Recent developments in driver control theory: from task difficulty homeostasis to risk allostasis.

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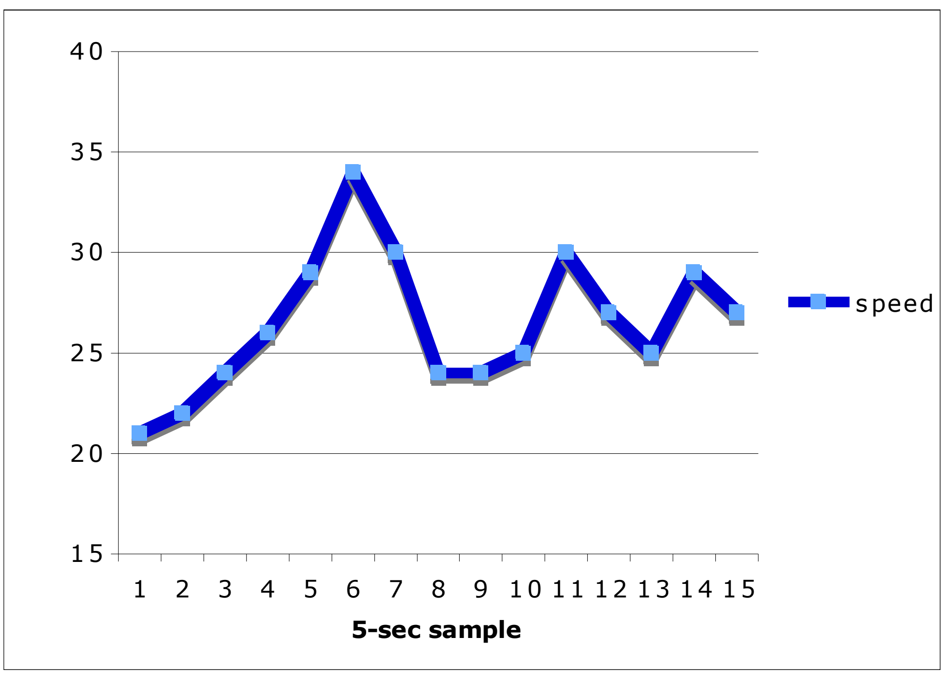
What this chapter is about

Driving may be described as a control task in an unstable environment created by the driver's motion with respect to a defined track and stationary and moving objects. The task includes requirements for route choice and following, coordination of manoeuvres in support of navigational objectives and adjustments of steering and speed (Allen et al., 1971, cited in Fastermeier and Gstalter, 2007). Adjustments of speed can be on a continuing basis. For example, Figure 1 shows such adjustments by a driver on a winding country lane, sampled at 5 second intervals. What might be the nature of the control process that produces this variation in speed?

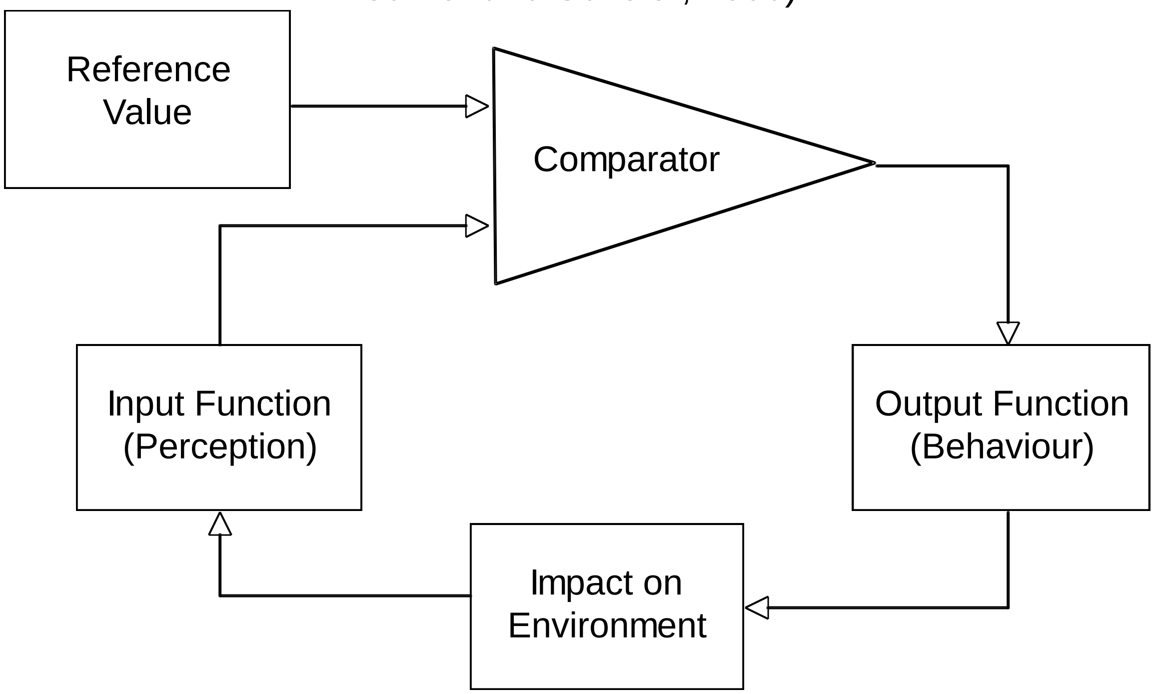
Figure 1. Variation in speed on a country lane



Control theory is predicated on the assumption that driver control actions are dependent on perceptual processes that select information which is compared to some standard or standards.

Drivers act to keep resulting discrepancies within acceptable limits in a negative feedback loop as the means of control in their goal-directed behaviour (see Figure 2). This control theory formulation is a

Figure 2. Schematic description of a feedback loop (adapted from Carver and Scheier, 1990)

