The role of intervening variables in driver–ACC cooperation

Bako Rajaonah*, Nicolas Tricot, Françoise Anceaux, Patrick Millot

Laboratoire d’Automatique, de Mécanique et Informatique Industrielles et Humaines, UMR CNRS 8530, Université de Valenciennes et du Hainaut-Cambrésis, Le Mont Houy, 59313 Valenciennes Cedex 9, France

Available online 22 September 2007

Abstract

This paper analyzes the behavior of drivers using Adaptive Cruise Control (ACC) within the theoretical framework of Human–Machine Cooperation. The study was carried out on a driving simulator. Driving task performance data and responses to a trust questionnaire were analyzed in order to examine the relationship between driver reliance on ACC and such intervening variables as trust, perceived workload and perceived risk. The participants were divided a posteriori into two groups according to their use of the ACC device during the experimental run. The results show that high-use drivers seemed to cooperate more with ACC than low-use drivers, who tended to perceive more risk and a higher workload. These findings are discussed in the light of Riley’s theory of operator reliance on automation.

1. Introduction

Adaptive Cruise Control (ACC) is a kind of Intelligent Driver Support System (IDSS). Equipped with sensors, positioned on the front of the vehicle, this ACC can detect preceding vehicles and determine their range and speed. If a preceding vehicle is detected, the speed of the ACC-equipped car is adjusted to conform to a pre-set headway time; if not, the ACC maintains a pre-set speed, just like traditional cruise control. Thus, both the driver and the ACC are able to perform longitudinal control tasks (speed and headway regulation) simultaneously, and this simultaneous control may lead to interference. For example, if a preceding vehicle brakes suddenly (Interference 1, normally managed by driver–ACC cooperation), the deceleration brought about by the device may be insufficient to avoid a collision (Interference 2, related to the braking power of the device). The second type of interference requires the driver to reclaim control of the vehicle from the device and brake hard to avoid a collision.

Such driver–ACC interaction can be considered from the perspective of Human–Machine Cooperation (HMC). Cooperation is an interference management activity that supplements an agent’s individual activities (Loiselet and Hoc, 2001). According to Castelfranchi (1998), interference occurs when “… the effects of the action of one agent are relevant for the goals of another …” (p. 161). Two agents are in a cooperative situation only if their individual activities may interfere with one another and only if at least one of the agents tries to manage that interference in order to facilitate either an individual activity or a common task (Hoc, 2001, 2005).

Hoc and Blosseville (2003) have described several modes of cooperation between drivers and automation. Cooperation with ACC is in the control mode category, which is itself part of the function delegation mode. In this mode, drivers can delegate the longitudinal control to the ACC as long as they desire and can reclaim control from the ACC at any moment, based on their initial evaluation of the context and/or their subsequent evaluations concerning (i) the actions that must be taken to manage the real or potential interferences detected, and (ii) the agent that can best perform those actions. The adaptability of the human–machine system depends on the know-how-to-cooperate skills of the agents (Millot and Hoc, 1997). “Know-how-to-cooperate” requires both being able to...
detect and manage interference and being able to facilitate the achievement of other agents’ goals (Millot and Lemoine, 1998). Several variables can intervene in operator decision-making activities and thus must be taken into account, given that the “best” task allocation decisions result from the interaction between an agent’s know-how-to-cooperate and these intervening variables.

Intervening variables have been described by Muir (1994) as hypothetical constructs that cannot be directly observed because they “reside in the human mind”, but that nonetheless “mediate the human’s observable responses to environmental stimuli” (p. 1099). Muir named trust as one of the mediators in an operator’s use of automation. Muir and Moray (1996) later showed that trust in automation could be positively correlated with the time operators spent using automation: in other words, operators tend to use automation when they trust it; when they do not trust the automation, they prefer to do the task manually.

Riley’s initial theory of operator reliance on automation (see Riley, 1994, 1996) would appear to be relevant to the analysis of intervening variables in the use of automation and in operator cooperation. Riley hypothesized that operators decide to rely on automation based not only on their level of trust in automation, but also on their level of self-confidence. More precisely, Riley argued that operators will do the task manually if they have more confidence in their own ability to do the task than they have trust in the automated device; on the other hand, if their trust in automation is higher than their level of self-confidence, operators will rely on automation. Lee and Moray (1994) had already shown that automation use patterns are better explained by taking self-confidence and trust in automation into account; however, as Riley (1996) emphasized, the relationship between trust in automation, self-confidence, and use of automation is also mediated by other factors, including operator workload and the level of risk associated with the situation. Fig. 1 presents a schematic diagram of Riley’s initial theory of operator reliance on automation.

As the figure shows, operator confidence is influenced, among others factors, by perceived workload and perceived risk, while reliance on automation is influenced by confidence and trust in automation, which is in turn influenced by machine accuracy.

In the following sections, the intervening variables mentioned above (trust, self-confidence, perceived workload, and perceived risks) are described in detail.

