Consumer Rights Day (Metro, 2011).

Figure 5 – In an extreme case of automotive revenge a wealthy Chinese entrepreneur, frustrated at persistent faults with his £500k supercar, ordered a group of men to smash it up with sledge hammers (Sources: Reuters, AFP/Getty Images, 2011)

Revenge Types

Five types of revenge manifestation have been identified by Bies and Tripp (1996) and are here related to the driving domain. Vehicle designers may find them familiar. First are revenge fantasies. Having had their trust expectations violated, and attributed these violations to an intention on the part of the vehicle and/or its maker, the driver will begin to form vivid negative images of possible future courses of action. Although they never normally become as graphically manifest as those shown in Figure 5, they are present in various anti-corporation and ‘anti-car’ websites (such as ihatemycar.net), even YouTube videos and Facebook pages. The advent of forums like these enables drivers to ‘go beyond the manufacturer’s borders’ and alert the wider public in an uncensored way (Gregoire, Tripp & Legoux, 2009). Interestingly, research has shown that, for some people, these vivid revenge cognitions are associated with feelings of pleasure (e.g. de Quervain, 2004) but perhaps only because of the release from protracted rumination over the original injustice (Carlsmith, Wilson & Gilbert, 2008).

The second type of revenge manifestation, self-resignation, is more common. The driver simply gives up and accepts that any act of revenge would be unprofitable and ineffective, simply 'not worth it' in the short term (Bies & Tripp, 1996). The long term effect, however, is much more damaging. Research shows that while revenge does decrease with time, avoidance of a product or marque increases: customers do hold a grudge, more so if they began the customer experience from a favourable, trusting starting point (Gregoire, Tripp & Legoux, 2009).

The third type of revenge manifestation is bound up in feuding. Here there is a constant battle between the vehicle and the driver, the complete antithesis of favourable driver vehicle interaction. Bies and Tripp (1996) cite occasions of extreme frustration and violence under such conditions. Here the violence may well fall short of ultimate revenge fantasies, but is still directed at the vehicle, the aim being to vent these negative feelings in the form of deliberate damage, misuse, and abuse.

Identity restoration, the fourth type of revenge manifestation, reveals itself in the driver making attempts to restore their superior position and to use that as a way of demeaning the offender (in this case the vehicle; Walster et al. 1978). This manifests itself as disuse or even active driver abuse of a vehicle or vehicle system. In cases where social identity and self-esteem have been violated vengeful attempts are made to actively restore it. This could involve assuming or seizing manual control and regaining autonomy and power back from the vehicle or system, whether it is appropriate or not to do so. The driver may deliberately choose to use the vehicle or system in a manner that is beyond its capabilities, taking control by punishing the vehicle.

Coming full circle, the last and possibly most paradoxical type of revenge is that of forgiveness. Forgiveness is inextricably bound up in discussions of trust and revenge, the defining feature here is that the driver, who may be a victim of poor and frustrating vehicle/system performance, is the agent who reinitiates trust and system cooperation. Though undoubtedly a noble response, forgiveness is rarely granted, with individuals dissuaded from an entire car marque for life based on one negative experience (Gregoire, Tripp & Legoux, 2009).

Table 1 – Revenge types and their manifestation

Type	Example	Outcome
Revenge fantasies	Make feelings of dissatisfaction public.	(Grudging) Use / Disuse
Self-resignation	Future avoidance of technology or car marque.	(Grudging) Use / Disuse
Feuding	Deliberate attempts to damage and/or stress a vehicle or vehicle system	Abuse
Identity restoration	Seizing back control from vehicle system.	Abuse / Disuse / Misuse
Forgiveness	Future avoidance of technology or car marque	Disuse

Measuring Trust

In order to take into account the role of trust as an intervening variable in vehicle design, it has to be accurately assessed or measured. There are a number of conceptual issues, not least that trust “must be decomposed into measurable specifics that fit both the context and the phase of the trust process addressed (Fitzhugh, Hoffman & Miller, 2011). For practical purposes there are a number of structured methods that the designer can usefully employ throughout the design lifecycle. . It is upon such measurement that user centred vehicle design decisions can be based and the pitfalls illustrated in the earlier case studies, not to mention the drastic effects of mistrust and revenge, can be avoided.