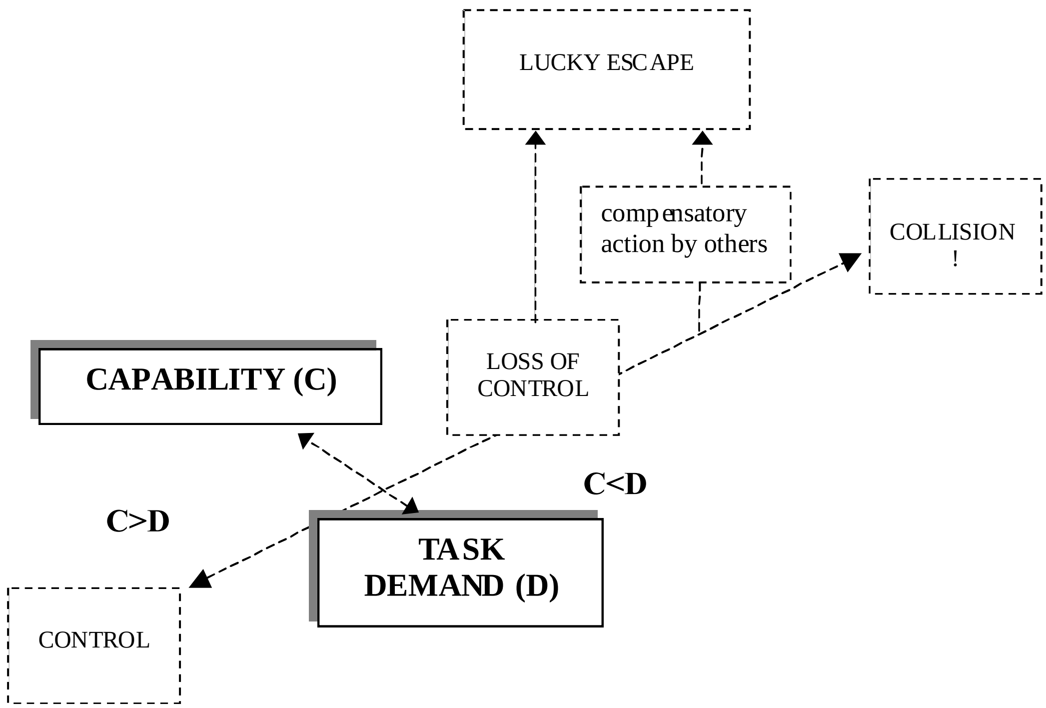


shared characteristic of RHT (Wilde, 1982), Zero-Risk theory (Summala, 1986), Vaa's 'monitor model' (Vaa, 2007), Summala's 'comfort zone model' (Summala, 2007) and the Task-Capability Interface model (Fuller, 2000). Where all these models differ, however, is in terms of their claims as to what the reference standard or standards in the control system are. The principal aim of this chapter is to describe recent developments of the TCI model, but it will conclude by exploring whether the different reference standards that have been proposed by Vaa and Summala can be assimilated within the same model.

The Task-Capability Interface model

The Task-Capability Interface model (TCI) model starts from a recognition that driver perceptual processes and control actions both have rate limitations. Thus the driver needs to continuously create and maintain conditions for driving within these limitations. That is, s/he must ensure that the demands of the driving task are within his/her capability (Figure 3). Loss of control occurs when, for a multitude of possible reasons, drivers allow task demand to exceed their capability. It is the identification of these reasons which promises to throw light on how safety might be more reliably achieved as a concomitant outcome of our seemingly insatiable desire for greater mobility.

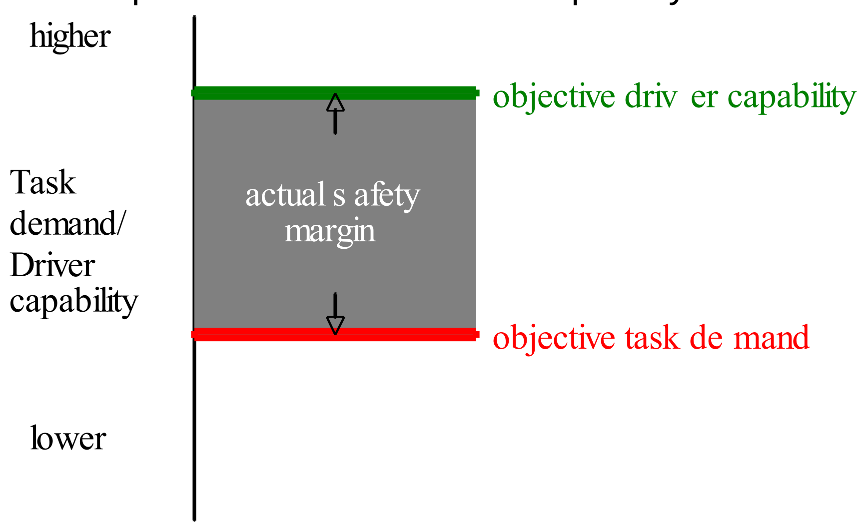
Figure 3. Starting point for the Task-Capability Interface Model (2000): Limited capacity concept at the interface between driving task demand and driving task capability



From the perspective of the driver, the statistical probability of loss of control and collision (or road run-off) is not some potentially variable phenomenon and influence, as implied for example in Risk Homeostasis Theory. Once a driver begins to move her or his vehicle the statistical probability of collision is essentially one. It is a certain outcome unless, of course, s/he continuously makes adjustments to avoid collision (or road run-off). For this reason my original theoretical explorations of driver decision-making focused on the concept of threat avoidance (Fuller, 1984a). However, that concept provides only a partial account, as has been discussed elsewhere (see Fuller, 2005a).

The difficulty of the driving task is inversely related to the degree of separation between the demands of the task and the driver's available capability. In principle, the greater that capability is, relative to task demand, the lower the difficulty of the task and vice-versa. In general, the separation between demand and capability is equivalent to concepts such as spare capacity and safety margin (see Figure 4). Where capability is more-or-less stable, changes in task demand will be directly related to task difficulty. In this typical situation, task difficulty will be equivalent to workload and may *in part* be operationalized in terms of time-to-collision and time-to-line crossing, assuming resource demand (i.e. speed of information-processing and response) to be inversely related to the time available (Wickens and Hollands, 2000).

Figure 4. Driving task difficulty is inversely related to the degree of separation between driver capability and task demand



As task demand or workload increase, the margin of available capability to deal with additional demands decreases and the driver becomes more vulnerable to acute high demands such as in an emergency situation. This phenomenon has been demonstrated in a simulator study of the effects of eating and drinking on driving by Young et al. (2008). They found that although these activities increased subjective ratings of physical workload, there was no effect on driving performance measures. However when a pedestrian unexpectedly walked in front of them, there was a reduced ability to avoid collision. The authors concluded that whilst drivers may be able to cope with eating and drinking during normal driving, it is the response to a sudden peak in demand which is affected by the additional activity.

Driving task demand has both information input and response output characteristics, corresponding to the requirement to determine the situation ahead and the requirement to manoeuvre the vehicle appropriately. It arises out of a number of factors which, from more distal to more proximal influences include vehicle performance and information display characteristics, route choice, physical characteristics of the environment (e.g., visibility, road surface) and the presence and behaviour of other road users. From a safety perspective, one can think of task demand in terms of the difficulty of information acquisition along dimensions of discriminability and flow rate, the number of potential conflicts for space in the driver's trajectory, and controllability associated with vehicle handling, road surface quality and the time available for decision-making and response (which for any given situation decreases with increases in speed).

Driver capability arises, again from more distal to more proximal influences, from the driver's basic physiological characteristics, education, training and experience. These provide conditional rules for action as well as a real-time mental representation or simulation of the situation which enables top-down or feed-forward control decisions (see later). This capability arms the driver with strategies for information acquisition and the capability of pre-adaptation to anticipated changes in task demand.

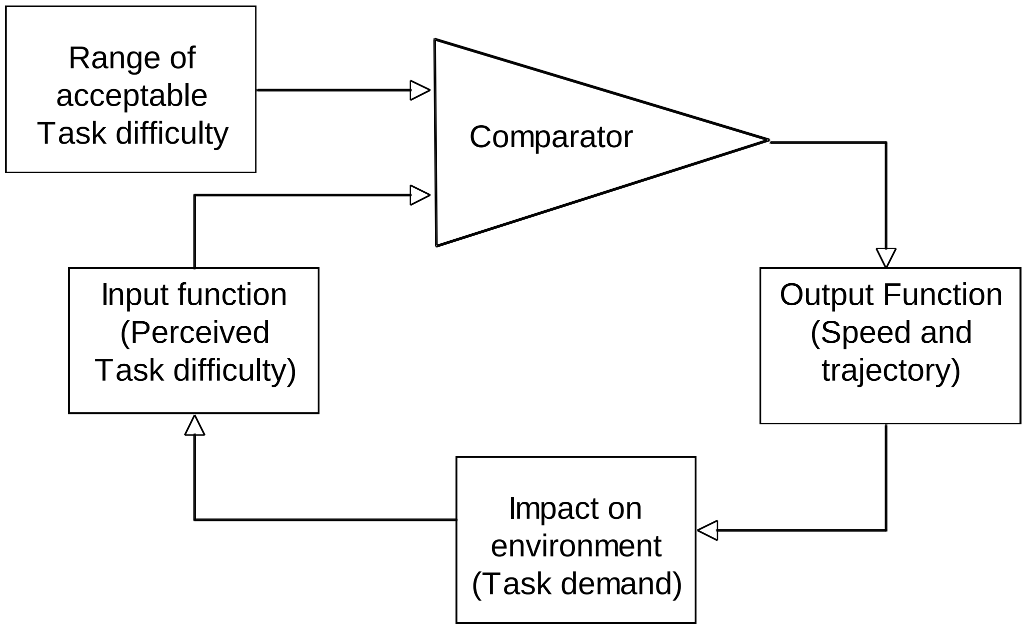
Fastenmeier and Gstalter (2007) have used task analysis to develop a typology of both road/traffic situations and driver behavioural requirements which they call SAFE (Situative Anforderungsanalyse von Fahraufgaben – Situational analysis of behavioural requirements of driving tasks). A road/traffic situation is defined as "a bounded section from traffic reality that the driver experiences as a unit in time and space". Behavioural requirements are a specification of relevant cognitive and psychomotor performances linked to successful negotiation of each situation. The authors support a distinction between a conscious information processing system, which is a sequential processor of limited capacity and speed and underpins reasoning and decision-making, and a subconscious processor, which operates as a parallel, distributed system to perform a continuous, dynamic simulation of the environment and the individual's position within it. This simulation provides the basis for a feed-forward control of the driver's actions as well as a reference for detecting deviations from intended outcomes.