### 1.1. Trust

For several authors (e.g., Zuboff, 1988; Sheridan, 1992; Parasuraman and Riley, 1997), trust is particularly important in the domain of human supervisory control. Indeed, trust in automation has been shown to play a role in its use (Lee and Moray, 1992; Dassonville et al., 1996; Muir and Moray, 1996; Bisantz and Seong, 2001). Based on a review of the existing literature (e.g., Muir, 1994; Lee and See, 2004), the definition of trust proposed in this article is appropriate for analyzing the decision-making situations encountered during human–machine interactions in which human operators can choose whether or not to delegate function(s) to the automated part of the system. Trust is defined as a psychological state (e.g., Rousseau et al., 1998) resulting from knowledge, beliefs, and assessments (e.g., Castelfranchi and Falcone, 2000) related to the decision-making situation, which creates confident expectations (e.g., Corritore et al., 2003).

Operators have expectations of themselves, the automation, their cooperation with the automation, and the overall human–machine system performance. Their expectations of themselves relate to self-confidence, or in other words, to their “anticipated performance during manual control” (Lee and Moray, 1994, p. 154) or to the “perceived reliability of manual control” (Dzindolet et al., 2001, p. 8). Expectations of the automation are essentially related to its competence, the operator perceptions that the automated control will, or will not, perform its function properly (Muir and Moray, 1996). Rajaonah et al. (2006a) assumed that expectations of cooperation with automation include expectations about the cooperation itself (e.g., perceived quality of interaction) and expectations about the results of the cooperation (e.g., decreased stress). According to these authors, this last type of expectation may correspond to another kind of trust—trust in the cooperation—while expectations related to the system performance may correspond to overall trust in the human–machine system; trust in the cooperation and overall trust are assumed to play an important role in the operator’s choice of automated or manual control.

Trust may be too high, too low or just right, depending on the situation: in the first two cases, the performance of human–machine system will not be optimized (Muir, 1994; Dzindolet et al., 2003). Thus, learning to calibrate trust may be a part of acquiring “know-how-to-cooperate” in order to rely appropriately on automation. Calibration is the correspondence between operator trust in the
automation and the automation’s capabilities (Lee and Moray, 1994; Muir, 1994; Lee and See, 2004). Moreover, Castelfranchi and Falcone (2000) distinguished two kinds of trust attribution: (i) internal trust related to the evaluation of the other agent’s “ability/competence”, and (ii) external trust resulting from the evaluation of the external conditions (i.e., whether the conditions are or are not propitious for “the performance and for its success”) (p. 6). Thus, if the tactical decision to use, or not to use, an automated device is based on trust, the level of trust for a given situation must be adjusted according to both the perception of anticipated performance (self performance, device performance, global performance of the joint system, and consequences of the cooperation) and the situation characteristics. However, as emphasized by Lee and See (2004), “trust guides—but does not completely determine—reliance” (p. 51). As mentioned earlier, the relationship between operator trust and the use of automation is mediated by other factors, such as perceived workload and perceived risks (Riley, 1996).

1.2. Perceived workload

De Waard (1996) defined workload by linking it to task demands and effort. “Task demands are determined by goals that have to be reached by performance. [...] Workload is the result of the reaction to demand; it is the capacity that is allocated to task performance. Effort is a voluntary mobilization process of resources” (De Waard, 1996, p. 17). The subjective aspect of workload is the mental effort that the operator is conscious of making, the attention deliberately allocated to performing a task (Kahneman, 1973).

According to De Waard, who applies his research to the “driving” task, automation is one of the environmental factors that can affect driver workload. Stanton et al. (1997) mentioned that removing drivers from the control loop may lead to decreased attention to the overall driving task. The drivers are not in the control loop of a driving subtask if the subtask is delegated to the automated device, which acts autonomously to carry out the subtask. The result may be that some subtasks are less well-controlled: for example, poor control over lane position (Ward et al., 1995), excessively hard braking (Hoedemaeker and Broekhuis, 1998), and delayed responses to emergency situations (Rudin-Brown and Parker, 2004). Therefore, paradoxically, the consequence of this decreased attention to the overall task is that drivers may be overloaded in emergency situations (Stanton et al., 1997), both in terms of lateral and longitudinal control.

One effect of increased workload that is often cited in the literature about human–machine systems is decreased vigilance. Oken et al. (2006) noticed that the term vigilance has various definitions. Indeed, psychologists and cognitive neuroscientists define it as sustained attention; for animal behavior scientists and psychiatric clinicians, “vigilance” refers to attention to potential threats; and clinical neurophysiologists use the term “vigilance level” to refer to “arousal level on the sleep-wake spectrum without any mention of cognition or behavioral responsiveness” (Oken et al., p. 1885). Nevertheless, it seems that vigilance and arousal can be functionally distinguished: “vigilance is associated with attentional availability, whereas arousal is independent of attention and is based on neuronal activation” (Tassi et al., 2003, p. 83). Indeed, from a psychological perspective, the constructs for vigilance and attention are superimposed: more precisely, vigilance is the ability to sustain attention on a task over a period of time (Davies and Parasuraman, 1982) and the vigilance decrement marks the decline in the quality of the sustained attention over time (Mackworth, 1948).