Primary Task Measures

One of the more powerful ways of measuring trust is by employing primary task measures. This level of analysis is particularly good at assessing driver/vehicle performance in terms of predictability, because this is a facet of trust that can be easily and objectively measured.

The key to the approach is to establish the actually existing predictability or reliability of the system, and to measure driver performance whilst using the system. Does the driver make full use of the vehicle or system in the manner intended by the designer, and in a manner commensurate with the actual level of system reliability? Any clear disparity between levels of objective predictability and actual system use is indicative of poorly calibrated trust. One limitation of this approach is that it requires that the design concept be at an appropriately advanced stage to enable users to perform tasks with it. The main limitation, however, is that it does not explicitly assess levels of user dependability and faith, and it is within these 'softer' aspects that significant design inroads could be developed. For these aspects to be properly addressed, certain subjective measures can be employed.

Subjective Scales

As mentioned at the beginning of the paper, the domain of trust research is still relatively new, therefore, robust measuring instruments are not extensive. Muir and Moray (1996) developed a trust questionnaire comprised of ten sub-components of trust: competence, predictability, dependability, responsibility, responsibility over time, faith, accuracy, trust in display, overall degree of trust, and confidence in own rating. This has been relatively popular in previous vehicle technology research (e.g. Stanton & Young, 2005; Kazi et al., 2007) due in part to the questionnaire's availability within the peer reviewed literature (see Muir & Moray, 1996). Numerous, much simpler questionnaires have been developed in a more ad-hoc fashion for individual studies, such as the four item questionnaire related to navigation system research described by Kantowitz, et al. (1997). More recently, however, and in recognition of the growing importance of trust, attempts have been made to develop robust multi-dimensional trust instruments applicable to a wide range of domains. Yagoda and Gillan's (2012) Human Robot Interaction Trust Scale comprises five dimensions based on a comprehensive process of factor/question reduction, expert review via 120 participants, and the complimentary use of Rotter's (1967; 1971) interpersonal trust scale. Like Muir and Moray's (1996) questionnaire this is also available in the open literature (see Yagoda & Gillan, 2012; Yagoda, 2011) and applies well to a growing class of more autonomous and capable vehicle technology.

Repertory Grids

This technique takes a more grounded theory/data driven approach. Rather than impose a set of questionnaire dimensions on a given trust problem, allow the problem/context to describe itself. The repertory grid technique (see Stanton et al, 2013) is an interview-based approach that can be used to systematically analyse driver's perceptions or views regarding different types of vehicle technology. The technique was developed by Kelly (1955) to support his theory of personal 'constructs'. This theory assumes people seek to develop a view of the world that allows them to combine their experiences and emotions into a set of constructs, which can then be used to evaluate future experiences in terms of how positively or negatively they relate to those constructs. Repertory grid analyses have been employed by Stanton and Ashleigh (2000) in the context of trust research. The study required individuals to list their opinions regarding trust in a particular context. Three of these opinions were taken, and the first task was to establish what two opinions shared a commonality to the exclusion of the third. The commonality that determined this difference went on to represent a trust construct in the grid. This process was repeated in order to develop a list of constructs. The logical opposites of these constructs were then defined and also represented in the grid, and a list of elements or examples from the trust scenario were rated according to the complete list of constructs. Ashleigh and Stanton (2001) used this approach to identify nine constructs common in human supervisory control domains. For trust in technology, these constructed were ranked in order of importance as follows: quality of interaction, reliability, performance, expectancy and communication and understanding (jointly ranked fourth), ability, respect and honesty (jointly ranked sixth). For manufacturers of vehicles, this means that effort expended on quality of interaction, reliability, and performance of automated systems is likely to yield the greatest benefit in helping drivers calibrate the appropriate level of trust and help gain acceptance of the system. This process can also be a valuable pre cursor to the design of bespoke trust questionnaires and categorisation schemes for future use.