The work of Fastenmeier and Gstalter provides important first steps in identifying at a micro and measurable level both the nature of driving task demands and the capabilities required of the driver to meet those demands. It is important to note, however, that capability is vulnerable in real time to a range of human factor variables such as emotion and fatigue.

Task difficulty homeostasis

The control theory concept at the centre of the TCI model is the hypothesis of Task difficulty homeostasis (Fuller, 2005a), the proposition that drivers continuously make real-time decisions to maintain the perceived difficulty of the driving task within certain boundaries, mainly by adjusting their speed (see Figure 5). Thus, for example, snow and sleet and darkness additively reduce traffic flow speeds (Kilpeläinen and Summala (2007). High proportions of drivers state that they drive more slowly than usual when task difficulty increases, such as in fog (98%), heavy rain (96%) and on unfamiliar roads (88%) (Campbell and Stradling, 2003). Drivers also typically reduce speeds while negotiating intersections, but more so while simultaneously completing car-phone tasks (Liu and Lee, 2005) and choose to drive more slowly on a narrower version of the same road (Uzzell and Muckle, 2005; Lewis-Evans and Charlton, 2006). In this latter simulator study, ratings of difficulty and of subjective risk were also higher for the narrower road. Drivers were not aware of the road feature that mediated these differences, suggesting that decision-making was occurring at a pre-conscious level.

Figure 5. Task difficulty homeostasis

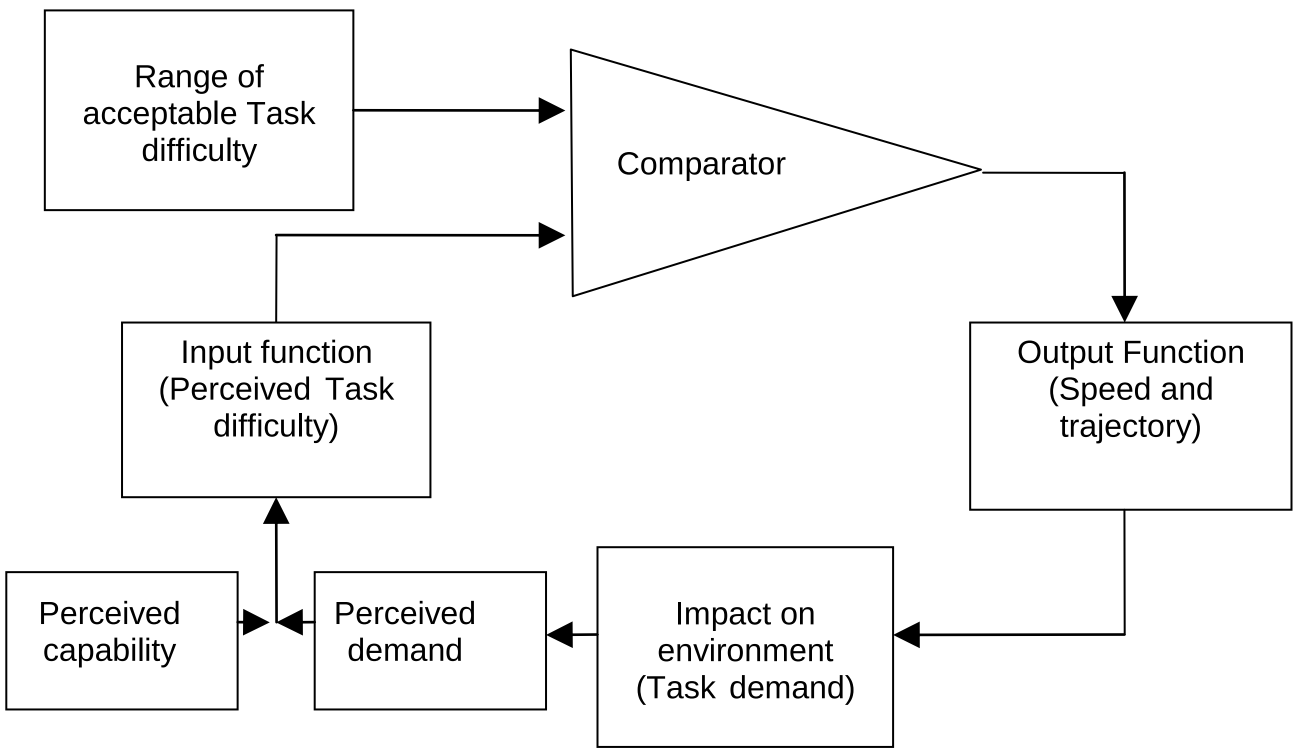


On occasions speed is not the only variable that drivers can adjust in order to control the level of perceived task difficulty. For example, in a following situation, time headway may similarly be used. In a study of the effects of prolonged driving on truck drivers, Fuller (1984b) found that as drivers' ratings of drowsiness increased, so did their time headway.

The corollary to this is that when task difficulty drops, such as when roads are empty at night-time, speeds increase (Broughton, 2005; Lam, 2003a). Compensatory increases in speed have also been found by Larsen (1995) who measured the free speeds of drivers on different road segments in a 50 km/h zone. He observed an 11 km/h range from 49.2 km/h to 60.2 km/h, with the highest mean speeds associated with what Larsen rated as the *easiest* driving conditions.

Calibration. We need to modify the representation of the control process to show that perceived task difficulty arises out of the interface between *perceived* task demand and *perceived* capability (Figure 6). Accuracy of driver perceptions is referred to as the driver's calibration accuracy. Clearly if drivers either underestimate task demand or overestimate their capability the perceived level of task difficulty will be less than is objectively the case. Unfortunately both of

Figure 6. Perceived task difficulty arises from perceived capability and perceived demand



these conditions pertain to novice drivers in general (see review in Fuller et al., 2008a) and their poor calibration may explain in part the overrepresentation of this group in collision statistics. Harré and Sibley (2007) have demonstrated that the disposition of young male drivers in particular to believe they are more capable than others, occurs with both a traditional explicit measure of attitude and with a new *implicit* measure. The advantage of the latter is that it avoids possible social desirability influences.