Clearly, vigilance is required for monitoring automation. But, maintaining vigilance has a cost in terms of workload (Parasuraman et al., 1996). Thus, as Bainbridge (1983) noted “ironically”, implementing automation in an effort to reduce workload may paradoxically cause an increased workload, due to the greater cognitive workload associated with monitoring the automated device.

Furthermore, vigilance and trust in automation may be closely linked (Lee and See, 2004). Muir and Moray (1996) observed that the more operators trust automation, the less often they monitor it. Parasuraman et al. (1993) showed that multitask situations requiring that attention be distributed over many sources may produce complacent operator behavior, with the result that operators fail to detect problems in the automated control of a system-monitoring task. Such results are often interpreted in terms of trust (see Lee and See, 2004). It seems that the higher the trust in automation, especially highly reliable automation, the more failures will pass undetected.

It is assumed in the present paper that perceived workload has a variety of aspects from the operator viewpoint: the mental effort and the attention required to do the task, as well as decreases in vigilance. If operators perceive that using automation alters the human–machine system’s performance, by either increasing the effort required, increasing the attention required, and/or decreasing vigilance, they may prefer to use manual control. Clearly, if the operators’ perceived workload is too high (whatever the cause), the risk is that they will not choose to use the automated device, even when using it would improve the overall performance of the human–machine system.

1.3. Perceived risk

Risk is another factor linked to trust, particularly with regard to the decision to use an automated device, or not to use it. Indeed, an operator deciding to use the automatic control becomes “a risk-acceptant agent” (Castelfranchi and Falcone, 2000, p. 8). “A situation is experienced as being full of risk when a person expects that, in the future, he/she might eventually experience negative results that he/she cannot control, as the result of this situation” (Numan,
According to Numan, perceived risk depends on both the expected probability of a negative situation (e.g., perceived probability of collision with the preceding car attributed to the use of anti-lock brake system) and the seriousness of the situation.

Concerning the use of automated control, the perceived risks are primarily related to the riskiness of the device, or in other words, the probability of unexpected outcomes when using the device. If the device is perceived to be risky, then operators will ask themselves what negative outcomes might occur—either as a result of eventual failures or as a result of the actual limitations of automation (i.e., even the most sophisticated machine is not infallible)—and how serious the consequences of these outcomes might be. Above all, operators must decide if they will be able to react correctly should these negative outcomes occur. Clearly, any risk taken must remain within acceptable limits (Castelfranchi and Falcone, 2000; Luhmann, 2000). Therefore, logically, perceived risks are also closely linked to self-confidence, or the operators’ confidence in their own capabilities. This link is graphically illustrated by Riley’s initial theory of reliance on automation (see Fig. 1).

The link between trust and risk resides in the functionality of the former. Trust presupposes a situation of risk (Shapiro, 1987; Brower et al., 2000) that arises when individuals are confronted with a choice and have incomplete knowledge concerning the possible outcomes of their choice (Luhmann, 2000). For Lewis and Weigert (1985, p. 969), trust is the mechanism that minimizes the feeling of risk by allowing people to live “as if certain rationally possible futures will not occur”; for Numan (1998), trust allows people to anticipate the future “assuming that [it] is certain” (p. 32). In other words, according to these authors, trust relies on anticipation, which consists of mentally reducing the possibility of negative outcomes resulting from an individual choice. Thus, to trust is to temporarily believe that problems will not occur, that the future will be all right. The higher the perceived risk, the greater the trust required (e.g., Brower et al., 2000).

Given the influence of perceived risk on confidence, trust, and reliance on automation, this factor must be taken into account when seeking to explain the task allocation decision-making process. Correctly evaluating the risks, as well as the means of managing them, requires abilities that may be acquired along with the know-how-to-cooperate skill.

This paper examines how the intervening variables mentioned above influence the way the driver interacts with an ACC device. Clearly, when negotiating the risks associated with the use of ACC—that the device will not detect valid targets, for example—drivers must ask themselves whether they will be able to deal with the negatives outcomes should such outcomes occur. If the driver is not familiar with the ACC, the attentional demand may well be very high. Certainly, above and beyond the attention allocated to road monitoring, attention must be allocated to ACC use (monitoring of the interface and manipulating the command buttons). Added to this already complicated mixture is the notion of trust. As Ashleigh and Stanton (2001) have shown, driver trust may influence use of ACC; a more recent experiment has found a positive correlation between overall driver trust and the time spent using the device (Rajaonah et al., 2006a). For these reasons, the interplay of the intervening variables is important and merits close examination.

2. Method

The main objective of this study was to investigate how trust in ACC, trust in the cooperation with ACC, self-confidence, perceived workload, and perceived risk could explain the way drivers use and cooperate with an ACC device, allowing the various driver behaviors to be differentiated. A driving simulator was chosen for the experiment because such equipment allows the same driving scenarios to be used with all the participants. A questionnaire completed after the experimental run was used to collect the drivers’ assessments of their trust, perceived workload, and perceived risk during the run.

