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Towards a model to interpret driver behaviour in terms of mismatch between real world complexity and invested effort

Robert Broström[a, b*] and Staffan Davidsson[a, b]
[a] *Vehicle HMI-Dept 94750, Driver Interaction & Infotainment, Volvo Car Corporation PV32, SE-405 31 Göteborg, Sweden*
[b] *Engineering Psychology, Luleå University of Technology, SE-971 87 Luleå, Sweden*

Abstract. Driving behaviour has been less documented than driver workload. The possibilities to define a framework that could be part of a driving behaviour model were investigated. The results present a framework that defines twelve scenarios in which drivers have misinterpreted a driving situation. The descriptions show evidence of increased user experience for some scenarios while other indicates reduced traffic safety. The results suggest that by using the framework-descriptions on how and why mismatches occur, design guidelines for in-vehicle systems can be developed.

Keywords: Workload, user experience, framework, safety, in-vehicle system

1. Introduction

Improved car design in terms of passive and active systems has contributed to substantial improvements in driving safety over the past 50 years. During the same period of time several human information processing models have been developed within the field of human factors and ergonomics. These models describe limitation in terms of human performance [18] during situations of different levels of workload, and have been used to minimize risk of accidents in the process-, the flight-, and the automotive industry.

The Human Computer Interaction (HCI)-industry also make use of human factors and ergonomics knowledge [2]. In contrast to the risk-approach used in the other industries, the HCI-industry has focused on human behaviour, e.g. in terms of usability and user experience (UX) issues [6]. The term UX include a wide variety of meanings, ranging from traditional usability to beauty, hedonic, affective or experiential aspects of technology use [6]. In addition, the methods that include usability and UX are included in the toolbox for designers of consumer products while methods that include workload-models are not [1].

Car systems have similar requirements, and designers with similar education as those in the consumer product domain. However, in driving, human mental workload and performance is different from human behaviour. Performance reflects a person's capability in a certain environment, whereas behaviour is that person's actual actions in the same environment as they are mediated by the person's goals, needs, and motivation [14]. Models of driver performance have successfully described how many perceptual and motor limits influence driving performance, but models of driver behaviour still await development [13].

Therefore, the objective of this research was to outline a model of driver behaviour that included definitions familiar to designers of consumer products.

[*] Corresponding author. E-mail: rbrostr1@volvocars.com

1.1. Driving safety

Drivers most often adapt their behaviour and drive safely [15]. Even if there are individual differences, for example depending on age, drivers know their skill-level and adapt their behaviour to the complexity of the present driving situation. For example, older drivers might reduce there driving during dark hours and complex traffic situations. On the other hand, even if young drivers also adapt their behaviour they may overestimate their level of skill. This overestimation may affect their driving behaviour towards the real complexity in a specific traffic situation [13].

The results from the 100 car study [11] show that when an incident or an accident has occurred there is clear evidence of poor driver behaviour. Reports [11, 12] from the study show a direct relationship between driving behaviour and crash/near-crash involvement in terms of odds ratio (OR). The reports show that various secondary tasks increased OR compared to driving (OR=1). For example: *Reaching for a moving object* (OR=8.82), *Looking at external object* (OR=3.70), *Applying makeup* (OR=3.13) and *Dialling a hand-held device* (OR=2.79). On the other hand, the results showed that some secondary tasks actually reduced OR. For example: *Adjusting the radio* (OR=0.55), *Talking to a passenger in the adjacent seat* (OR=0.50), *Talking to a passenger in the rear seat* (OR=0.39), and *Combing hair* (OR=0.37). Based on these results future advancements in reducing traffic safety risks will depend on enhancing driving performance by improving driver behaviour. To do this there is need to clarify why drivers sometimes engage in tasks that increase risk, and how this behaviour can be reduced.

1.2. Human performance

The Multiple Resource Theory (MRT) present explanations of human's limited resources in different modalities, and also suggest optimal combination of modalities, codes and responses during the different stages of the information process [18]. MRT can be used to understand multiple-task interference.