Younger drivers also appear to be less well calibrated when it comes to estimating the effects of distracting events on their performance or taking account of human factor variables which may undermine capability. Horrey et al. (2008) asked younger and older drivers to complete a hand-held or hands-free cell phone task while navigating a closed test-track in an instrumented vehicle. Although drivers generally (correctly) rated their performance as poorer when distracted, across all driving measures subjective estimates were not related to the magnitude of the distraction effect. Some drivers who estimated the smallest effects actually exhibited the largest and these were typically younger males.

With regard to human factor variables which undermine capability, younger drivers are more vulnerable to low doses of alcohol (Preusser, 2002; Keall et al., 2004) as well as fatigue and distraction. A recent review of young driver crashes (OECD, 2006) concluded that younger drivers are over-represented in sleep-related crashes; the impact of fatigue on crash rate appears to be greater in inexperienced truck drivers and the rate of inattention-related crashes and near crashes is four times higher for 18-20 year old drivers than for those over 34 years.

Poorly calibrated drivers, who overestimate capability or underestimate task demand, will visit the boundary where task demand meets capability more frequently: they will typically operate with less spare capacity. Evidence for this in less experienced drivers comes from a study by Patten et al. (2006) using a secondary peripheral detection task in real driving. Less experienced drivers had significantly longer reaction times to the peripheral stimuli and higher miss rates (although it should be noted these results may have been confounded in part by familiarity with the route and sex of participant).

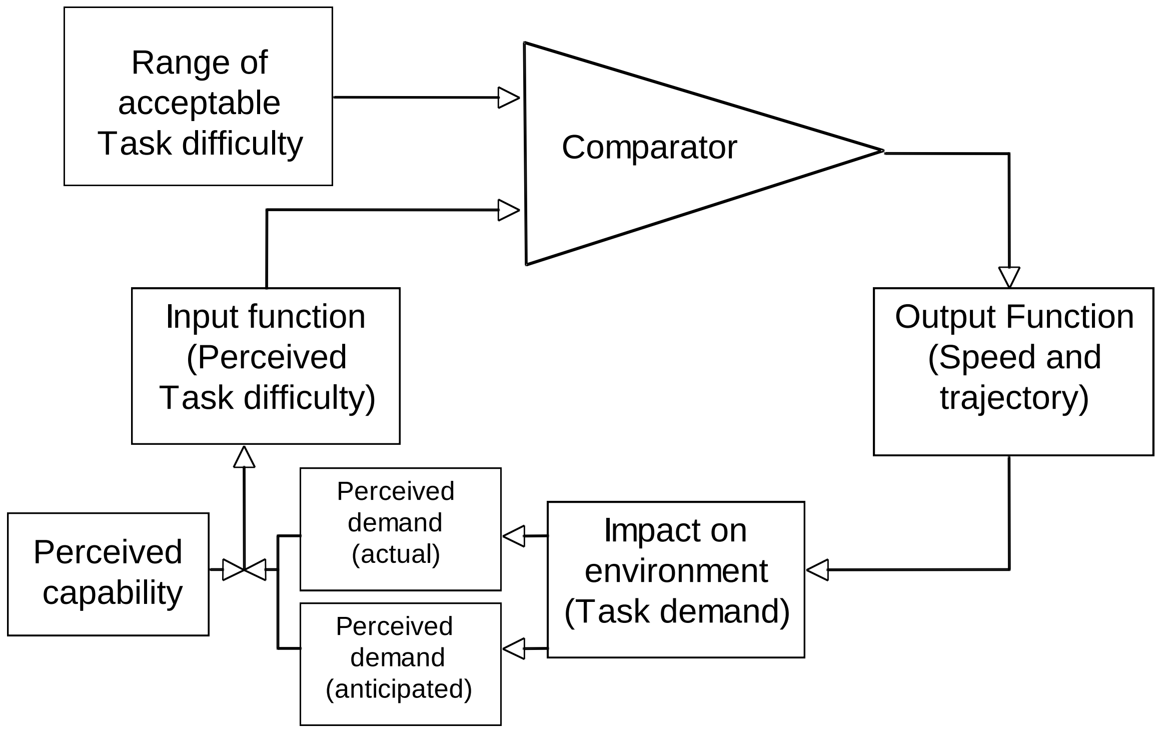
The concept of Task difficulty homeostasis is not exclusive to the TCI model and Summala has recently argued a similar case:
"The more complex the task (e.g. traffic environment), given same speed, the higher the workload. By adjusting speed, however, (the) drivers can reduce the information processing rate and provide themselves with more time, make their task more controllable and less loading, simply speaking, less *difficult*" (Summala, 2007, p.194, italics this author). With reference to time-to-line crossing, he cites evidence that on a wider road, more time is available and hence drivers allow longer glances and more time for subsidiary tasks (Wikman et al., 1998, Wikman and Summala, 2005). Similarly, on a road with a series of bends, available spare capacity diminishes and subsidiary tasks typically drop out (Summala, 2007).

Evidence for the proposition that drivers try to keep task difficulty more-or-less constant over the short-term comes from the work of Godthelp (1988) who instructed drivers in open road conditions to correct their path only at the moment when it could still be corrected comfortably (to prevent lane boundary crossing). Godthelp found that *over a wide range of speeds*, time-to-line crossing at the point of decision was essentially constant. In a field study, van der Horst asked drivers to brake hard at the last moment they thought they could stop in front of the simulated rear end of a stationary passenger car (see van der Horst, 2007). He similarly found that time-to-collision appeared to be *independent of approach speed.* And in a simulator study of car following, Van der Hulst et al. (1999) found that when drivers expected decelerations in the lead vehicle, they maintained the same minimum headway irrespective of whether the lead vehicle decelerated or not, implying that they were maintaining a consistent safety margin (time-to-collision).

Hysteresis, top-down and feed-forward control. It may be noted, however, that there is some evidence that under certain conditions there can be an hysteresis effect in this homeostatic process, where drivers' adjustments to changes in task demand lag behind those changes. Thus, for example, Andrey et al. (2003) found that the first snow-fall days of the year were especially prone to increased accidents.

On the other hand, a key component of driver capability is a valid mental representation of what may happen next. It is this that enables top-down or feed-forward control decisions, where drivers' adjustments to changes in task demand can anticipate those changes. We can represent this function in the model by including not only actual perceived demand but also perceived demand as immediately anticipated (see Figure 7). Evidence that less experienced drivers have poorer anticipatory adjustment to changes in task demand comes from the work of Saad, et al. (1990), who found that younger drivers adjusted their speeds less (than older drivers) when approaching an intersection. How to accelerate novice driver progression from more reactive to this kind of anticipatory task difficulty management, and how to sustain this kind of management in the face of frequent feedback that it was not actually necessary, are real challenges for research and development.

Figure 7. Representation of actual perceived demand and anticipated demand



In addition, the action the driver takes creates by and large the future with which s/he has to deal. This is why the driver needs to know the effects of those actions in the context of the unfolding road and traffic situation ahead. Evidence of poorer knowledge in less experienced drivers is clearly exemplified in their higher involvement in single vehicle crashes.

Boundaries of preferred task difficulty. The lower boundary of task difficulty will be determined by a minimum consistent with making satisfactory progress and providing sufficient stimulus to avoid boredom and perhaps prevent a progressive decline into drowsiness and sleep. The upper level will be determined by such variables as the driver’s perceived capability, motivation to put effort into the task and goals of the journey in question. Journey goals may, of course, have a direct influence on choice of speed – but if that choice of speed is higher than would otherwise be the case, perhaps because one is running late and needs to make up time, this will also require a raising of the upper boundary of acceptable task difficulty.