Conceptual Model Building

Another approach to the measurement of trust has been reported previously in this journal (Kazi et al., 2007) and similar approaches are becoming more widespread in the domain of vehicle automation (e.g. Beggiato & Krems, 2013). In this study the dynamics of trust were examined by subjecting different groups of drivers to different levels of ACC reliability, on repeated occasions. After each exposure to the system the drivers were asked to complete a drawing exercise whereby they represented their understanding of the system using sticky notes (showing elements of the ACC system) linked by arrows (showing how they perceived the elements to be interrelated). An example of the outputs produced by this approach are shown in Figure 6, where it can be seen how the driver's conceptual model changed over time. An extension to this approach reported by Kazi et al. (2007) is in the use of network analysis. The elements represent nodes and the arrows links, and by these means a number of standard graph theory metrics can be calculated. These, in turn, provide information to the vehicle designer about what elements of the system become more or less important to drivers, where and how the designer's conceptual model (as embodied in the 'system image'; Norman, 1998) becomes decoupled from the user's model, and insight into what elements and interrelations to target at different stages of the trust calibration process.

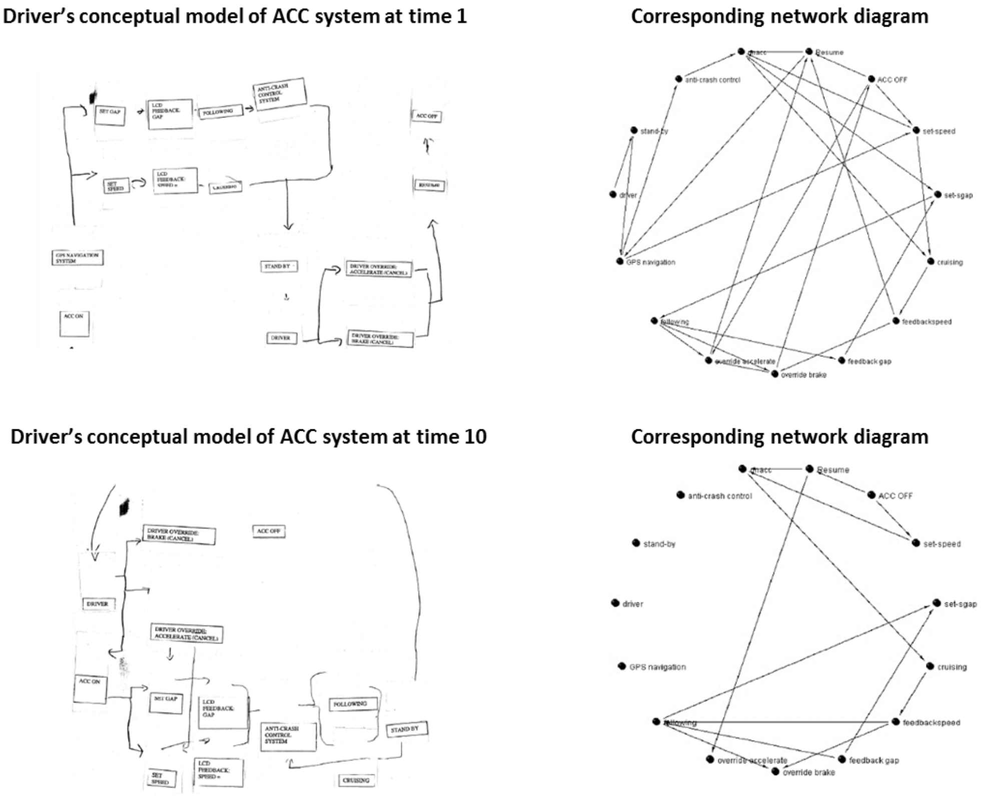

Figure 6 – Example of a conceptual model building exercise and its outcomes over a ten day study of driver trust in ACC.

