6 Behavioral Adaptation and Acceptance

Marieke H. Martens[1,2] · *Gunnar D. Jenssen*[3]
[1]TNO, Soesterberg, The Netherlands
[2]University of Twente, Enschede, The Netherlands
[3]Transport Research, SINTEF, Trondheim, Norway

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Abstract: One purpose of Intelligent Vehicles is to improve road safety, throughput, and emissions. However, the predicted effects are not always as large as aimed for. Part of this is due to indirect behavioral changes of drivers, also called behavioral adaptation. Behavioral adaptation (BA) refers to unintended behavior that arises following a change to the road traffic system. Qualitative models of behavioral adaptation (formerly known as risk compensation) describe BA by the change in the subjectively perceived enhancement of the safety margins. If a driver thinks that the system is able to enhance safety and also perceives the change in behavior as advantageous, adaptation occurs. The amount of adaptation is (indirectly) influenced by the driver personality and trust in the system. This also means that the amount of adaptation differs between user groups and even within one driver or changes over time.

Examples of behavioral change are the generation of extra mobility (e.g., taking the car instead of the train), road use by "less qualified" drivers (e.g., novice drivers), driving under more difficult conditions (e.g., driving on slippery roads), or a change in distance to the vehicle ahead (e.g., driving closer to a lead vehicle with ABS).

In effect predictions, behavioral adaptation should be taken into account. Even though it may reduce beneficial effects, BA (normally) does not eliminate the positive effects. How much the effects are reduced depends on the type of ADAS, the design of the ADAS, the driver, the current state of the driver, and the local traffic and weather conditions.

1 Introduction

The introduction of ITS (Intelligent Transportation Systems) is generally seen as a positive step toward reducing crash risk and improving road safety. ITS includes informing, warning, and actively supporting the driver in his or her driving task by means of ADAS (Advanced Driver Assistance Systems). However, when the safety effects that result from the introduction of these safety systems are estimated, an important bias may occur. The following example illustrates this bias:

"In 30% of all accidents, driver fatigue was the major cause. The introduction of a fatigue alertness system will therefore reduce the number of accidents with 30%."

This bias is a bias since accidents are caused by a complexity of factors, and may not be the result of fatigue only. Even more importantly, safety systems can have unintended effects on driver behavior that offset – or even negate – some of the intended benefits. What if we design systems that are not acceptable and are therefore being switched off, what if drivers continue to drive for longer periods of time since they know they will be warned, or even worse show other types of behavior in order to prevent alarms from going off since the alarm is extremely annoying? To what extent do drivers actually use and drive with the systems as intended by automotive engineers?

In terms of driver psychology, the expression "behavioral adaptation" (BA) refers to the collection of unintended behavior(s) that arises following a change to the road traffic system. Although their effect on road safety can be positive, negative, or neutral, it is the unintended and negative consequences of behavioral adaptation that are of primary concern to road safety professionals. Wilde was one of the first to start this discussion with the introduction of the Risk Homeostasis Theory (e.g., Wilde 1982, 1988, 1994). This theory was the basis for a large number of road safety studies in the 1990s, introducing the term "risk compensation." This describes the phenomenon that drivers adjust their behavior based on their perceived risk. Behavior may start to be less cautious in case of the introduction of safety enhancing systems (since the perceived risk decreases), and may be more cautious in case of unsafe conditions (rain, snow, darkness, not wearing seatbelts, so an increased perceived risk). However, the terms "compensation" and "homeostasis" were not considered to be adequate. Even though behavioral changes occur, there is hardly any nill effect. Therefore, the term "behavioral adaptation" is used nowadays instead of "risk compensation."

1.1 Direct Behavioral Adaptation

It is useful to note that ADAS may have direct and indirect effects on driver behavior. The direct effects on driver behavior are realized through system parameters set by the vehicle manufacturer. These direct effects are often called *engineering effects*, which are intended by system designers and implied by the systems functional specifications. For example, in an ACC (Adaptive Cruise Control) system headway distance is monitored and adjusted based on sensors with an electronic link directly to the engine, ABS, and ESC. ACC monitors the longitudinal area of safe travel in relation to stop distance parameter limits, set by the manufacturer and the driver only controls pre set choice options of the HMI. The general connotation of the concept is that it is beneficial to safety effects by changing the car following behavior. Yet, not all ADAS are specifically marketed as safety systems. For example, ACC is primarily marketed as a comfort system, although it obviously may have beneficial safety effects due to direct engineering effects on safe headway distance.

1.2 Indirect Behavioral Adaptation

It should be noted that in traffic research, behavioral adaptation most often refers specifically to the unintended and therefore indirect effects as defined by OECD (1990), "Those behaviors which may occur following the introduction of changes to the road-vehicle-user system and which were not intended by the initiators of the change." (p. 23). The general connotation of the concept is that it is detrimental to the beneficial safety effects. However, there may also be unintentional positive safety effects of behavioral adaptation to ADAS, e.g., the increased use of turn-signal among drivers with Lane Departure Warning Systems (LDWS). In contrast to direct behavioral changes which are intended by engineers, designers, manufacturers, the OECD (1990) definition only refers to unintended effects, which hence all are indirect in nature. In other words the driver is the x factor in the equation, which may to a larger or lesser extent moderate the direct intended safety effects.

The most widely known example of behavioral adaptation to driver assistance technology is probably the case of Antilock Brake System (ABS). According to engineering predictions of ABS' impact, it should only affect lateral control and stopping distance (OECD 1990; Vaa et al. 2006; Smiley 2000). However, studies by Fosser et al. (1997) show that drivers with ABS equipped cars drive with shorter following distances than drivers without ABS. Other well-documented examples of behavioral adaptation in road traffic is that road users have a narrowing of the eye scanning area at hight speeds and in car following situations, that speed increases with increasing lane width, wider shoulders, and better road surface (OECD 1990; Mourant and Rockwell 1970; Smiley 2000). Thus, adaptation to a change is predictable and may appear in many different aspects of the driving task such as a change in headway, overtaking rate, lane change frequency, speed, braking, attention, motivation, etc. That adaptation will occur is predictable. According to Smiley (2000) we should be more surprised by its absence.

2 Models of Behavioral Adaptation

These factors are summarized in a qualitative model of Behavioral Adaptation Rudin-Brown and Noy (2002) (*Fig. 6.1*).