Engineering psychology models, such as the MRT, emphasize human's limited mental capacity and due to the use of technical metaphors, such as "filter" or "computer", they are readily accepted by engineers and thus have influence on system design in the car domain. This can be exemplified by IDIS (Intelligent Driver Information System), a system that delay incoming phone calls and text messages, in order to reduce the potential for driver information overload [3].

The limited capacity models described above, however, have not taken into consideration human's capability to adapt to different situations. That may explain why less design effort has been put on systems that support adaptive behaviour.

1.3. Driver behaviour

Drivers change their behaviour depending on their goals, needs, and motivation [14]. For example, when a stressor appears, such as an increased risk in a traffic scenario or when drivers select to engage in other tasks than the driving task they take different actions to compensate for the changed demand. For example, drivers can change strategy, add resources or remove stressors [9]. Driver can also choose to do nothing which may affect driving performance negatively. Moreover, drivers can compensate for changed demand by mobilizing effort. The effort mechanism is active in the case of attention demanding information processing, or in the case that the operator's state differs too much from the required state [8]. According to this theory, central executive mechanisms compare the current cognitive state with a required or target state. Whenever there is a mismatch between these two states, changed effort can actively manipulate the current state towards the target state. By investing mental effort the detrimental influences of stressors can be successfully counteracted. A similar way to compensate for changed demand is to adjust distance to factors such as: time to collision, smooth and comfortable travel and rule following [17]. This mechanism results in a comfortable state called "comfort zone".

The same way of reasoning can be used for In Vehicle Information Systems (IVIS). If an IVIS feels difficult to use drivers either increase safety distance or avoid using the IVIS-function. For example, a driver can turn the volume down on the radio when stressed, turn the telephone off in complex driving situations, and wait to input a destination until the car is stationary. Hence, strong links can be found between the driving task, UX, and driving safety.

This reasoning is also supported by several simulator studies that have shown that drivers change their behaviour in situations with different levels of complexity. For example, a study on driver attention found that drivers abandoned the Peripheral Detection Task (PDT) when the driving task got to difficult. This behaviour obviously resulted in worse PDT performance but at the same time the driving performance measures were improved [19]. A similar change of driving behaviour was found in a study that investigated effects of different touch screen positions [5]. The simulator study tested four positions (near high, near low, far high, far low), and the results showed that drivers sacrificed the speed on the in-vehicle task to maintain safe driving performance in a similar manner as they would do on the road [5].

All the above mentioned theories and studies show that drivers adjust their behaviour in various situations to maintain their comfortable and safe zone. To be able to understand why they sometimes do not adapt their behaviour, this paper is meant to contribute to a first step towards a model to interpret driver behaviour. In this first step we have limited our work to define mismatch-scenarios. We have therefore left out other factors that influence driving behaviour such as: strategies, skill and motivation [9, 16], see figure 1.

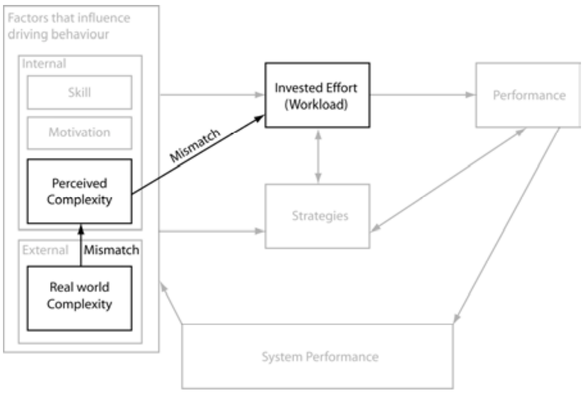

Figure 1. Inter-relationship between factors that influence behaviour, invested effort and performance. With influence from: "Adaptive control and mental workload" (p. 307), by R. Parasuraman in *Stress, Workload and Fatigue,* 2008, New York, CRC Press.