Whilst the methodology adopted to assess trust is dependent on the vehicle device being assessed, it may be that a toolkit approach could be adopted. Here a selection of the methods described above are used at different points throughout the design lifecycle to assess elements of end-user's trust. Figure 7 shows where each of the approaches can be usefully applied. It will be noted that several methods can be applied very early in the conceptual and mock-up stages where it is relatively inexpensive to make changes that could have big behavioural outcomes.

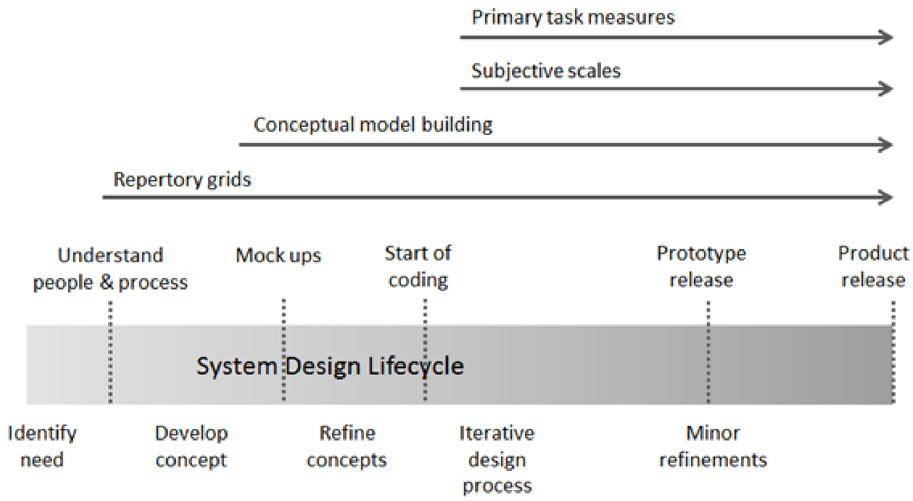

Figure 7 – Different methods of assessing driver trust can be applied at different points in the system design life-cycle.

Conclusions

It is through measuring trust that vehicle designers can make decisions to ensure driver trust is properly established and maintained, that technology is accepted, and used in ways that are intended. The dynamics of trust inform us exactly how trust can be established and maintained, and also the processes that lead up to failures of trust, and even revenge. It should be emphasised again that trust, though often fragile, is not brittle. The attainment of trust is also influenced by factors such as driver confidence, locus of control, and the reliability or predictability of the system. It is multi-dimensional and highly context sensitive. This paper concludes by taking the disparate literature on trust and distilling it into recommendations that vehicle designers can put to use in advancing a more user-centred agenda to new vehicle systems. The recommendations draw heavily from the work performed by Muir (1994) but repurposed for the vehicle design context.

Ensure high levels of system transparency through feedback.

Part of the reason why driver trust in current vehicles is generally so favourable (e.g. MacGregor & Slovic, 1989) is because of the abundant feedback provided to the driver. The operation of the vehicle is not only quite straightforward (considering the complexity and dynamism involved) but the results of actions are sensed and felt immediately and in abundance. The direct mechanical link between the main vehicle controls and the systems under control facilitates this high level of system transparency. The design imperative here is to ensure that the designer's mental model of how a new vehicle system works is in accordance with how the user's mental model conceptualises the system. The result of a match between these two mental models is a good system image, and this is the desired vehicle design end state (Norman, 1998). The key to this match is the information or feedback the vehicle or system provides to the driver. This is something the designer can do something about. The driver needs to observe and understand the behaviour of the system (at least at an operational if not a technical level). Observation relies on the system providing good feedback. Good feedback can be defined with reference to the sensory modalities the user will employ (auditory feedback, visual feedback, tactile feedback etc.), the content of the feedback, its accuracy or ability to support the required understanding of the system, and finally in the timing of feedback, with rapid or even instantaneous knowledge of results usually the best for performance and learning (Welford, 1968; Walker et al., 2006).