According to the model, behavioral adaptation may occurr on all the levels of the driving task as defined by Michon (1985). At a strategic level, ADAS may affect the decision to drive, both in negative and positive ways. Driver monitoring systems may (indirectly) encourage a sleepy driver to keep on driving, when he or she otherwise might have stopped. ACC and collision avoidance systems may encourage drivers to keep on driving in fog or heavy rain when they otherwise would have stopped. Navigation systems

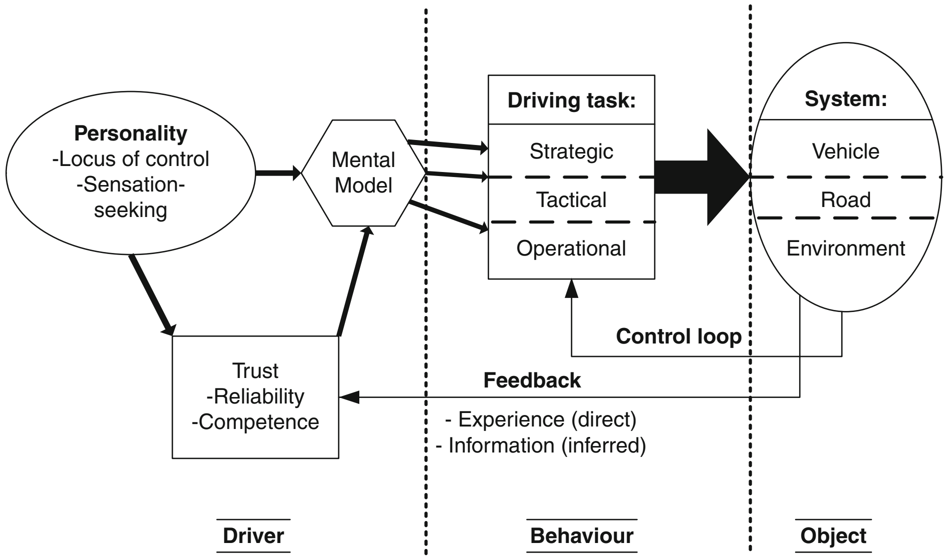


Fig. 6.1
Qualitative model of BA by Rudin-Brown and Noy (2002)

with traffic information may lead to a decision to stay home or a shift to public transport when a critical link in the road network is blocked. At a tactical level, a blind spot warning system may lead to an increased number of lane changes and overtaking maneuvers. On an operational level, increased visibility under night time driving with Adaptive Front Lighting Systems (AFS) or Vision Enhancement may lead to higher driving speeds.

The qualitative model of behavioral adaptation (Rudin-Brown and Noy 2002) gives perhaps the best account of the important components in behavioral adaptation (personality, trust, mental model), and its effect on different levels of the driving task (strategic, tactical, operational). The model does not, however, describe relevant feedback and the impact of the control loop, which may differ dependent on vehicle characteristics (e.g., ADAS, IVIS). For example when an ADAS like ACC is activated the driver is out of the loop in terms of acceleration and deceleration control actions. The driver is only in the loop if he or she monitors the process and decides to intervene (some may use the spare capacity ACC system assistance offers to send text messages, glance at incoming mail etc.) The ACC sensors take over the driver detection of headway and have a direct impact on headway distance with a feed forward loop to the traffic situation as the movement of the ACC equipped car can be observed by other road users. This feedback loop to other road users is based on characteristics of system function, not on driver actions. IVIS is on the other hand has an indirect impact on the traffic situation as observed by others. IVIS is based on driver detection of displayed system information or warnings and resultant driver actions (driver in the loop).

Similar aspects are characterized in a process model developed by Weller and Schlag (2004) (➋ *Fig. 6.2*) and named by Bjørnskau (1994, cited in Elvik and Vaa 2004). Compared to the model of Rudin-Brown and Noy, this model explicitly addresses potential changes in a Situational Awareness, attention, and workload. For example, as ADAS relieves the driver from certain driving tasks, the reduced workload may be seen as an opportunity to focus on other tasks, e.g., talking on the cell phone or reading an email on a SmartPhone.

The main focus of BA lies in the subjectively perceived enhancement of the safety margins. If a driver thinks that the system is able to enhance safety (e.g., by means of information from advertisements) and the driver also perceives the change in behavior as advantageous (subjective enhanced utility of adaptation), adaptation will occur. That is, the amount of adaptation is still (indirectly) influenced by the driver personality, his or her driving motives, and via trust, workload, locus of control, etc. This also means that the amount of adaptation differs between different user groups and may even vary within one driver (e.g., is a driver in a hurry or not?).

Many of the early models on behavioral adaptation refer to the *Peltzman Effect* which is the hypothesized tendency of people to react to a safety regulation by increasing other risky behavior, offsetting some or all of the benefit of the safety regulation (Peltzman 1975). Peltzman, an economist and true behaviorist, is however criticized for leaving out crucial human factors dimensions of response, which may be highly relevant to new advanced driver assistance systems (Smiley 2000; Carsten 2001). Examples are human factor dimensions like complacency, human error, and the well-known effects of workload, leading at one end of the spectrum to underload, low arousal, and loss of situation