1.4. Purpose

The purpose of this paper was to define mismatch-scenarios that could occur while driving, and to arrange these scenarios in a framework that emphasized driver behaviour.

2. Method

A literature study and a workshop were performed to gather information to the framework which was supposed to interpret driving situations that contain combinations of driving related and non-driving related tasks. The suggested framework was based on previous research on workload [4, 10] and divided into three constructs that may be aligned or separated:

1. ***Real world complexity (RC)*** describes the combined complexity of a single and/or multiple tasks that a driver engages in during driving in a specific situation. Thus, the real world complexity represents the same level despite driver's capacity.
2. ***Subjective complexity (SC)*** describes the perceived complexity or the expectancy towards a specific situation. The subjective level can differ depending on personality, self confidence etc.
3. ***Invested effort (IE)*** describes the amount of effort that a driver chooses to invest in relation to the perceived complexity in a specific situation.

Moreover, it was defined that if one or more constructs failed to match with any other level in the framework, a *mismatch* had occurred. For example, if a driver would adapt perfectly to the *Real world complexity* of a specific situation all three constructs in the framework would be aligned, i.e. drivers matched their *Invested effort* according to the *Subjective complexity* level and the *Real world complexity*.

After defining the terms framework and the mismatch they were discussed in a one-day workshop with six human factors professionals. The professionals were: two professors with more than 20 years experience in several human factors domains (including the automotive), two representatives from a car manufacturer with more than 10 years experience in designing in-vehicle systems within the automotive domain, and two PhD candidates that performed research in interaction design issues related to the automotive domain. The literature study and the workshop results were summarised in a report which has been the basis for this paper.

3. Results

Based on the definition above, thirteen mismatch-scenarios were identified, see table 1. Scenario 0 represents normal driving while scenarios 1 through 12 were mismatch-scenarios. Among the mismatch-scenarios 1-6, one construct diverted from the other two. Scenarios number 7-12, on the other hand, included mismatch between two constructs, see table 1 and figure 2.

Table 1

Mismatch scenarios. When real world complexity (RC), subjective complexity (SC), and invested effort is in the same box no mismatch is present. When the constructs (RC, SC and IE) are in different boxes there is a mismatch-scenario. Scenario 0 represents normal driving while scenarios 1 through 12 are mismatch-scenarios.

Scenario no. / Levels	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Level x	RC, SC, IE	RC, SC	IE	SC	RC, IE	SC, IE	RC	RC	RC	SC	SC	IE	IE
Level x-1		IE	RC, SC	RC, IE	SC	RC	SC, IE	SC	IE	RC	IE	RC	SC
Level x-2								IE	SC	IE	RC	SC	RC

In scenarios 1, 6, 7, 8 and 9 the invested effort was lower than the real world complexity (RC>IE). These types of mismatch-scenarios indicate increased probability of *risky driving behaviour and worse UX*.

In scenarios 3, 5, 9, 10 and 12 the subjective complexity was higher than the real world complexity (SC>RC). These mismatch-scenarios indicate *increased risk of worse UX*.

In scenarios 2, 5, 10 and 12 the invested effort was higher than needed according to the real world complexity (IE>RC). These mismatch-scenarios indicate *increased risk of fatigue*.

In scenarios 4, 6, 7, 8 and 11 the real world complexity was higher than the subjective complexity (RC>SC). These types of mismatch-scenarios indicate increased probability of *risky driving behaviour*.

In scenarios 2, 4, 8, 11 and 12 the invested effort was higher than the subjective complexity (IE>SC). These types of mismatch-scenarios indicate increased probability of better *driving behaviour and better UX*.

In scenarios 1, 3, 7, 9 and 10 the subjective complexity was higher than the invested effort (SC>IE). These types of mismatch-scenarios indicate increased probability of *risky driving behaviour and worse UX*.

To further understand and interpret the scenarios, all three constructs in the framework (RC, SC and IE) have to be analysed simultaneously. This result was not fully exploited in this paper, however, a few examples where simultaneous analysis has been made were developed, see table 2 and figure 2.