Task difficulty as risk feeling. One further point in the elaboration of the TCI model, research completed by us five years ago, although rather belatedly published this year (Fuller et al., 2008c) showed that *drivers experience task difficulty in the same way as they experience feelings of risk*. Participants were asked to rate video sequences of the same segments of a roadway traveled at a wide range of different speeds which were systematically varied. Ratings were recorded of task difficulty but also of feelings of risk. Estimates of the statistical risk of loss of control and collision were also obtained. In several replications we found that ratings of task difficulty and feelings of risk covaried very closely: the typical correlation between the two variables being of the order of $r = 0.97$. However such ratings were independent of estimates of statistical risk at lower levels of rated difficulty and risk feeling. Thus risk feeling and statistical risk estimates are not the same thing, but risk feeling can behave as a surrogate for task difficulty. This finding has since been replicated by Kinnear et al. (2008) and Lewis-Evans and Rothengatter (2008).

That feelings of risk should be so closely associated with perceived task difficulty should really come as no surprise, given that the outcome of loss of control of the task may be potentially so punishing. If we consider how task difficulty may be represented in the 'comparator' element of the task-difficulty homeostasis model, one possibility is that it involves a metacognitive process which is sensitive to the degree of deviation from sub-goals of the driving task. Relevant sub-goals which relate to speed choice, because they are time critical, are the maintenance of directional control (adhesion to road), sampling and processing of required information and enabling of required response. Thus deviations from these sub-goals, such as loss of directional control, loss of time to sample needed information and loss of time to enable response execution, may trigger a fear or anxiety response because of the potentially punishing consequences. It is a question for future research to determine whether or not the degree of fear felt is systematically related to such measurable variables as time-to-line crossing or time-to-collision or is triggered in an all-or-nothing manner (i.e. driven by possibility rather than probability – see Loewnestein et al., 2001).

Individual differences in boundaries of preferred task difficulty. Accumulating evidence reveals that drivers vary in their individual dispositions to adopt a particular range of task difficulty. In a recent study with Steve Stradling's group at Napier University (project HUSSAR - High UnSafe Speed Accident Reduction, funded by the Department for Transport, UK), we interviewed a national sample of British drivers and in part of this we presented respondents with a picture of a single carriageway rural road and asked them about two speeds: what speed would they normally drive at and what speed would put them right at the edge of their safety margin. There was wide variation in preferred speed: 81% of the sample were distributed over a range of nearly 30 mph (36–64 mph). Furthermore, 7% indicated a speed lower than 36 mph and 11% a speed higher than 64 mph. There was similarly very wide variation in what speed they thought would put them right at the edge of their safety margin. A majority (61%) said that a speed below 65 mph would. Twenty-two per cent said a speed of 65–74 mph would, 11% said a speed between 75 and 84 mph, and 6% a speed of 85 mph or more (Stradling et al., 2008). Despite this wide individual variation in preferred speeds, feelings of risk and stress did not vary with the speed chosen, implying that the feeling of risk was similar, whether you were a driver who preferred a relatively low speed or a relatively high speed on the same segment of roadway.

Project HUSSAR also confirmed, on the basis of a 12-year literature review, the national survey and four focus groups, earlier findings by Musselwhite (2006) that there are four distinguishable groups of drivers. We have labeled them Low Risk Threshold, High Risk Threshold, Opportunistic and Reactive (see Fuller et al., 2008a). Risk threshold in this context refers to the upper limit of task difficulty that a driver is motivated to tolerate.

Low Risk Threshold drivers comply with speed limits, reduce their speed if they realize they are traveling faster than the speed limit and are unlikely to change their driving behaviour in a 30 mph (50 km/h) zone as a result of momentary influences, including if they are in a hurry. They are typically older, more experienced and represent about 40% of male and female drivers.

In marked contrast, High Risk Threshold drivers have positive attitudes to high risk behaviour and a thrill-seeking and expressive use of their car (see also Machin and Sankey, 2008), often as part of a youth sub-culture that exploits driving as a recreational activity that is functionally related to their life situation (Møller and Gregersen, 2008). They drive at higher speeds, commit more, and more extreme, speed limit violations and other forms of dangerous driving behaviour and have more convictions. Not surprisingly they are more involved in collisions. This group are typically young, inexperienced and male and are poorly calibrated. They represent about 14% of drivers.

The origins of the driving style of at least some of this group may go right back to early childhood. In a seminal paper by Vassallo et al. (2007), which was concerned in part to identify longitudinal precursors of high risk driving behaviour, three clusters of drivers were identifiable at age 19-20 years who differed reliably in their engagement with risk-related driving behaviours such as excessive speeding, drink-driving, drug-driving, driving when fatigued and not using seat-belts. The high risk group, which formed 7% of their sample of 1135 young adults, were mainly male (77%) and were found to have been involved in more speeding offences and collisions. Compared with others they were more antisocial in behaviour and choice of friends, more aggressive, more irresponsible, showed less empathy and were more likely to engage in maladaptive coping (such as multi-substance use). But what was particularly intriguing in their findings was that the characteristics of antisocial behaviour and aggressiveness differentiated between the groups as early as age 5-8 years and persisted throughout later childhood and adolescence. Does this intriguing finding imply that we can now identify certain types of high risk driver as soon as they are old enough to go to school? And if so, what implications might this have for early intervention?

Opportunistic drivers do not pursue high speed for its own sake, unlike the High Risk Threshold drivers. They tend to adjust their speed to the conditions, rather than to the speed limit and will exceed the limit if they feel it is safe to do so. They exploit opportunities to get ahead. About 23% of drivers can be labeled as primarily Opportunistic and they are more likely to be male than female. The latter, on the other hand, are more likely to be Reactive drivers. This group are not persistently concerned to make good progress and tend to avoid unsafe high speed and dangerous overtaking. However they can be strongly influenced by their emotional state, driving faster if annoyed or angry or under time pressure. Consistent with this is the recent finding by Björklund (2008) in a questionnaire study that women drivers report more irritation than men when impeded or exposed to reckless driving and evidence presented by Lustman and Wiesenthal (2008) that female drivers report more aggression than men when feeling low levels of anger in similar scenarios.

Dispositional influences on driver risk threshold, and therefore speed choice, are partly captured by the social and cognitive variables which form the core elements of the Theory of Planned Behaviour (TPB) (e.g. intentions, attitudes and perceived social norms). Correlations between measures of these variables and measures of actual behaviour are not particularly strong, perhaps explaining around 25% of the variance in the behavioural variable (see for example Åberg and Wallén Warner, 2008) and it is perhaps self-evident that such a conceptual approach cannot provide either a comprehensive model of dispositional influence and most certainly not an account of real-time speed decisions by drivers. Thus Paris and Van den Broucke conclude in a recent evaluation of the TPB that actual speeding behaviour can only partially be predicted from TPB concepts and that "…the cognitive determinants of safe driving as identified by the TPB need to be complemented by other factors, including less "conscious" cognitive factors such as personal identity and habit formation, as well as external factors, such as cues to action, reinforcers, or the design of roads" (p. 179).

Temporary influences on risk threshold. In addition to dispositional differences, a wealth of research has demonstrated that several variables may temporarily raise a driver's risk threshold. Such variables include feelings of anger and aggression, competitiveness, thrill-seeking to get an 'adrenalin rush', feelings of power, social influences, the pressure of being late, to see how fast the vehicle can go, and so on (see review in Fuller et al., 2008a). For example, Ellwanger (2007) has shown that young drivers' 'delinquent' driving responses, such as speeding, aggressive driving and risk taking, are strongly correlated with individuals' ascribing their frustration to the voluntary and intentional actions of others on the road. Jamson (2008) has reported that drivers drive closer to the car in front when their emotions are aroused. Similarly King and Parker (2008) have shown that relatively high levels of anger are associated with increased commission of both aggressive and highway code violations and that accident involved drivers are more angry and hostile than accident free drivers.