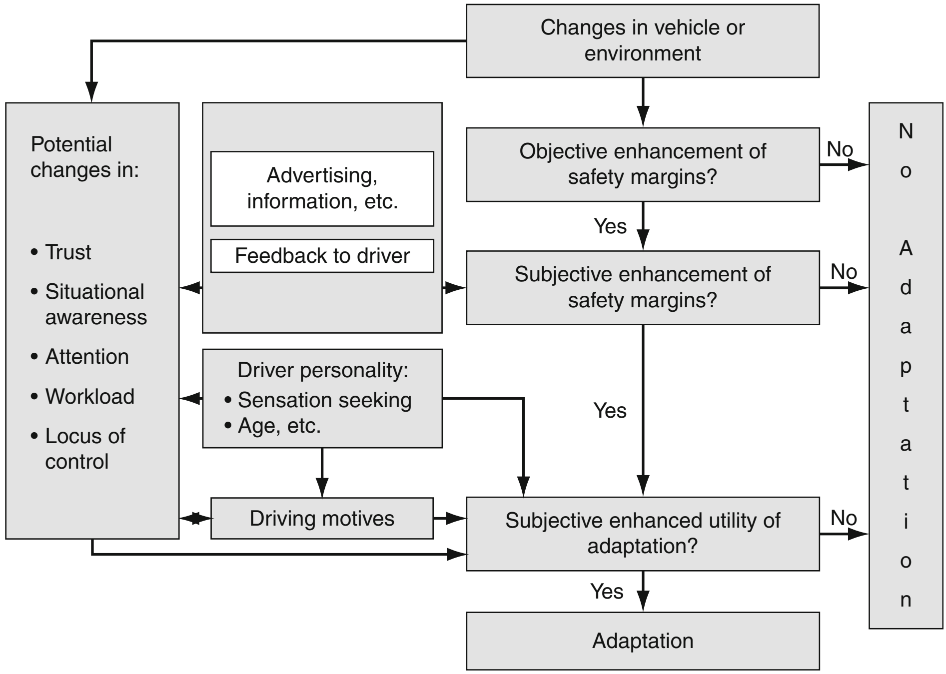


Fig. 6.2
Process model of behavioral adaptation by Weller and Schlag (2004)

awareness, and at the other end of the spectrum to overload and stress leading to poor performance.

Under what circumstances is BA expected to be most safety critical? It is suggested that the most dangerous situation is low workload induced by driving with ADAS followed by a critical high-workload event, which could occur if a driver assistance system is not able to cope with a situation and therefore driver intervention is required (Carsten and Nilsson 2001). This is the type of situation ACC manuals now warn for, e.g., when a car suddenly changes lane and cuts off a driver, the driver may after a long drive have low workload and little attention, due to low traffic density, the monotonous task, and overreliance on the ACC system to keep a safe distance. The narrow beam of the ACC sensor is not sufficient to respond to vehicles outside the lateral system envelope. Drivers do not necessarily understand the limitations of ADAS imposed by the designer and inherent sensor limitations. This is exactly the reason why these systems are sold as comfort systems and not so much as safety systems. The driver is still responsible for safety and needs to act when the system fails. Whether drivers are always aware of this responsibility remains unknown.

Engström and Hollnagel (2005) state that BA models specifically aimed at the interaction with ADAS/IVIS functions are considerably less common than the substantial number of more generic driver behavior models. They argue particularly that a generic model of drivers' interactions with in-vehicle systems and Advanced Driver Assistance Systems, including behavioral adaptation is still lacking.

Even though there are models that include part of the elements of a generic driver behavior model including ADAS/IVIS impact, such as the COCOM and UCOM models (Hollnagel and Woods 2005), these models do not leave room for describing how aspects of an ADAS function may partially or completely take the driver out of the loop and how behavior of ADAS equipped vehicles affect surrounding traffic. Many of the older models have their basis in the 1970s, not allowing to include aspects like the introduction of ADAS. A good model has a predictive value, allowing to predict outcomes of the process in situations where the contingencies for the model change, as is the case with ADAS. ADAS like ACC and Intelligent Speed Adaptation (ISA) will change the way we drive and, consequently, will change the basis for theories, models, and tools used to explain or estimate traffic flow, capacity, safety impact, etc. For further discussion, see Modeling Driver Behavior in Automotive Environments (Cacciabue 2007).

3 Types of Behavioral Adaptation

From the models presented above, it is evident that behavioral adaptation may lead to a wide range of possible changes in driver behavior. Changes in behavior may be grouped into the following categories:

- Perceptive changes (seeing, hearing, feeling)
- Cognitive changes (comprehending, interpreting, prioritizing, selecting, deciding)
- Performance changes (driving, system handling, error)
- Driver state changes (attentiveness/awareness, workload, stress, drowsiness)
- Attitudinal changes (acceptance, rejection, overreliance, mistrust)
- Changes in adaptation to environmental conditions (weather, visibility, etc.)

Driver support systems, such as ACC, extend a driver’s perceptual capabilities, since the system accounts for continuous monitoring of headway distance unaffected by fatigue. Sensors of the ACC system extend the possibility to detect lead cars in fog conditions beyond what is possible with the human eye. Future ADAS based on car-to-car communication and car-to-infrastructure systems (so-called cooperative systems) will extend the perceptual capabilities of ADAS even further. This is positive in terms of traffic safety as long as the driver does not (mis)use this benefit by driving faster than he or she otherwise would or by choosing a time headway shorter than what is safe.

There are several ways in which behavioral adaptation may influence safety. We will present different forms of behavioral adaption with some examples.

1. The generation of extra mobility. Using a driver support system can increase the amount of kilometers a person drives per year. For example, on the one hand, navigation systems reduce excess mileage because of more direct routes without people getting lost. On the other hand, they generate extra mileage into areas that were formerly avoided. Entrepreneurs who formerly “lost” 5% or 6% of the mileage driven by their fleet, because drivers selected nonoptimal routes to their destination,

may now plan an extra trip a day because navigation performance has become flawless. Also, drivers may feel more secure driving in unfamiliar areas, taking the car instead of the bus.

2. Road use by "less qualified" segments of the driving population. It is to be expected that some categories of users that did not dare to venture out in busy traffic, realizing their own imperfections, will do so if offered an extra amount of "built in" safety by means of driver support systems (e.g., elderly drivers).
3. Driving under more difficult conditions, e.g., driving at night time or on slippery roads. Due to night vision systems, the extra visual aids offered will tempt road users to drive at night, whereas they avoided these situations before. Also, having winter tires on the car drives people into harsh winter conditions, whereas they used to stay home if they would not have these tires.
4. Change in driving speed, e.g., driving faster with a new car since the brakes are more effective than the brakes on the older car that you used to drive.
5. Change in distance to the vehicle ahead, e.g., driving closer to a lead vehicle with ABS.
6. Driving less alert or concentrated, e.g., trying to read your mail on your Smartphone while driving, knowing that you are driving with a lane departure warning system that will warn you when you will drive out of your lane.
7. Avoiding, misleading, or compensating for interventions by the system, e.g., when driving with intelligent speed adaptation, drivers are restricted in their free choice of speed. This may lead to stronger accelerations to the speed limit, since this is the only part that is still under their control. Also, drivers may choose to pass a red light because they feel that time was lost because they cannot drive as fast as preferred, trying to save some time this way.

To exemplify further possible negative system effects, it can be useful to consider the results of a study on behavioral adaptation to Intelligent Speed Adaptation (ISA).