2.1. Apparatus

2.1.1. The driving simulator

The experiment was carried out using SHERPA, the LAMIH driving simulator (Fig. 2). At the time of the experiment, SHERPA was a fixed-base simulator, able to project images on four screens to provide a 180° front view and a 45° rear view. The simulator was composed of three modules: a workstation, a video projection system, and a driving compartment. The latter was a fully instrumented Citroën Xantia, equipped with a steering wheel, torque feedback system, and a sound feedback generator that reproduces wind and engine noise. A 6-in screen placed in the middle of dashboard allowed interaction between the driver and the ACC.
2.1.2. The Adaptive Cruise Control device

The characteristics of the ACC device used in this experiment were similar to those of “classic” ACC. A 6-in screen placed in the center of the dashboard serves as the system interface. Using a steering column switch situated on the right-hand side of the steering column, drivers can modify the cruise speed (between 0 and 170 km/h in steps of 5 km/h) and the time headway (1, 1.5, 2 or 2.5 s) at any time. The device is activated by using a steering column switch and can be totally deactivated either by using the same steering column switch or by depressing the brake pedal more than 30%. When the accelerator is depressed more than 20%, the ACC device is temporarily deactivated, resuming control when the pedal is released. The braking capacity of the ACC was limited to 30% of the braking capacity of the vehicle. When the device was activated, the cruising speed and time headway values, the device state (activated or deactivated), and the distance with the target vehicle were displayed on the interface screen (Fig. 3). A beep and a pictogram on the interface screen informed the drivers when their intervention was necessary.

2.1.3. The simulation software

The experimental run included (a) 13 km on a major road passing through several small villages, (b) a motorway access ramp, (c) 25 km on a bi-directional two-lane motorway, (d) a motorway exit ramp, and (e) 12 km on a major road passing through one village. Twenty-five traffic situations were incorporated into the run in order to make the scenario realistic. These included being overtaken by another vehicle both on the major road and on the motorway (two situations), being hindered in an overtaking maneuver by another vehicle coming in the opposite direction on the major road (one situation), being cut off by another vehicle on the motorway (one situation), the sudden slowing of the preceding vehicle both on the major road and on the motorway (two situations), and overtaking without problem and car-following (19 situations). The duration of the experimental run was about 35 min.

2.2. Participants and procedure

Forty-two unpaid drivers—13 women and 29 men between 22 and 51 years of age ($M = 28$, S.D. = 7)—participated in the entire experiment. All participants had held a French driver’s licence for an average of 10 years (S.D. = 7, minimum = 2, maximum = 30). There were 23 students (16 students in Applied Sciences from the Institute of Science and Technology in Valenciennes and 7 humanities students from the University of Lille) and 19 workers from various socio-professional groups. When the participants were recruited (volunteers from among the researchers’ acquaintances), they were invited to participate in an experiment using a driving simulator, without any other precisions being given about the study. Six of them had participated in a previous experiment carried out using a mini-driving-simulator and an ACC with a pre-set reference speed and time headway of 130 km/h and 1.5 s, respectively (see Rajaonah et al., 2006a, b).

After completing a preliminary questionnaire about their personal characteristics and usual driving behaviors, the participants performed two short training sessions simulating driving on a major road and on a motorway. The two sessions were separated by a slide presentation about the device. The first session aimed to familiarize participants with the simulator; the second, with the ACC. During the second session, the experimenter was seated at the driver’s side in order to explain how to use the ACC. After the two training sessions were completed, the participants performed the experimental run. The pre-run instructions were just to activate and deactivate the ACC as desired. Following this run, two different research teams asked the participants to complete four questionnaires: (1) conditions after driving on the simulator, (2) trust and its dimensions, (3) interaction with the ACC, and (4) opinions about driving with the simulator. Only the second questionnaire about trust and its dimensions was used for the present paper.

2.3. Dependent and independent variables

2.3.1. The dependent variables

The dependent variables came from two kinds of data: the raw data about the driving task and the scores from the questionnaire.

The raw data about the driving task—including the ACC state (activated vs. not activated), speed, time headway (THW), position of gas pedal, position of brake pedal and steering wheel angle—were recorded automatically at a frequency of 30 Hz (i.e., data were recorded 30 times per second). To assess the driver’s cooperative behavior, three indicators were examined:

**ACC use rate**: The percentage of time spent using ACC was calculated three times (on the motorway, on the major roads, and over the entire experimental run), using the formula time spent using the device × 100/time driving on the motorway (respectively, on the major roads, and over the entire experimental run);

**ACC deactivations during the experimental run**: The number of times the device was overruled using the
on/off button, the brake pedal or the gas pedal was counted. The weighted number of ACC deactivations was also calculated by using the formula number of deactivations \times 100/ACC use rate;

*Modifications to the reference speed and THW during the experimental run:* The number of times the speed and the THW were modified was counted and the weighted number of modifications was calculated.