Consider the need for the driver to explore the behaviour of the vehicle system.

The driver needs to be made explicitly aware of what the system is designed to achieve. For example, ACC is designed as a comfort system for use on motorways, and in this environment the user can expect the system to perform in a trustworthy manner. Part of the dynamics of trust acquisition is for the user to safely discover for themselves, through exploration, higher levels or even the safe limits of the system. Perhaps some form of simulation mode would enable the driver, whilst in manual control, to witness how ACC would be responding at the same time. This would provide evidence and understanding to the driver of what ACC system performance means to them, and permits an appropriate driver trust criterion to be fostered (e.g. Larsson, 2012). After all, the driver's expectations of the system may be entirely inappropriate when compared to actual system performance (Muir, 1994).

Trust training.

Obviously the driver/vehicle context is not particularly amenable to further overt and structured training, as it might normally be understood, but there may be ways of getting the system to subtly engage the driver in activities that increase predictability and dependability if a ‘leap of faith’ has not been made. Comparisons with how the automated system would have performed (provided while the driver is in manual control) could, for example, provide a more overt way of stimulating sampling behaviours. Innovative approaches such as ‘gamification’ could be another strategy, whereby performance targets and comparisons are facilitated. Beyond that the issue becomes one of embedding the function and capabilities of emerging technologies in formal driver training. This is somewhat beyond the scope of vehicle designers.

Consider the use of soft automation and dynamic allocation of function.

Part of the defining feature of trust, and a theme that has cropped up repeatedly, is the notion that trust is inextricably linked to the driver vesting power in a system to perform as it should. In order to help avoid all the pitfalls of misuse, abuse and revenge, the trust literature seems to advocate a softer, more collaborative form of automation rather than a hard, enforcing type. Intentionality is an important aspect of trust and conveying the technology's intentions correctly, and avoiding it becoming seen as an 'abusive authority', is important.

Understand that mistrust is difficult to overcome, and forgiveness rare.

Trust is fragile. If trust is not achieved in a situation of soft automation then the driver will more likely revert to manual control, and in doing so effectively denying the automation or system any further chance of proving its worth. In a case of hard automation, at least the system has further opportunities to demonstrate its worth and regain trust. Under such situations expectations underpinning vengeance behaviours may have been violated, and forgiveness of the system by the driver is rare, with continued frustration, dissatisfaction, and lack of acceptance being the likely on-going consequences.

Trust is complex, multi-disciplinary, multi-faceted, and multi-level (Tharaldsen, 2010). This paper has had to tread a careful course through the disparate literature, choosing work that builds from proper foundations of genuine insight and scientific rigour. It is at this level of abstraction that realistic, practical and workable design guidelines can be recommended. Nevertheless, in the domain of trust research there is still much work that needs to be done. This includes clarifying how vehicle system design can better support appropriate levels of user trust, but also research studies which examine the effects of different designs on drivers' trust and driving behaviours. The omnipresence of trust belies the fact that it is not a well-studied phenomenon, despite its very real importance for the acceptance and use of new forms of vehicle technology. Trust is an intervening variable, it is bound up in psychology, and more specifically in the way in which drivers process information about the performance and benefits of vehicles and their systems. The purpose of this paper has been to show that through a proper understanding of the mechanisms underpinning trust the designer can take active steps. These steps can help vehicles and systems suit the nature and dynamics of trust, and moreover, to directly influence it through insightful and intelligent application of human factors knowledge and practice. The opportunity bound up in trust's high context dependence, multi-dimensionality and non-linearity is, quite simply, that small, clever vehicle design solutions could yield big effects on driver behaviour.

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