The relationship between speed and accident risk is well known. Therefore, it seems reasonable to introduce safety systems that restrict driving speeds. Studies of ISA generally show considerable reduction in accident risk. However, a study of ISA in Finland indicates that behavioral changes may take place when driving with ISA that negatively related to safety when used under snowy and icy conditions with slippery road, jeopardizing safety (Peltola and Kulmala 2000). This adaptation took place since the type of ISA studied gave feedback to the driver about the current driving speed compared to the officially posted speed, but did not include reduced speed advice due to slippery road. The study, therefore, showed that without dynamic feedback on road conditions (in this case with ISA), drivers drove faster than they otherwise would under such conditions without ISA.

This observation of behavioral adaptations to ISA among Finnish drivers may involve several types of underlying changes. For example, a change in attitude (i.e., overreliance/shift in locus of control) may lead to a change in driver state (inattentive). The changes in attitude may lead to perceptive changes (not seeing, feeling the slippery icy road as dangerous). This is possibly linked to cognitive factors (e.g., not comprehending the limitations of ISA).

Behavioral changes, i.e., driving too fast on icy roads and faster than non-equipped is also demonstrated in earlier driving simulator studies (Comte and Jamson 1998) that found similar changes to driving with ISA in fog. As long as ISA speed limits are fixed and not variable, the combination of ISA and low friction warning is necessary and sufficient to avoid such negative behavioral adaptation, as demonstrated in the INTRO project (Kircher and Thorslund 2009).

4 When Does BA Occur?

Of course, it is very interesting to understand when behavioral adaptation will occur. The first item that needs to be changed in order for BA to take place is a change in the road-vehicle-user system. In case there are no changes in this cooperation, there will not be any behavioral adaptation process. A second precondition for behavioral adaptation is that the feedback can also be perceived. This means that drivers either have to notice the positive or negative effects themselves, or they receive information about the expected positive or negative effects of the change.

5 Behavioral Adaptation in a Longer-Term Perspective

Changes in driver behavior may occur shortly after driving with a system (e.g., if a driver is time pressed, intoxicated, bored, etc.) but the behavioral change may also occur on a longer-term basis, for instance as we age or, over time, grow accustomed to ADAS. By driving in new social settings or rarely occurring traffic scenarios, we may learn new aspects of ADAS use or experience new system limitations. It is important to take into account the fact that an effect may not appear immediately when the driving context is changed, but usually appears after a familiarization period. This is important to realize, since an experiment, aiming to study the effects of a safety system by studying driving behavior as response to the system may reveal positive effects, whereas they disappear after longer-term use.

Draskóczy (1994) outlines chronological phases in behavioral adaptation to driver assistance systems, which incorporates the establishing of stability in performance. She suggests that studies should be done (a) before system activation, (b) immediately (within a month) after system activation, and (c) after 6 months of system use. Only then the real safety effects can be studied and insight into the behavioral adaptation can be found. It has been proposed that traffic safety research on ADAS would benefit theoretically, methodologically, as well as scientifically in terms of more valid predictions of safety effects by extending the scope of interest to include behavioral adaptation in a longer-term perspective (Nardi 1996; Draskóczy 1995; Smiley 2000; Carstens and Nilsson 2001; Saad 2006).

➋ *Table 6.1* summarizes characteristics of the learning phases and the adaptation to ADAS (Jenssen 2010). It is supported by recent experiences from longer-term studies of ISA (Carstens 2008; Berg et al. 2008) and studies of longer-term use of ESC (Rudin-Brown

Table 6.1

Characteristics of five learning phases in the behavioral adaptation to ADAS

Learning phase	Level of experience	Behavior	Duration	Scenario experience	Typical learning	Typical problems
1. First encounter	Tabula rasa	Exploratory	First day <50 km 1–6 h	Limited	Interface use	HMI related – distraction – distrust
2. Learning	Novice	Unstable	3–4 weeks <1,000 km 10–40 h	Most urban, rural road/ traffic conditions including day/night driving	Controllability	HMI related distraction System limitations
3. Trust	Relatively experienced	Relatively Stable	1–6 months	Most urban, rural road types including day/night driving and many weather conditions	Trust Shift in locus of control	Passive monitoring Overreliance Drowsiness
4. Adjustment	Experienced	Stable	6–12 months	All urban rural road types most summer winter conditions	Functional limitations Malfunction	Resentment
5. Readjustment	Expert	Very stable	>1–2 years	All relevant road traffic conditions	Rarely occurring hazard events System limitations and Malfunction	Mistrust Resentment Loss of manual control skills

et al. 2009). There seem to be five learning phases characterized by level of experience, driver behavior, typical learning, and typical problems. Some of the interviewed drivers had driven with ACC and ESC for up to 6 years and could report both sudden and gradual changes in understanding and control of their ADAS equipped vehicles.

Sudden changes do not occur until a change in the combination of driver state/behavior/workload, ADAS configuration, and road traffic condition occurs.

Examples are: long journey with ACC with a driver glancing at newspaper in passenger seat while a dog suddenly crosses the road or that ESC hinders you from getting up a snowy hill in wintertime. Such hazard events are rare, and might first be experienced after 1–2 years of driving or after a winter season.

The *First encounter* phase is characterized by initial learning of the system interface use. Some drivers read instructions carefully prior to use, but the in-depth interviews and survey results (Jenssen 2010) indicate that most drivers learn as they drive. The duration of the first phase depends on how self-explaining and intuitive the HMI solution is.

The second phase *Learning* is better documented in the literature and typically has a duration of 3–4 weeks. The duration of the learning phase may, however, vary to some extent depending on the type of ADAS studied. How intuitive the ADAS and respective HMI solution is, may play an important role. For example, the ACC system requires system input of set speed and distance to lead vehicle and an understanding of the interface, while ESC requires no input from the driver. ACC may thus take longer time to learn. Yet, optimal effect of, e.g., ESC is first achieved if the driver knows how it works best, i.e., use of full brake force. It is not given that all drivers will learn this by trial and error. Some minimum education or training on ADAS function might be required to optimize safety benefits.

After behavior reaches some kind of stability (phase 3) ADAS use is characterized by system *trust*. A shift in locus of control from driver to vehicle system may develop in this period. However, if there is no trust in the system, this phase 3 will not be entered and the driver will inactivate the system. Related problems are typically overreliance, passiveness, and drowsiness.