Concerning the drivers’ assessments, only 11 of the items on the trust questionnaire were taken into account. These items were categorized a priori according to whether they referred to trust, perceived workload, or perceived risk. Because several authors (e.g., Muir and Moray, 1996; Jian et al., 2000) consider trust to be a continuous variable, an analogical scale like the one used by Muir and Moray was chosen for the questionnaire to quantify the level of trust (from 0 to 10 cm), but also the levels of perceived workload and perceived risk. This choice reflects the assumption that these variables are also continuous.

**Trust.** In evaluating driver trust, distinctions were made between overall trust, trust in the ACC, trust in the cooperation with the device, and self-confidence. The questionnaire items included the following:

1. When driving with the ACC, I felt confident.
   This was due to:
2. Trust in the ACC,
3. Self-confidence,
4. Trust in the relationship with ACC.

The first item was used to measure the overall trust. The term “cooperation” refers to a concept used by researchers to guide the design of adaptive human–machine systems, but this term is not used in the same context in everyday life. Fearing that the term “cooperation” would not be understood correctly by the participants, “relationship” was substituted for “cooperation” in the questionnaire. However, in this paper, the results are presented using the original term, speaking of “trust in the cooperation” with ACC instead of “trust in the relationship” with ACC.

**Perceived workload.** Three indicators were used to measure driver workload: effort, attention and vigilance. These indicators were derived from Kahneman’s definition of workload as a combination of mental effort (i.e., the effort that is consciously expended) and attention (i.e., the attention deliberately allocated to a task). The English translations of the French questionnaire items are respectively: “Using the device has required a lot of effort”; “Using the device has required a lot of attention”; Using the device has decreased vigilance”.

**Perceived risk.** To assess perceived risk, three types of risk-related elements were measured: the perceived “riskiness” of the ACC, the perceived risk of collision with a preceding vehicle, and the perceived risk taken by using the device. The questionnaire items are respectively: “The device is risky”; “Using the device increases the risk of collision with the preceding vehicle”; “Using the device forces me to take a lot of risk”.

To sum up, the dependent variables were: ACC use (%), number and weighted number of ACC deactivations, number and weighted number of the modifications to the reference speed and THW, overall trust, trust in the ACC, trust in the cooperation, self-confidence, effort required, attention required, decrease in vigilance, riskiness of the ACC, risk of collision, and risk taken by using the device.

### 2.3.2. The independent variable

There was only one independent variable, determined a posteriori: the driver type, based on the analysis of the ACC use rate over the entire experimental run. Two types of drivers emerged from the analysis—high-use drivers and low-use drivers (see the second part of the results section for definitions). Differences between high-use drivers and low-use drivers were expected, in terms of the way they cooperated with the ACC and their assessments of trust, perceived workload, and perceived risk.

### 3. Results

The data were analyzed using XLSTAT 2006 (Addinsoft). All statistical tests were two-tailed, with an alpha level of .05. The non-parametric Mann–Whitney U-test was used for measuring the statistical significance between the means because observational data did not follow a normal distribution (as shown by the Shapiro–Wilks test). For the same reason, the Spearman correlation coefficient was used to study the links between the variables instead of the Pearson coefficient.

Tables 1–4 present the results for driving behavior, trust, perceived workload, and perceived risk, respectively. The tables report the means (with standard deviations in parentheses) for each group (high-use drivers and low-use drivers), the computed values of Mann–Whitney U-test (with the p-value in parentheses), and the probabilities of a Type II error (β). The β-values were calculated manually from the results of the Puissance 22 tool (Le Pape, 2006), which calculates the power of the Mann–Whitney test.

Table 5 presents the Spearman correlation matrix, which gives the correlations between the dependent variables. For some correlations, the β-values presented in the text were calculated using the same tool as for the Mann–Whitney test.

### 3.1. Categorization of the intervening variables

Using an agglomerative hierarchical clustering method, similar groups of intervening variables were created using the observed data. The objective was to test whether the indicators used to measure the driver’s perceived workload and perceived risk can actually be categorized in this way. The Euclidian distance dissimilarity coefficient was used to measure the similarity of the observations and the Ward method was used to define the agglomeration criterion.
Fig. 4 presents the contents of the two clusters that resulted from an automatic cut (i.e., two clusters were “requested”):

1. The first cluster groups the effort and attention required to use ACC, and the perceived decrease in vigilance during the driving task due to using the device.
2. The second cluster groups the inherent riskiness of the ACC, the perceived risk of collision with a preceding vehicle, and the risk taken by using the device.

The variables in each cluster correspond to the a priori categorization. Given that each cluster groups the most similar variables, it would seem that both perceived workload and perceived risk can be analyzed using the chosen indicators. Overall indicators can be calculated by summing the variables effort, attention and decreased vigilance to generate an overall indicator of perceived workload, and the variables riskiness, risk of collision and risk taken to generate an overall indicator of perceived risk.
Indeed, in a field study carried out by Fancher et al. (1998), the ACC use was 72% (14.35). This value is relatively high.

These two overall indicators were added to the set of the dependent variables.