Table 2

Examples on detailed descriptions of mismatch-scenarios.

Scenario no.	**How**	**Why**	**Design implications (examples)**
0	Regulation of effort match with perceived need and task complexity	Most common state. Normal/Good driving behaviour. No missing schema.	Not needed
4	Invested effort and real world complexity is matched but task is perceived easier than it is.	Good design, simplistic, good UX.	No countermeasures needed. Good UX
6	Don't see Don’t understand	Hidden hazard Missing knowledge Missing Schema Gulf between evaluation and execution	Feed forward Educate Design to reduce gulf. Difficult task should be perceived as difficult
7	Subjective complexity estimated less than the real world complexity. Put less effort into the task than perceived.	Personality. Similar to 0, i.e. the normal state for this personality. Wrong "Main driving Schema" Hidden hazard Missing knowledge Missing Schema Gulf between evaluation and execution	Coaching, encouragement, social media Feed forward Educate Design to reduce gulf. Difficult task should be perceived as difficult
11	Task complexity is perceived low. Still put a lot of effort into the task.	Personality, careful, waste effort may cause fatigue Good design, simplistic, good UX.	Not needed for UX. Coaching needed for increased safety.

4. Discussion

The purpose of this paper was to define mismatch-scenarios that could occur while driving, and to arrange these scenarios in a framework that emphasized driver behaviour.

In difference to other models that focus on users limited resources, i.e. situations of overload [18], this framework describe mismatch-scenarios that affect driving safety and UX. The framework is based on the assumption that drivers adapt their behaviour and drive safely in a majority of all driving situations [15], and that they indeed have available resources to solve a majority of all driving situations. However, when drivers for different reasons misinterpret the actual situation the framework suggest that there is a mismatch between one or two constructs.

4.1. The framework

In scenarios where the invested effort generally is lower than the real world complexity (RC>IE: scenario 1, 6, 7, 8 and 9), design implications can be how to design the road environment and in-vehicle systems to be perceived as difficult. In scenarios where the subjective complexity is higher than the real world complexity (SC>RC: scenario 3, 5, 9, 10 and 12) the driver instead experience risk. It may also, in the long run, be negative for traffic safety if drivers waste more effort than needed, as in scenario 2, 5, 10 and 12 (IE>RC). A challenge for these scenarios includes how to bring the driver back in the comfort zone to increase UX. This can be done, for example, by designing the road environment and in-vehicle systems to be perceived as ease.

Moreover, the descriptions that are presented in table 2 and figure 2 show a more detailed analysis. For example in *Scenario 0*, drivers manage to regulate effort according to the real world. This is the most common driving behaviour and does not include any design implications. In *Scenario 4*, on the other hand, drivers perceive the task as is easier than it is, even thought the invested effort is aligned with the real world complexity. This "mismatch" is wanted and a result of good design that support UX. In *Scenario 6* drivers invest as much effort as they think is appropriate to meet the real world complexity. However, a misinterpretation leads to less invested effort than needed and e.g. increased traffic risk. This risk can be reduced by feed forward information or by education. In *Scenario 7* drivers perceive the task as less difficult than it is. However, they invest less effort than needed, for example due to complacency. Examples on design implications can be coaching, social media etc. In *Scenario 11* drivers perceive the task easier than it is but still invest more effort than needed to meet the real world complexity. This can be good for UX, however too much waste effort may cause fatigue.