Phase 4 involves *adjustment* of trust as some of the most frequent system limitations are revealed. Resentment against system use may evolve and surface in this phase. The learning phases 3–5 seem to be more dependent on scenario experience than kilometers driven. If you mainly drive the ADAS equipped vehicle back and forth on the same route (e.g., to work), you do not necessarily learn relevant functional limitations that are scenario dependent.

Functional limitations and malfunctions may be learnt first after a winter season or after leisure time related to driving in more diverse and novel surroundings for ADAS use (Adjustment phase).

Readjustment of behavior (phase 5) may require as much as 1–2 years of ADAS driving since this readjustment is based on rarely occurring hazard events which are revealed only when a certain combination of road traffic conditions occurs. Mistrust as well as loss of manual control skills may typically surface in this phase.

During the learning process behavior changes from effort-demanding controlled behavior (e.g., learning to use and understand HMI interface and system function) to effortless automatic behavioral control. The novice driver uses conscious problem solving to implement actions while for the experienced driver action control is driven by expectations.

Incidents or accidents in the first two phases can be related to spending too much time and effort on HMI tasks or errors in setting of system parameters, while breach of expectations related to ADAS function can typically occur at the *trust* and *readjustment* phase.

This has implications for methodological challenges in the study of ADAS and interpretation of results from short term versus longer-term exposure to ADAS.

6 Relation Behavioral Adaptation and Safety

As indicated, BA affects safety. In some cases, this adaptation can be positive in terms of safety (e.g., a driver slowing down while making an important business call), or negative. Since this book focuses on intelligent vehicles and driver support systems, the behavioral adaptation in that case will mostly be decreasing the originally aimed for safety benefits.

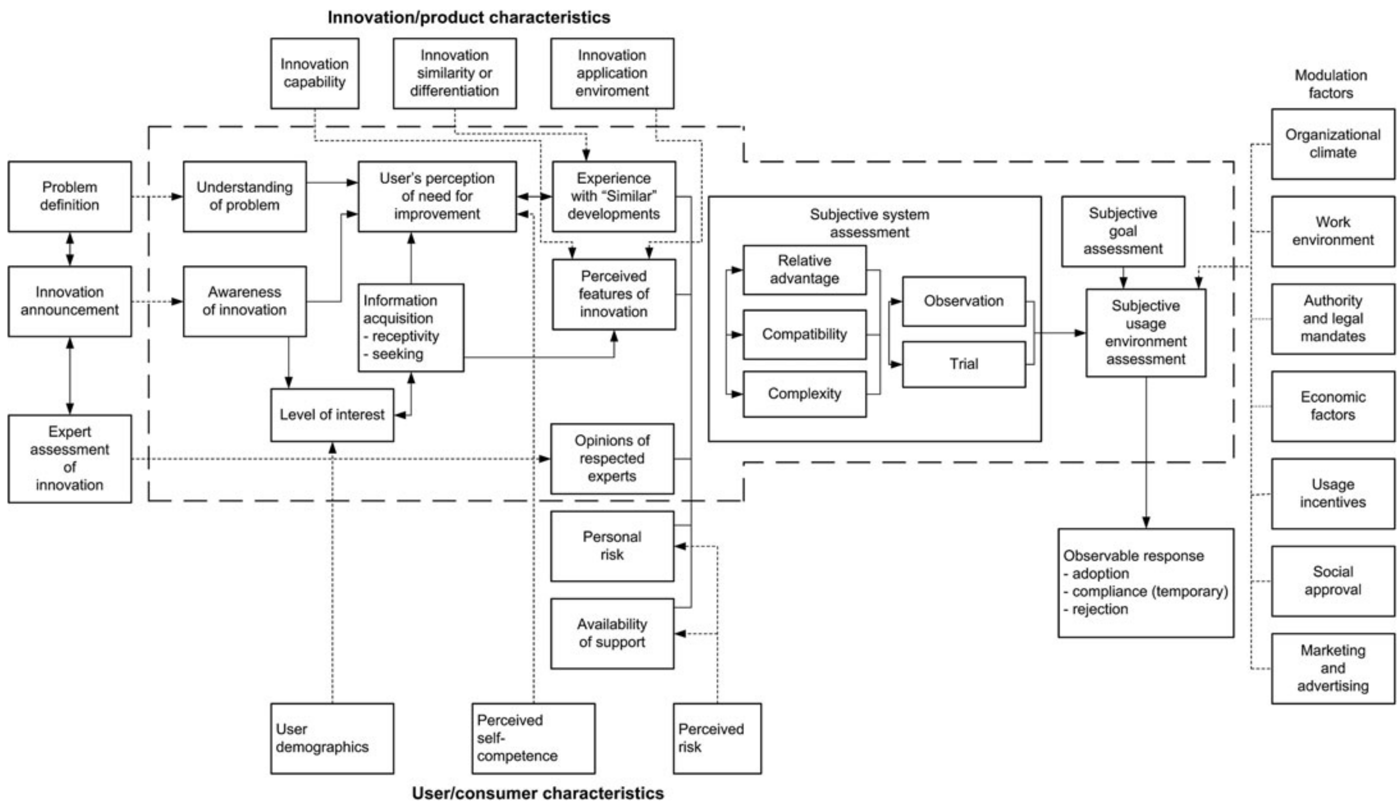
However, we should keep in mind that BA does not totally eliminate the effects of the safety measures. How much the safety effects are reduced by means of behavioral adaptation is unknown, since it will depend on the type of ADAS, the design of the ADAS, the driver, the current state of the driver, and the local traffic and weather conditions. It is not yet clear whether BA always happens, or what would distinguish cases in which they do from cases in which they do not.

To come to terms with these questions we would need up-to-date valid and quantitative models of road user decision making. Elementary utility models (O'Neill 1977; Janssen and Tenkink 1988) have already paid some services in this respect. In the Janssen and Tenkink model (see *Fig. 6.3*), the road user is assumed to balance the (dis)utilities of time loss during the trip, plus the possible accident risk, against the utility of being at the destination. From this a choice of optimal speed, and possibly of other driving behavior parameters, then follows so as to be at the optimum of that balance. It has been derived from this type of consideration, e.g., that a device that has an expected effectiveness (i.e., an engineering estimate) ε will not reduce accident risk with that same factor but with a factor that happens to be

$$\hat{\varepsilon} = 1 - (1 - \varepsilon)^{-1/(c+1)}$$

in which c is Nilsson's (Nilsson 1984) parameter in his speed-risk function, which has values of between 3 and 7 for different types of accidents. For fatalities, $c = 7$. It is clear that the safety effect to be realized will always be less than the expected effectiveness: see *Fig. 6.4*.