This evidence of factors which may have an immediate influence on the level of task difficulty which drivers are prepared to accept implies that the hypothesis of task-difficulty homeostasis is not completely satisfactory and that a more appropriate concept is that of allostasis. Whereas homeostasis is the process by which a target condition is maintained in the face of external variation in a negative feedback loop system, allostasis refers to adaptation to a more dynamic target condition and is defined as *maintaining certain levels of biological conditions that vary according to an individual's needs and circumstances* (Kalat, 2008). So what we should really be discussing here is task-difficulty allostasis.

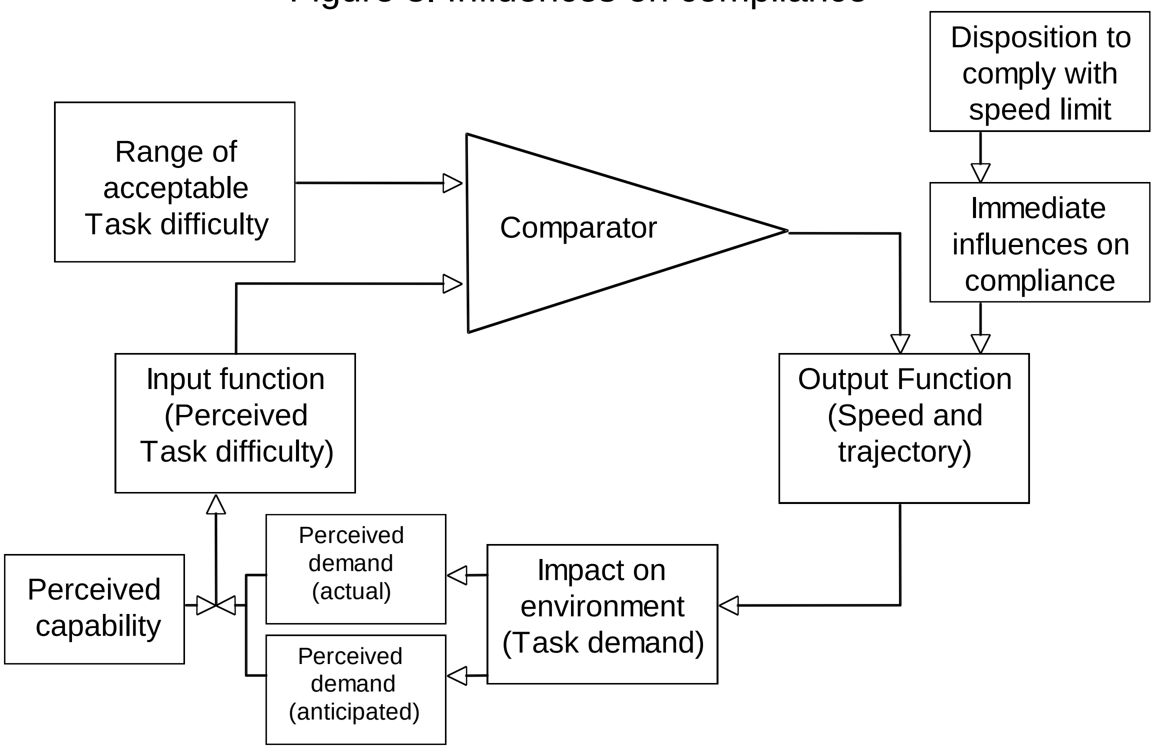
As an example of this allostatic variation in needs and circumstances, consider some results from a study we have just completed looking at the conditions under which drivers of emergency service vehicles (ESVs) are more likely to crash (Walsh, Hannigan and Fuller, 2008; Gormley, Walsh and Fuller, 2008). For both ambulances and fire appliances, significantly more collisions are reported under blue light (BL) conditions (responding to an emergency situation with blue lights on and usually with accompanying siren) compared with non-blue light (nBL) conditions. For every one nBL collision there were three BL collisions. This contrast is useful in the sense that fire appliances provide their own controls for a comparison of driving under time pressure in one direction and without that pressure in the other (albeit confounded by condition order). Drivers were quite open about their acceptance of an increased task demand level on the way out to a serious case:

P3 You can justify driving at a certain speed when its three kids in a house, if you're standing in front of a judge. You can't justify that kind of driving if it's a bin on fire.

And in a questionnaire survey of these ambulance and fire-appliance drivers, they were significantly more likely to say they would overtake and take risks whenever possible when driving under blue lights. Thus under certain conditions the reference criterion for acceptable task difficulty can change: allostasis, not homeostasis.

One further component needs to be added to the model to make it more complete. The decision output from the process of task difficulty allostasis may be an achievable speed but which is *in excess of* the legal limit for the road segment in question. Hence we need to include the driver's disposition to transfer from choosing a speed based solely on task difficulty to a speed consistent with the legal limit (see Figure 8).

Figure 8. Influences on compliance



Evidence indicates that there is considerable variation in drivers' dispositions to comply with limits, variation which represents both more-or-less stable individual differences (as discussed above and see Fuller et al., 2008a) and momentary influences on compliance (Stradling et al., 2008).

With regard to individual differences, cognitive style may relate to degree of non-compliance with limits (and other forms of deviant behaviour), in particular whether or not the individual tends to focus on potentially positive outcomes of choices and discount potentially harmful consequences or vice-versa. Lev et al. (2008) have shown that in a gambling task, traffic offenders give more weight to gains compared with losses, relative to control drivers, with the implication that when speeding their minds are more focused on the gains involved rather than the possible costs in terms of detection and penalty or loss of control. Interestingly they were also found to be more extraverted, which would also dispose them to be more sensation-seeking in their profiles.

Despite individual differences in disposition to comply, whatever its basis, violation of speed limits is a pervasive phenomenon: the OECD estimates that at any one time about 50% of drivers are exceeding the speed limit (OECD/ECMT, 2006). It is important to point out that for a proportion of drivers this behaviour does not represent some kind of willful contempt for rules and regulations but is rather an expression of their adjusting task demand to the prevailing conditions as they perceive them. Hence their anger at getting caught and fined and the general lack of social censure from others for minor violations. In the HUSSAR study referred to earlier, all four of our focus groups supported the view that non-compliance is not necessarily unsafe and that an immediate influence supporting non-compliance is that the speed limit is perceived to be too low:

> *Well it can be safe at times, can't it? To break the speed limit?* (Group C). Five group members immediately agreed.
>
> *If they expect you to slow down using your common sense, why not go faster using your common sense?* (Group C).
>
> *…when it was busy, forty limit, past road-works … even when maybe there weren't many people working there, most people were respecting the speed limit. Seven o'clock at night, quiet, not much traffic, nobody around, everybody was thinking, 'what the hell are we doing forty for?', and they are all doing fifty, and it was perfectly safe.* (Group B) (extracted from Fuller et al., 2008b).

The sooner authorities appreciate the process underlying this behaviour the quicker will they realise that punishing drivers for minor infringements may only serve to alienate them and that attention should rather be focused on ensuring that limits are appropriate for the road conditions to which they are applied and that penalties are sensitively linked to the seriousness of the violation.