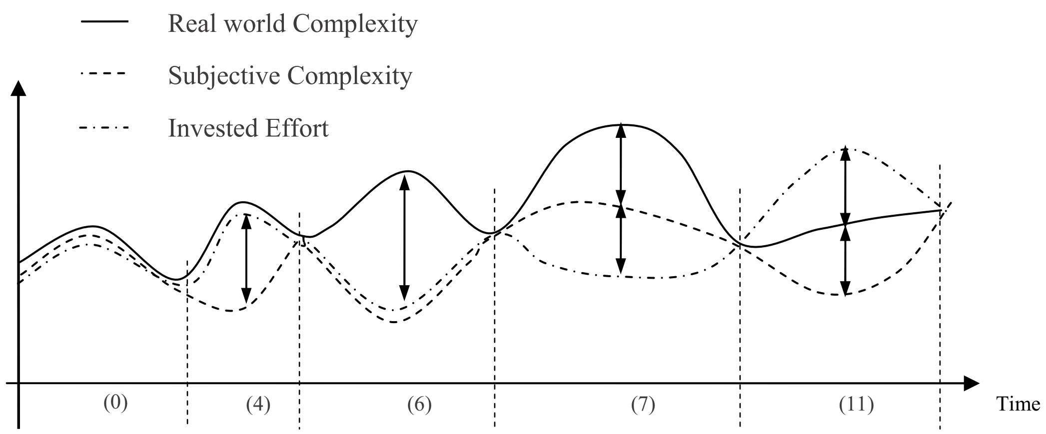

Figure 2. Examples of possible mismatches. Mismatch-scenario number 0 represents normal driving, number 4 and 6 represents single mismatch-scenarios while number 7 and 11 represents double mismatch-scenarios.

4.2. Effects on traffic safety and user experience

Even if drivers obviously can change their behaviour towards their goals, needs, and motivation [14], and towards the real world complexity [5, 19], it is clear that drivers are involved in scenarios that include mismatch between real world complexity and invested effort. Many of these mismatch-scenarios clearly occur due to driver's behaviour. The 100-car study show that risk for incidents and accidents increase when drivers are reaching for moving objects, looking at external object, applying makeup, and dialling hand-held devices [11, 12]. Many of these, particularly those with the highest odds ratio (1. Reaching for a moving object, 2. Looking at external object, and 3. Applying makeup) are tasks in which the drivers engage in a voluntary manner, and thus are more difficult to reduce with design measures. On the other hand, the same study shows that some tasks actually reduce accident risk (1. Adjusting the radio, 2. Talking to a passenger in the adjacent seat, 3. Talking to a passenger in the rear seat, and 4. Combing hair). These results show that drivers can increase traffic safety, by, e.g. make use of simple in-vehicle tasks while driving. Hence, an in-vehicle-system that is sensitive for changes in driver behaviour, e.g. IDIS [3], can encourage drivers to talk to passengers or use the radio to increase traffic safety.

Moreover, it has been found that drivers' subjective estimates of distraction with the actual distraction effects (the distracting effects of a hand-held or hands free cell phone conversation) are not well-calibrated [7]. However, training to recognize or attend more closely to driving activities may help drivers' determine when their performance is below the real world complexity [7].

4.3. Conclusions

In most cases, the perceived complexity in driving situations is aligned with the real world complexity and the invested effort. This paper suggests a framework that analyse driving situations from a perspective of mismatch between real world complexity, subjective complexity and invested effort. The results show twelve mismatch-scenarios that can be used to analyse safety and user experience. By using the framework descriptions on how and why mismatches occur can be developed, and implications for design can be defined.

In conclusion, the results reported here offer an opportunity to develop a safety and user experience model with descriptions and implications for interaction design. The framework can also be further expanded into design guidelines for in-vehicle systems.

4.4. Further work

Models of driver performance have successfully described how many perceptual and motor limits influence driving performance, but models of driver behaviour still await development [13]. Further research should be added to the framework developed in this paper. Examples on research questions are:

- Which mismatch-scenarios are relevant for safety and UX?
- Are there difference between single and double mismatch-scenarios in terms of safety and UX?
- Do skill and motivation affect mismatch?
- How do the different factors that influence driving behaviour relate to each other?
- How can the defined mismatch-scenarios be confirmed and measured, during driving, during tests in simulator and by subjective methods?
- Will this framework be easier to use for designers of in-vehicle systems compared to previous workload-models?

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