For example, with a commonly expected safety effect of $\varepsilon = 0.43$, the estimated effect to be achieved for the fatality rate per kilometer would be in the order of 7% rather than 43% (at 100% use rate).



■ Fig. 6.3

Utility model (Janssen and Tenkink 1988) shows how drivers select optimum speed as a function of time (opportunity) losses and accident risk, so as to make the resulting total expected loss minimal. It appears to be generally true that whenever accident risk is objectively reduced (''after'' situation) the optimum speed that is selected will move toward the higher end of the scale

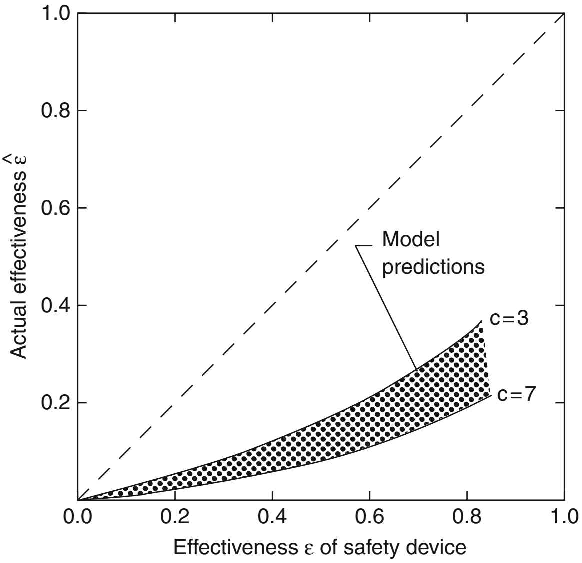


Fig. 6.4
Expected and actual (i.e., pre- or postdicted) safety benefit, according to a simple utility model of driver behavior

In order to have proper ex-post safety estimations of safety systems, there need to be a detailed accident analyses (most of the time they are not available) and in-detail comparisons between drivers using these systems and drivers not using these systems. In order to get better safety estimates, Field Operational Tests are being implemented, analyzing the data from many road users with various systems under normal and realistic driving conditions (for more information on FOTs, see the EuroFOT project from the European Commission, http://www.eurofot-ip.eu/).

7 Behavioral Adaptation and Acceptance

One important element in the context of behavioral adaptation is "acceptance." Intelligent in-vehicle systems are introduced to improve throughput, safety, emissions, or driver comfort. Therefore, user acceptance of any system is of major importance. If a system will not be accepted, it will be switched off, drivers will bypass the system, and it may be distractive and counterproductive. However, user acceptance does not always lead to good results, e.g., because drivers may overrely on the system (in case of good acceptance) or show more risky driving behavior due to the subjective feeling of safety. This directly relates to behavioral adaptation.

The issue of user acceptance of in-vehicle technology is a complicated one, since acceptance is not a status quo. People may state on forehand that they will accept a certain system. However, after using the product for a while, they no longer do. The other way around, driver acceptance may improve after training. Therefore, it is important to understand the aspects that lead to user acceptance when thinking about BA.

In general, we can state that acceptance depends on the following aspects:

- Relative advantage of having the system
- Apparent complexity of the system
- Ease of use
- Compatibility with driving activities
- Safety improvements (subjective)
- Relative importance of the system for driver
- Relative personal risk
- Costs
- Trust in the system
- Reliability of the system

By looking at this list, one can see that a proper design, taking the future user as a starting point, is of major importance when designing an acceptable system. Ergonomics is the basis for the design of any system. However, after a system has been developed, it depends on the type of system, its reliability and experienced use how acceptable a system is and what the behavioral consequences are.

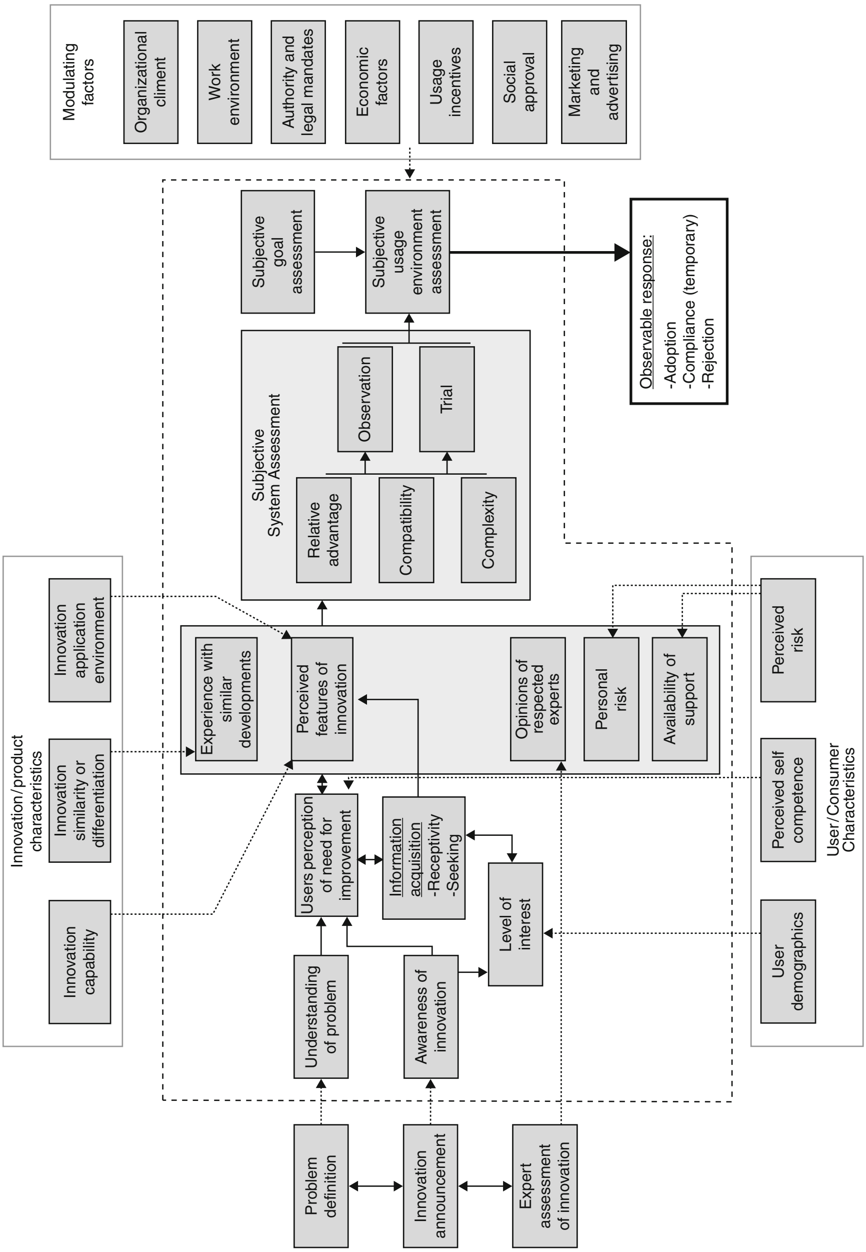
In this, the ratio between hits and misses/false alarms (see also *Table 6.2*) is of utmost importance. If a driver is warned for something that was not experienced to be dangerous (false alarm), the system will lose credibility points, decreasing acceptance. The same holds for misses; In case the system does not warn for something that was indeed experienced to be dangerous, the system will not be accepted.