### 3.2. Categorization of the drivers

For all participants and all types of road, the mean use of ACC was 72% (14.35). This value is relatively high. Indeed, in a field study carried out by Fancher et al. (1998), the analysis of data collected from 108 participants driving a car equipped with both a conventional cruise control (CCC) and an ACC in diverse road environments showed that, for a total time of 3049 h, the drivers activated the CCC for 165 h and the ACC for 534 h, and spent 2350 h under manual control. The ACC use in their study was about 17.51%. Thus, it seems that the 72% ACC use observed in the present study is relatively high compared with real driving condition.

The ACC overall use rate in the present study ranged from 40.48% to 94.44%. The middle value of 67.46% between 40.48% and 94.44% was selected as the arbitrary criterion according to which the drivers were split into two groups a posteriori: the first group (n = 26) is the “high-use” group, whose drivers used the device more than 67.46%; the second group (n = 16) is the “low-use” group, whose drivers used the device less than 67.46%. This a posteriori variable permitted a comparison of the way the two groups cooperated with the ACC and assessed their levels of trust, perceived workload and risk.

As mentioned in Section 2.2, 6 of the 42 participants had participated in a previous experiment carried out using a mini-driving-simulator and an ACC. Their results for the present study do not appear to have been influenced by their prior experience using an ACC for any of the dependent variables, except ACC use on the motorway. Indeed, the results on the motorway for these specific participants were: n = 6, M = 82.82, S.D. = 3.49, minimum = 78.68, maximum = 87.55, while for the others the results were n = 36, M = 89.19, S.D. = 11.41, minimum = 57.98, maximum = 100.00; the result for means comparison is U = 169, p = .03. In other words, it appears that on the motorway, the participants with prior ACC experience used the device more than the participants without prior experience, though the two groups did not differ significantly on the major roads. In addition, the participants with prior experience seem to have more homogeneous use behaviors than the others.

### 3.3. Driving performance with ACC

#### 3.3.1. ACC use on the motorway and on the major roads

As is shown in Table 1, low-use drivers use ACC less than high-use drivers both on the motorway and on major roads. The difference between the two groups is quite large.
for driving on a major road. This difference helps to explain the difference in overall use of the device since ACC use on the major roads is highly correlated with overall use (Spearman correlation coefficient $r_s (41) = .93$, $p < .0001$). Use of the device is also significantly different for the two groups on the motorway.

3.3.2. Cooperation with the ACC

As Table 1 shows, the number of ACC deactivations is not significantly different for the two groups of drivers; however, the two groups do differ significantly in terms of the number of modifications in the reference speed and THW, with the high-use group making more modifications than the low-use group. For all the participants, the Spearman coefficient of correlation between the ACC overall use and the number of deactivations is not significant: $r_s (41) = .082$, $p = .603$. In contrast, the correlation between the ACC overall use and the number of modifications in the reference speed and THW is significant: $r_s (41) = .707$, $p < .0001$.

This means that the more the drivers used the device, the more they modified the reference speed and THW. In fact, since we used the number of modifications in the reference speed and THW as an indicator of cooperation, we could conclude that the more the drivers used the ACC, the more they wished to cooperate with the device, which involved managing interference between contradictory goals. For example, if the ACC detects a target vehicle (e.g., a truck in front of the ACC-equipped vehicle), the speed will be automatically decreased to maintain a safe distance. However, this action may interfere with the driver’s goal to maintain a certain cruising speed. Thus, the driver may decide to decrease the reference THW and/or to pass the truck. In the latter case, the driver may decide to increase the reference speed to pass the truck quickly without bothering the driver behind the ACC-equipped vehicle (a second kind of interference). These two kinds of interference were highlighted by Rajaonah (2001) in a study carried out with INRETS and Renault using an ACC in real driving condition. In the present study, it could be that willingness to use the ACC is related to willingness to cooperate with the device. Likewise, unwillingness to cooperate with the ACC might explain its non-use. Additionally, the unwillingness to cooperate might have been due to the driver’s desire to not divide his/her attention between the driving task and the interaction with the ACC.

3.4. Driver assessments of trust, perceived workload, and perceived risk

3.4.1. Assessments of trust

Table 2 shows that driver assessments of overall trust, trust in ACC, self-confidence, and trust in the cooperation with the device are relatively high. For all participants, the means (with standard deviations in parentheses) are, in order, 6.72 (1.59), 7.05 (1.87), 6.49 (2.61), and 7.13 (1.54). The two groups did not differ significantly for any measure of trust even when the low-use drivers may have felt less trust than the high-use drivers, assuming that trust and reliance on automation are closely linked. The results are discussed in Section 4.

3.4.2. Assessments of perceived workload

Table 3 shows that the two groups of drivers differed appreciably in their assessment of the different aspects of perceived workload. The low-use drivers perceived significant increases in the attention required as well as significant decreases in vigilance than did the high-use drivers. On the other hand, they did not differ significantly in their perceptions of required effort. Nevertheless, the $\beta$-value of .64 for this variable indicates that the chance of finding a difference that truly exists in the population is 36%, which is not negligible. However, the two groups differ significantly in terms of the overall indicator of perceived workload, with low-use drivers being more negative than high-use drivers.