Risk Allostasis Theory

Prevalent emotions surrounding speed choice are likely to be fear and frustration, fear determining the upper level of difficulty tolerated (the driver's risk threshold) and frustration the lower level (driver's frustration threshold, arising from deviations from driving goals which would otherwise have been positively or negatively rewarding). In relation to fear, over forty years ago Taylor (1964) concluded from on-road observations of drivers' autonomic activity that drivers adopt a level of anxiety that they wish to experience when driving, and then drive so as to maintain it. Mesken et al. (2007) have shown more recently, in a study in which participants drove an instrumented car in real road environments and gave self-reports at critical points, that anxiety associated with safety-related events was the most frequent on-road emotion (from a choice restricted to anger, nervousness and happiness) and this was in turn associated with increased perceived risk (and heart rate).

In the HUSSAR study mentioned earlier (Stradling et al., 2008), in response to the open road scenario, feelings of risk were positively correlated with ratings of task difficulty (r = 0.64) and significantly inversely related to perceived safety margin: the larger the margin, the less the feeling of risk. Most respondents (76%) agreed that if they drove any faster than normal they would feel less in control, the task of driving would be more difficult (67%) and it would feel too risky (75%).

The upshot of this link between perceived task difficulty and risk feeling, discovered in our digital video studies mentioned earlier (Fuller et al., 2008c), is that we can now refer to the model as Risk Allostasis Theory (RAT), which is somewhat more pithy than the hypothesis of Task-difficulty homeostasis subsumed within the Task-Capability Interface model. With this change in nomenclature it is important to note that we are not simply substituting allostasis for homeostasis in the theory known as Risk Homeostasis (Wilde, 1982). In Wilde's model, the risk concept is operationalised in terms of statistical risk estimates *in conjunction with* feelings of risk (see Simonet and Wilde, 1997). Estimates of statistical risk have no part to play in RAT as currently formulated. This rejection of the role of statistical risk in driver decision-making has also recently been emphasized by Vaa (2007) in his critical analysis of Risk Homeostasis Theory (RHT): "…the target (risk) should not be regarded as a number, but as a certain kind of *feeling*" (p.214) and "…drivers are seeking a target *feeling* rather than a target *risk*" (p. 266). Furthermore in RHT, the determination of preferred risk levels ('target risk', in Wilde's terminology) arises out of an inferred cost-benefit analysis of safe and risky behavioural choices, rather than the variables of perceived capability, journey goals, effort motivation and dispositional and immediate factors identified in RAT.

The role of feelings in decision making. The role of feelings in decision making has a long history, being explored for example in the early work on emotion of William James and Carl Lange in the nineteenth century and significantly developed as a concept in the work of Zajonc in the twentieth (Zajonc, 1980). Nevertheless one gets a sense that the so-called cognitive revolution has until relatively recently largely neglected this role. However a new emphasis on the importance of emotion and feeling in decision making has emerged in particular through the work of Damasio (1994, 2003) with his concept of the 'somatic marker hypothesis'.

Feelings are the experiences concomitant with reward and punishment, with incentives and deterrents, with things we seek and things we avoid. They are the engines of the values we have and the goals we seek. Thus although our decisions about how to realize our goals may principally involve cognitive operations, it is feelings which select our goals, enabling us to choose between them, and which energize or motivate our approach to them.

Thus driving goals are feelings-motivated and must involve at the same time both positive, approach-motivating feelings associated with the achievement of the mobility goal (whether destination, journey or both) and negative, avoidance-motivating feelings associated with collision or road run-off.

Once goals are identified, to a certain extent we can leave it up to cognitive operations to guide decisions which enable us to attain these goals. From a feeling perspective, however, there is one important difference between goals of approach and goals of avoidance. In the former, feelings (positive) intensify as the goal becomes nearer and are presumably fully experienced when the goal is reached. In the latter, feelings (negative) decrease to the extent that the avoidance goal is achieved. Thus negative feelings are presumably rarely fully experienced when avoidance is successful, (as is the case nearly all of the time when driving) thus giving the impression that feelings of risk, for example, are generally not important in decision-making. As Carver and Scheier note (1981, p.199), self-regulation is relatively affect free *as long as normal discrepancy reduction processes are uninterrupted and are proceeding without difficulty*. However, when discrepancies cannot be easily reduced, then affective processes become important" (p.360-361). Despite this assertion, it is most important to stress that the stimuli which trigger avoidance responses *must retain their emotive characteristic*, otherwise they will become neutral stimuli, mere shadows that are powerless to elicit an avoidance response (see below). The driver still has risk feelings associated with objects-to-be-avoided: these are what determine avoidance goals. But when operating with a safe margin from objects-to-be-avoided, those feelings are not intensified and may not enter conscious awareness.

It is just this condition that is captured so nicely by Summala's zero-risk hypothesis, with risk feelings only kicking in when the safety margin has shrunk to some critical level. Summala's model argues that action is continuously monitored by a subjective risk/fear monitor (Summala, 2007), however this only takes a role in decisions when some threshold has been reached: "It is assumed that drivers normally feel full control over the task and no risk while driving. At certain (inherent and learned) thresholds of safety margins, corrective steering and speed adjustment is triggered. Too short time or space distances make drivers (to) feel uncomfortable, and they do not tolerate it at least without a very strong motive to continue" (p. 199). Risk feelings must continuously play a part to enable the driver to maintain safety margins, even if they have the characteristic of 'whispers of affect', as Slovic et al. (2002) described such responses.

Without continuously taking account of the emotions triggered by elements in the road and traffic environment and discrepancies between current and goal states, the driver would have no basis for decision-making, for her or his choices.

Interestingly in a recent study funded by the Irish Road Safety Authority, we have obtained evidence which suggests that younger drivers are less disposed to think (and presumably therefore feel) immediately of the severest consequences of extremely dangerous behaviour (Gormley and Fuller, 2008). In an interview survey of four age groups of male driver, aged 17-19, 20-22, 23-25 and 26-28 years attending the World Rally Championships in Ireland in 2007, we presented the following crash scenario and asked respondents to list as many consequences as occurred to them:

> *I am now going to describe to you a crash and when I finish I would like you to tell me what you think the consequences might be*
> "John, a young man of 20, loved driving fast and showing his mates how he could push his car to the limit. One rainy day, with two of his mates with him in the car, he took a corner too fast, lost control and slammed into a tree at 120 km/h (about 75 mph)."
> *What do you think might be the consequences of this crash?*

In the subsequent analysis, attention was paid to the *order* in which particular responses were given. The three main categories of consequence identified in order of frequency were Death, Serious injury and Damage to car/property. No differences between age groups were found in the frequency of reporting any particular category. However Death was significantly less likely to be mentioned *early* as a consequence by the youngest group of drivers. Consistent with this, Taubman-Ben-Ari (2008) found, in a survey of young drivers in compulsory service in the Israeli Defence Forces, that the cost of risk to life was not a predictor of any reckless driving measure. Glendon (2008), in a comprehensive review of brain imaging studies and decision-making, has pointed out that less well-developed executive functions of the brain in late adolescence may mean that implications of hazards are not so readily accessed. Linked to this is the observation that the integration of emotion with cognition, which appears to be mediated by the amygdala and hippocampus, is still maturing during this period.