A structural model (see *Fig. 6.5*) of the components of innovation acceptance is based on Mackie and Wylie (1988, also described in Kantowitz et al. 1997). The model clearly shows that after understanding the problem and the feeling for the need for improvement, past experience determines the subjective assessment of the system. In this stage, relative advantage of the innovation, compatibility, and complexity of the observation (empirical data) and trials (hands-on experience with the system) determine the assessment. Subjective goal assessment refers to the assessment of factors that are related to the adoption process (e.g., travel time). Subjective usage environment assessment determines the response since it makes the trade-off between the negative and positive results of all factors.

Table 6.2

Explanation of hits, false alarms, misses, and correct rejections. The number of misses and false alarms should be as low as possible and the number of correct rejections but especially the hits should be as large as possible

Warning/situation	Dangerous	Non-dangerous
Warning	Hit	False alarm
No warning	Miss	Correct rejection



▪ Fig. 6.5
Mackie and Wylie's model of innovation acceptance (Adapted by Kantowitz et al. 1997)

There are many factors that can influence the acceptance of a driver support system. If the system works fine but the price is extremely high, the innovation may not be accepted in the end. Also, if it is not the driver's free will but rather forced or obliged to be used, acceptance may be low. If there is a privacy risk involved or the personal freedom is limited, acceptance may be low. Also, people have to be aware of the new technology before it can actually be accepted.

8 Future Directions

An important issue regarding ADAS development is whether we should aim to automate the driving task. In principle, when automating the driving task, a large accident source is eliminated, that is the human error due to impairment, mistakes, lapses, or violations. If we automate the driving task, with the driver completely out of the loop, behavioral adaptation is no longer possible, so will this save all our problems?

Speed control is a key component in emotional aspects of driving, related to pleasure, joy of driving, learning to master driving skills, and control of the vehicle. The car is a symbol of modern freedom and mobility with a strong links to self-esteem and life quality. The increasing automation of driver tasks with the introduction of ADAS raises general issues of new automation, all related to acceptance, such as mistrust, resentment, and resistance experienced in other areas of technological development. For drivers with exempted license due to physical, visual, or cognitive impairments, ADAS and robotic vehicles may afford new means of individual mobility.

Robotic crash free electric vehicles were demonstrated by engineers and scientists in 2009 as part of the European project, CITYMOBIL. This was a demonstration of state of the art driverless, crash free, and environmentally friendly vehicles, e.g., shuttling back and forth between a county hospital and surrounding car parks and mass transport terminals. Driverless vehicles are not any longer science fiction, but an end product of a long line of European projects like ADASE, Chauffeur, Netmobile, Cybermove, etc., aiming to develop so-called cybercars, cybertaxis, and other automated cybertransport for personal or public transport. These types of transport function are to a large extent like an elevator, except on the horizontal plane instead of the vertical one. The passenger control is absent or limited to pushing a button to select the desired destination much similar to user control of an elevator. Robotic vehicles so far have proven to operate safely at low speeds (max 30–40 km/h), but this may in the future be extended to speed levels suitable for motorway driving on dedicated lanes. According to researchers, there are still many barriers to high speed driverless vehicles and especially for safe high speed transport on the open road network (Wahl et al. 2007).

According to the development roadmap within the PReVENT project (Sjøgren 2008), quite some effort has so far been on longitudinal and lateral control of individual vehicles. Integrated safety between cars and infrastructure (i.e., Car to X safety) is aimed at the year 2018, with the ultimate goal of developing Cooperative integrated safety systems. Parent and Yang (2004) envisage a divided road traffic network; one network for automated driving and one network for manual control of vehicles. Dual mode vehicles may be developed in order to operate on both types of network. Hence, an important research challenge will be to study how drivers cope with the transition from one mode of driving to the other. The scientific challenge lies not only in identifying barriers to deployment, and overcoming resistance to automation, but also in research issues related to loss of manual control skills.

In the current transport scenario where vehicles with and without ADAS have access to the road traffic system, habitual ADAS drivers will experience an increasing gap between skills required for navigation, maneuvering, and control of new vehicles with ADAS, compared to normal cars still relying on manual control of all driver tasks. Drivers may lose the cognitive maps of a route we today learn and develop through mental notes of landmarks, nodes, etc. Will ADAS selective drivers in the future experience problems when trying to find their way in, e.g., London when occasionally using a vehicle without navigation aid? Will intervention be less effective or even hazardous in the future when driving in an unassisted mode or if ADAS, automatically controlling lateral and longitudinal maneuvering suddenly malfunction? Navigation support may relieve the driver and give more resources to the traffic situation, but malfunction and misguidance have already led to accidents as reported in several newspapers.

ADAS can already park the car for you (Automatic Parking), take you safely down a steep hill (Hill Descent Control), automatically brake the car if a minimum safe distance to the car ahead is overridden (ACC), control speed (ISA), automatically stabilize the vehicle in a skid (ESC), and warn you every time a vehicle is in your blind spot (LCA). Will observation skills and vehicle control skills deteriorate for habitual ADAS drivers – and at what rate?