It is interesting to note that perceptions of required effort and perceptions of required attention are both negatively correlated with perceptions of ease of use (the item was “The device was easy to use”); in order, the Spearman correlations are $r_s (41) = -.57$, $p = .0001$ and $r_s (41) = -.42$, $p = .006$. In other words, the more difficult (i.e., less easy) the ACC was to use, the higher the perceived workload was. The results are discussed in Section 4.

3.4.3. Assessments of perceived risk

Table 4 shows that the two groups differ significantly only for the perceived risk of collision, with the low-use drivers perceiving more risk than the high-use drivers. The simulated scenarios did not represent any emergency situations, thus the perceived risk of collision might correspond to the anticipated risk of using an ACC in real driving situations. In terms of the riskiness of ACC, the risk taken by using the device, and the overall indicator of perceived risk, the two groups did not differ significantly. Nevertheless, for the overall indicator, the $\beta$-value of .66 indicates that the chance of finding a difference that truly exists is 34%, which is not negligible.

3.5. Links between the variables

Table 5 shows the Spearman correlation matrix for all the variables (except the number of deactivations and the number of modifications in the reference speed and THW). There are only two significant correlations between ACC use and the driver assessments of trust, perceived workload and perceived risk: ACC use on the motorway is correlated with the risk taken by using the device ($r_s (41) = -.33$, $p = .032$), and ACC use on the major roads is correlated with the overall indicator of perceived workload ($r_s (41) = -.31$, $p = .048$).

The correlation between ACC use on the motorway and required attention is $r_s (41) = -.28$, $p = .069$, and the
The participants were divided a posteriori into two groups, depending on their ACC use rate during the experimental run: 26 participants were assigned to the high-use group, and 16 were assigned to the low-use group. High-use drivers used the device more, both on the motorway and on the major roads, and they modified the reference speed and time headway more actively, leading us to conclude that high-use drivers cooperate with the ACC much more than low-use drivers.

The two groups did not differ in terms of the different aspects of trust (overall trust, trust in the ACC, trust in the cooperation with the device, and self-confidence). However, they did differ in terms of the values of the other intervening variables. High-use drivers tended to display lower levels of perceived workload and perceived risk than low-use drivers when the overall indicator for each variable was taken into account.

Considering the variables separately, the low-use drivers appear to be more sensitive to the attentional demand of ACC use, and they perceived a much greater decrease in vigilance during the driving task. Furthermore, they perceived a greater risk of collision with a preceding vehicle than did high-use drivers.

Given these results indicating a negative assessment of the ACC by the low-use group, it is, at first, surprising to observe that the level of trust in ACC, which was globally high for all the participants \( (M = 7.05) \), did not differ between the two groups. However, Riley’s initial theory of operator reliance on automation (see Fig. 1) explains that perceived workload and perceived risk do not influence trust in automation directly, but rather influence operator confidence. Indeed, the results show that self-confidence is significantly correlated with the perceived risk of collision in the present study. It is interesting to note that in Riley’s revised theory based on experimental evidence, perceived risk no longer influences operator self-confidence (see Riley, 1996). In his second model, influence of perceived risk is added to self-confidence and trust in automation to explain reliance on automation. However, the results reported in this paper fail to indicate significant links between ACC use and trust in the device and self-confidence.

Using Riley’s presentation of his results as an example (see Riley, 1996, p. 33), Fig. 5 shows the links between the variables: ACC use, the different aspects of driver trust (overall trust and trust in the ACC and trust in the cooperation and self-confidence), the perceived workload (required effort and/or required attention and/or decreased vigilance), and the perceived risk (riskiness of ACC and/or risk taken by using the device and/or risk of collision). The solid lines show those links supported by evidence from the present study (i.e., significant correlations) and the broken lines show the hypothetical links, which were not confirmed by the results. Indeed, it was assumed that the cooperation with the ACC would be influenced by driver trust, perceived workload and perceived risk. The results showed that the ACC use is not linked with any kind of trust,

...
though it is linked with perceived workload and perceived risk.

**Trust.** The artificial experimental conditions and the fact that the participants were acquainted with the researchers could help to explain (a) the relatively high overall use of ACC, (b) the relatively high trust levels, and (c) the absence of significant correlations between any kind of trust and ACC use either on the motorway or on the major roads. Clearly, the participants could have been trying to make the researchers happy by using the ACC to the highest degree, in which case, trust has nothing to do with the results. On the other hand, the phenomenon of positive bias for automation described by Dzindolet et al. (2003) could have played a role: the drivers had very high expectations for the ACC because they did not have enough empirical information to make accurate judgments—neither about the ACC device, nor about driving with ACC. Furthermore, since the driving simulation did not test the ACC in emergency situations, trust levels had no reason to decline over the experimental run.