In the somatic marker hypothesis, Damasio argues that elements of experience, such as objects, persons, scenarios and so on, automatically trigger an emotional response, albeit often only a weak one, whenever their representation is activated in the brain by either external or internal stimuli. Damasio proposes that in any situation requiring a decision, emotional signals “mark options and outcomes with a positive or negative signal that narrows the decision-space and increases the probability that the action will conform to past experience” (Damasio, 2003, p. 148). This emotional signal has an auxiliary role that increases the efficiency of the reasoning process and is not usually a substitute for it. However, when we immediately reject an option that would lead to certain disaster, reasoning may be “almost superfluous”: the action may be taken without some intervening conscious cognitive processing. Because emotional signals are body-related, Damasio labeled this set of ideas ‘the somatic marker hypothesis’. Through learning, somatic markers can become linked to stimuli and patterns of stimuli. When a negative somatic marker is linked to an image of a future outcome, it sounds an alarm. Slovic et al. (2002) refer to a similar concept as ‘the affect heuristic’.

The key conclusions, however, are that not only is affect essential to rational action, affective responses have a direct effect on cognitive operations (see Fuller, 2007 for a fuller exposition of Damasio’s conceptualization). It should be added that, as discussed earlier, emotional responses in the form of somatic markers arise not only from stimuli external to the driver but also from perceived discrepancies between goal states and current states. Including in these discrepancies are where task demand exceeds the upper preferred boundary (yielding a conscious feeling of anxiety, risk or fear) and where progress goals are thwarted (yielding a conscious feeling of frustration or anger or rage).

The relevance of the somatic marker hypothesis for driver decision-making has been discussed by Summala (2007), who suggests that “In dynamic time-limited situations like driving, fast affective heuristics must have a big role” (p.198) and its potential implications for driver safety have been discussed in Fuller (2005b, 2007). Increases in risk may not be felt because of suppressed emotional reactivity (e.g. through alcohol, depression, denial, desensitization and perhaps in conditions where the outcome of the decision is uncertain (see van Dijk and Zeelenberg, 2006)) or because of the swamping effect of other emotions (e.g. anger, exhilaration). If felt, risk feelings may be misattributed to events other than those related to accomplishing the driving task (e.g. anxiety from interaction with a passenger). Furthermore, experience may not have been sufficient to provide learning opportunities to link particular scenarios to feelings of risk (as with a novice driver) (Wickens et al., 2008; Kinnear et al., 2008). These and related issues for further research are discussed in Fuller (2005c).

A preliminary study of the contrasting roles of emotion and cognitive decision-making as *dispositional* characteristics of drivers has been reported by Wickens et al. (2008). In their model, which incorporates the key processes described by Damasio, there are two systems. One system involves processes which are "fast and frugal and activate gut feelings that fit the immediate situation…much like reflexive behaviour". Included are processes of implicit and instrumental learning, over-learned associations and behavioural regulation by the emotions. The other system involves processes which are "slower, more controlled and effortful and necessitate active consideration of alternatives". Included are processes related to cognitive abilities and executive functions (op cit. p.1224). They suggest that cognitive failure could arise when affective information may be lacking or inadequate or too strong, requiring a more analytic and effortful response. They found that although cognitive failure was related to impulsivity and failures in attention regulation, there was no relationship with their measure of the quality of affective information. However it should be stressed that their dispositional measure of this variable was closer to one of affect discrimination and labeling, rather than sensitivity. What is ideally needed to further our understanding of the roles of these processes are real-time observations of driver decision-making while monitoring simultaneously both affective and cognitive activity.

Recent alternative conceptualisations of driver goals

Turning finally to examine recent proposals for what constitutes the driver’s control goals when driving, Vaa (2007) develops the implications of the somatic marker hypothesis for driver behaviour in his ‘monitor model’. This argues that drivers may make adjustments to the prevailing road and traffic conditions with varying degrees of conscious awareness, on a continuum from unconscious adjustment through to fully conscious decision making. He proposes that although risk feeling may describe one homeostatic target for drivers (referred to as tension/anxiety), other feelings may also be targeted. Candidates he suggests as ‘other feelings’ are avoidance of threat or difficulty, compliance and non-compliance, arousal, sensation, joy and relaxation.

Feelings of avoidance of threat or difficulty are clearly related to task difficulty and feelings of risk, as discussed as targets in RAT, which also now incorporates dispositional and immediate influences on compliance. However the wider range of target states motivating driver decision making proposed by Vaas’ monitor model describe rather the dispositional motives and immediate influences on risk threshold as described in RAT. Rather than being target conditions in themselves, I would argue that they operate to ‘set’ the target level of risk feeling in the negative feedback control loop. Thus the driver looking for more arousal raises his or her risk threshold to achieve that state - and the driver wanting to relax does just the opposite.

Summala’s theoretical development also appears to be moving in a more inclusive direction. Whereas the 1976 conceptualisation developed with Risto Näätänen (Näätänen and Summala, 1976) postulated a subjective risk monitor which kicked in when risk experience exceeded a risk threshold, to both alert the driver and influence decision making, he now suggests that drivers operate not with just one target variable but a whole range of them (Summala, 2007). He invokes the umbrella concept of a ‘comfort zone’ to represent the range of values relating to each variable that drivers are assumed to be motivated to target: “It is hypothesized that drivers normally keep each of them within a certain range (or above certain threshold) in a comfort zone” (p. 201). Comfort is defined as a general mood or emotion which is “pleasant but not especially aroused, tense or activated” (P. 201).

Included in Summala’s target variables are space and time margins and mental load specifically relating to control. He also includes motivation for compliance. These variables may be translated in terms of the concept of a target range of task difficulty (operationalised in terms of TTC and TTLC) and influences on compliance as represented in RAT. However Summala adds various other target variables. These include comfort in relation to thermal state, seating, vibration, glare, rate of speed change and progress. Clearly, Summala’s model is shifting from one specifically concerned with control and collisions to one concerned with more general motives which inform driver decision-making. From the perspective of RAT, ‘glare’ may be subsumed under task demand elements and ‘rate of speed change and progress’ under range of acceptable task difficulty. However Summala’s other comfort motives must be secondary to those relating to safety motivation. A driver will hardly survive for very long without crashing if s/he prioritizes temperature, seating comfort or vibration as the target states which direct decision-making. As pointed out by Carver (1994), “…certain kinds of discrepancies are more demanding - more important - than others… For example, the experience of threat to one’s physical safety can override an attempt to engage in activities that are otherwise quite important” (p. 389).

Nevertheless these suggestions by Summala have enriched our conceptualisation of potential aspects of driver motivation (we await empirical validation), even though their relevance to our understanding of why collisions occur is unclear. RAT is concerned with representing the process of driver decision-making and in particular how motivations influence the outcome for system safety. However in principle it can be expanded to include the kinds of motive proposed by Summala. Their influence may be included in RAT as a top-down controlled hierarchy of secondary reference targets in decision-making. Because a safe outcome normally has to be prioritized, they must enter the decision-making process *after* risk allostasis decisions have been made, perhaps at the point in the process where influences on compliance also have their effect.

Summala’s extended target variables do, nevertheless, raise a further question. When a system has multiple reference standards, as he suggests, how do they operate in relation to each other? For example, are they implemented in serial order, as suggested in RAT, where compliance standards emerge as secondary to task difficulty targets, or can they operate in parallel? If the latter, the further question remains as to how their separate outputs are eventually integrated into the behavioural decision. Thus if task difficulty is ‘calling’ for an increase in speed and simultaneously compliance is ‘calling’ for a reduction, how is the conflict resolved by his system?

But perhaps the main conclusion to be drawn here is that despite the discrepancies which have emerged in conceptualizations of what drivers are aiming for in their decision-making, these apparent tensions may in fact reflect a hidden consensus. At least, from the perspective of RAT, that is what I have tried to demonstrate. Above all else, there is a current convergence in recognizing the primacy of the role of feeling in driver decision-making and this recognition opens up a whole new set of exciting and promising research questions.

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