Young drivers, 16–24 years old, have the highest accident risk among all age groups. These drivers may also have the largest potential benefit from safety-related ADAS technologies with low opportunity for negative behavioral adaptation since there is no reference driving behavior yet. The largest safety benefit, related to behavioral adaptation is expected for systems for which the safety benefit is not easily perceived by the driver. Conscious speed violations and maladapted speed in road traffic situations due to risk proneness or inexperience is a frequent accident cause among young drivers, challenging further research and development related to speed controlling ADAS for this group of drivers. Designing ADAS with enhanced user acceptance for this age group is therefore important, unless there is political consensus to implement mandatory controlling solutions, such as completely taking the driver out of the loop.

New generations of drivers learning to drive vehicles with ADAS will have increasingly less experience with manually controlled vehicles. How to cope with this fact is a challenge for transport authorities and the research community. This may have a future impact on driver education, licensing, liability, and traffic regulation. Choice of action in this respect should be based on scientific knowledge.

Other points of interest are the fact that automated driving will only be for specifically dedicated lanes, and the fact that sensors are not as intelligent as human drivers in anticipating complex interactions with other road users. Where the human driver recognizes a child throwing a ball and anticipates that it will run into the street to get it, this is a complicated problem for an intelligent vehicle. Also, the transitions from automated driving to manual driving may lead to unsafety as well as most probably new type of errors.

9 Will New Skills Appear?

Future ADAS research should not only focus on loss of skills but also study how drivers acquire new skills and study new models of vehicle functionality, operation, and use with ADAS.

Anyone who has been introduced to a new car with different size and shape than their former car has experienced the problems of parking in a tight spot when you are unfamiliar with vehicle length. As we gain experience about the outreach of a vehicle and the necessary safety margins needed, this knowledge becomes part of our internal model of the vehicle and procedures for car parking. Hence, car parking can be performed more swiftly and accurately with learning. Even though the actual tip of the front or tip of the rear end is hidden from sight, we "know" where it is. Recent developments within cognitive science and neural correlates of skills confirm that we develop not only abstract cognitive models for objects but also develop connections on a neurological brain level representing this knowledge.

Studies with functional neuro-imaging have demonstrated the brain areas representing the tip of a stick, but not yet the corner of a car or the skill of handling it (Povinelli 2000; Johnson-Frey 2004). Functional neuro-imaging may in the future represent a convergent validation between behavioral investigation and imaging techniques, showing that the brain correlates conceptual knowledge and complex real world behaviors like driving cars equipped with ADAS. Neuro-imaging may also demonstrate the loss of concepts and skills.

Developments within automotive safety systems have already given and will continue in the future to contribute to a considerable reduction in road traffic fatalities. It is one of the most important potential contributors to increased traffic safety, especially in countries where traditional safety measures like road design, education, and surveillance are already exploited. With the current renewal rate of more international cars, car models from before 2000 will be renewed first in 2017. Sakshaug and Moe (2006) argue that in a 15 year perspective, incentives leading to a reduction in car renewal by 5 years may imply a reduction of 250 traffic fatalities just due to the improved passive safety in modern vehicles we had up to 2004 models. Potential reduction in traffic fatalities due to ADAS comes in addition.

10 International Aspects of Adaptation to ADAS

International differences related to user effects and the potential safety impacts of ADAS are important to establish. One good example related to international aspects of ADAS is eCall. eCall is a project of the European Commission intended to bring rapid assistance to motorists involved in a collision anywhere in the European Union. The eCall system developed employs a hardware black box installed in vehicles that wirelessly sends airbag deployment and impact sensor information, as well as GPS coordinates to local emergency agencies.

Virtanen et al. (2006) studied in-depth fatal accident data in Finland, covering 1,180 fatalities of which 919 were motor-vehicle occupants. Time delay between accident occurrence and notification of the emergency response center was calculated. Two trauma specialists evaluated whether a fatality would have been prevented had there been no delay in accident notification. The results showed that eCall could have prevented approximately 4–8% of the road fatalities that occurred in Finland during 2001–2003.

This result may not be transferable to all other countries. eCall is likely to be more effective on remote roads with low levels of traffic. A major part of the road network in Finland fits this description as well as northern parts of Norway. A seriously injured driver may in worst case lie unheeded for hours or days if involved in an accident in remote parts of the country. In comparison, eCall in densely populated countries like the Netherlands may have little or no effect. Accidents are immediately spotted and reported on a majority of the road network by other road users. Hence traffic density and the makeup of road network may have an important impact on the safety effect of a system like eCall.

The quality of emergency services may also play an important role. eCall will evidently be more effective in countries where emergency services are well organized, and delays in response following emergency call receipt are minimal.

International aspects of adaptation to ADAS can also be related to increased mobility. For example, there has been an increase in foreign freight transport and foreign professional drivers on Scandinavian roads with the open market policy in EU drivers who are unfamiliar with the Nordic road traffic conditions. With increasing use of ADAS in heavy vehicles there will be an increasing number of professional drivers who may encounter winter related functional limitations and malfunction of ADAS for the first time. The consequences of ADAS-related incidents and accidents may be serious with vehicles up to 50 t traveling on icy narrow roads not designed for this type of traffic, i.e., heavy vehicles with ESC not able to get up hills.

11 General Conclusions

That behavioral adaptation will occur with the introduction of ADAS is predictable – we should be more surprised if there is no sign of it. The nature and direction of these adaptations, intended or unintended, positive or negative, are important to verify in order to assess possible impacts on road safety.

How to prevent BA from occurring in relation to the introduction of ADAS is yet not fully understood. Based on our knowledge of conditions where BA is likely to occur, suggestions for further research and development of ADAS can be done. Some examples are research into the design and use of unperceivable or non-obtrusive measures, the use of measures that give little freedom of action, and the use of additional warnings to avoid errors based on malfunction, overreliance, or misunderstanding of system function.

Ideally, such warnings should be unnecessary if all aspects are considered and built into system functionality from early in the design process, yet it is human to err (even on the designers side) and it is likely that we have to search for ad hoc solutions to problems of behavioral adaptation also in the future. As long as designers take the presence of BA, and its potential to reduce the engineering estimate of safety, into account, a lot is already won. The next decades of research have to show the reducing effects of different types of ADAS.

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