**Perceived workload.** ACC use tends to be linked to the perceived level of attention required, both on the motorway and on the major roads, and even ACC use on the major roads is significantly correlated with the overall indicator of perceived workload. Furthermore, the low-use drivers had more negative perceptions than the high-use drivers, not only for required attention and the overall indicator of perceived workload, but also for perceived decreases in vigilance. Thus, it seems that the low-use drivers perhaps felt an increased attentional demand due to the need to monitor the ACC. It is probable that they used the ACC less in order to allocate much more of their attention to the driving task, notably the sustained attention required for vigilance. Thus, it appears that there are individual differences in the sensitivity to the workload which might have led to the observed differences in ACC use. Nevertheless, a previous analysis of the data from the questionnaire about personal characteristics and usual driving behaviors (see Section 2.2) showed that personal variables (e.g., gender, age, driving experience) had no effect on the dependent variables (results not shown). Thus, it would appear that eventual individual differences are due to other factors, which would be interesting to investigate further.

**Perceived risk.** ACC use on the motorway is significantly correlated with the perceived risk taken by using the device. There is no other significant correlation between ACC use and the perceived risk assessments. Furthermore, though low-use drivers perceived a significantly higher risk of collision than the high-use drivers, which tended to cause the perceived risk overall indicator to be greater for low-use drivers than for high-use drivers, it is not the perceived risk assessments that most differentiate the two groups of drivers, but rather the perceived workload assessments. Thus, it could be that the artificial conditions of the simulator minimized the perception of risk during the driving. On the other hand, the perceived risk assessments were much more connected to the different aspects of trust than the perceived workload assessments were. All the correlations between the different aspects of trust and the different assessments of perceived risk are negative. This result seems to confirm the hypothesis that holds that the higher the perceived risk, the greater the trust required (e.g., Brower et al., 2000) in order to minimize the feeling of risk (Lewis and Weigert, 1985).

From a theoretical perspective, speaking of cooperation with automation requires considering not only operator trust in automation and self-confidence, but also overall trust and trust in the cooperation. The first of these additional types of trust is a general form of trust in the human–machine system, and the second is a specific form of trust associated with expectations pertaining to the interaction with the automated control and the outcome of this interaction. Given that these aspects of operator trust can be differentiated, the links between trust, perceived workload and perceived risk appear to be much more complex than the ones underlined in Riley's models. In fact, Table 5 and Fig. 5 show that there are many more links between perceived workload/perceived risk and overall trust/trust in the cooperation than between perceived workload/perceived risk and trust in the ACC/ self-confidence. Given that a previous study has also shown that overall driver trust is significantly correlated with ACC use (Rajaonah et al., 2006a), it would appear that the influence of trust, perceived workload, and perceived risk on automation use is multiple and interconnected. Moreover, the operator’s experience also seems to play a role in the use of automation. In fact, as mentioned in the Section 3.2, the six participants with ACC experience used the device more than the participants without prior experience, at least on the motorway. Riley (1996) had shown similar results in a study in which the participants were commercial airline pilots.

From a methodological perspective, the inherent riskiness of automation and the perceived risk taken by using it

---

**Fig. 5.** Links between ACC use, driver different aspects of trust, perceived workload and perceived risk measures.
appear to be interesting indicators of perceived risk. The perceived risk of collision with a preceding vehicle is specific to the ACC device and cannot be generalized to studies with other IDSS. Furthermore, the indicators for perceived workload (required effort, required attention, and decreased vigilance) seem to provide accurate evaluations of a driver’s perceived workload when using an IDSS. Nevertheless, by introducing a secondary task, several authors have shown that ACC decreases workload (e.g., Rudin-Brown and Parker, 2004), leading us to think that a perceived increase in the workload does not necessarily correspond to an actual increased workload. The participants in this study, notably the low-use drivers, perhaps anticipated an increased workload, but they were not really overloaded. Further research, using secondary tasks to evaluate objective workload, is necessary to determine the link between workload and reliance on IDSS.

In general, the results show that driver behavior when working in tandem with ACC, specifically the drivers’ way of cooperating, was different depending on the drivers’ propensity to feeling overloaded, and their perception of the risk taken by using ACC. In the future, as mentioned above, it would be interesting to look at workload directly since none of our studies to date has focused on this variable. It would also be interesting to analyze other kinds of variables, such as locus of control and sensation-seeking. Indeed, a fairly recent study has shown that these personality factors seem to have some influence on the way drivers react to ACC (Rudin-Brown and Parker, 2004). Finally, it would be interesting to introduce ACC failures (see for example, Seppelt and Lee, 2007) in order to evaluate their effect on the intervening variables and the relationships between the intervening variables and the cooperation with ACC.

To conclude, this study is a multidisciplinary work combining the humanities and engineering sciences. These results, if applied to driver-IDSS cooperative system design, should help to improve the overall performance by taking into account the fact that IDSS use is mediated by several intervening variables, not only by the IDSS performance.

Acknowledgments

This research was done as part of ARCOS (the French acronym for the Driving Safety Research Program) with the financial support of the Ministries of Research, Transportation, and Industry.

Special thanks to M.P. Pacaux-Lemoine, J. Floris, P. Simon, and J.C. Popieul.

References


