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From technological acceptability to appropriation by users: Methodological steps for device assessment in road safety

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A B S T R A C T

This article presents the methodology developed within the framework of the research project SARI (Automated Road Surveillance for Driver and Administrator Information). This methodology is based on the logic of action research. The article presents the different stages in the development of technological innovation addressing vehicle control loss when driving on a curve. The results observed in speed reduction illustrate that no matter how optimal an innovation may be technologically speaking, it is only as effective as it is acceptable from a user standpoint. This acceptability can only be obtained if the technology is developed by engineers in liaison with social science specialists.

1. Introduction

The objective of this article is to present a research methodology based on action research logic, as it was applied in SARI (Automated Road Surveillance for Driver and Administrator Information). This methodology has made it possible to obtain results convincing enough to give rise to significant modifications in actual driver behavior. The SARI project took place from 2005 to 2010 and involved thirty-six laboratories and technical centers, eleven companies and three local authorities.

1.1. Issue of SARI

The objective of SARI was to study the possibility of new technological solutions to road security problems. This project took place in a particular context: a major road safety risk on rural roads (i.e., network outside urban area), a constrained resource budget and the need to find new solutions to road safety problems. In 2004 (before the project began) accidents on rural roads accounted for 38% of personal injury accidents in France. However, they represent 73% of fatal accidents, or 3781 deaths (out of the 5232 accounted for in mainland France) (ONISR, 2005). The severity (deaths/100 injuries) was also 3.9 times higher on rural roads than in urban areas.[1] Moreover, rural roads were also subject to the biggest budget constraints due to being managed by local communities and not the French State. Therefore, it was not possible to improve road security by rebuilding roads. New solutions had to be found. Considering the analyses carried out on potential sources of road safety measures

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[1] Thanks to the various actions carried out within the framework of PREDIT (French program of research, experimentation and innovation in land transport) and consistent political goodwill, the latest figures are 3963 road deaths, of which 2867 happened on rural roads (2011 data-ONISR, 2012).

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(Guyot, 2002), the choice was to work on the interaction between drivers and infrastructure.

Even if human error is responsible for 90% of road accidents (Dewar and Olson, 2002; Wegman, 2007), they result from the interaction between the driver and the external conditions of the driving task (Van Eslande, 2003). Moreover, road infrastructure configuration plays a part in about 30% of these accidents (Rumar, 1985). Similarly, the influence of road layout on drivers' behavior is emphasized by Saad (1988, 1992). "So it appears that it is often the situation that is primarily responsible for the failure of the driver, not his responses themselves. The idea is that these failures can result from a misleading perception of the environment induced by the road configuration and the environment" (Rosey, 2007, p.5). Drivers are therefore facing problems of complexity, visibility, legibility and so on (Van Elslande et al., 1997). Consequently, the aim of the research carried out in SARI was to develop new roadside technological solutions allowing for a reduction in accidents caused by vehicle control loss by warning drivers of any approaching adverse driving conditions that they might poorly perceive or not perceive at all. The aim was to correlate the risk of vehicle control loss with road characteristics in order to define the relevant information for drivers, making them switch from and ordinary state of attention to a state of alert, thus changing their behavior. SARI was composed of four work packages: three technical work packages (dealing with vehicle control loss) and one human work package called AJISE (for legal, individual, social and economic acceptability).

1.2. Methodology developed in SARI

The goal of this article is to present the methodology developed in SARI by means of the research work carried out on vehicle control loss in curves.[2] This methodology is based on a technological development stemming from a close collaboration between engineering (technical work packages) and social sciences (human work package). The system needs to meet optical technological conditions, but also be designed for user appropriation. In other words, it is necessary for the system to be acceptable (see for instance Lefeuvre et al., 2008; Lefeuvre and Somat, 2005; Lheureux, 2009; Molin and Brookhuis, 2006; Pianelli, 2008; Terrade et al., 2009). Acceptability can be defined as the degree of integration and appropriation of an object, in a context of use (Barcenilla and Bastien, 2009; Venkatesh and Bala, 2008).

The present research falls in line with action research logic as defined by Lewin: "a comparative research on the conditions and effects of various forms of social action and research leading to social action [. . . that uses] a spiral of steps, each of which is composed of a circle of planning, action and fact-finding about the result of the action" (1946, pp. 35 and 38). This article presents the different "spirals of steps" put in place to accompany the development of the technological solution while taking the human factor into account. These experiments were the subject of full-scale testing on real roads.

2. Spiral 1: Development of a technological solution

2.1. Planning: diagnostic method

In order to reduce the risk of accidents due to loss of vehicle control from physical disruptions on the road that are well-known sources of accidents (Brenac et al., 2000; McGee and Hanscom, 2006; Michel et al., 2005; Orfila, 2009; Sétra, 2002) the project team decided to develop a diagnostic method in order to find a pertinent technological solution to this problem. Two complementary approaches were used: the first one consisted in measuring users' trajectories on the infrastructure by video systems and roadside installed electromagnetic loops (called observatory of trajectories)—this observatory was developed as a part of this research project; the other one used an "innovative vehicle of diagnosis" to measure the stress on the vehicle at different speeds.

2.2. Action

After the analyses of several curves selected from real roads in the French administrative department of Côte d'Armor, one curve was chosen based on accident risk criteria. A diagnosis made it possible to identify and quantify the limiting trajectories of vehicles in the curve (particularly, the critical threshold speed). Based on the characteristics of the curve (curve radius, superelevation, slope, evenness), an estimate of the risk of vehicle control loss was calculated and used to develop a warning system able to inform the user of the lane departure risk for a given speed. The idea was to warn the user of a potential danger based on his speed approaching the curve (the warning applies only to individual users whose approaching speed is too high). Knowing speed profile (approach speed and threshold speed), it was possible to create an individualized alert from the approach speed of the vehicle. It is based on measuring the approach speed far enough before the curve for the driver to react on time. Based on previous work by the CETE-Normandie-Centre (2000), the approach area is estimated at 200 m for the selected curve given that user deceleration in this area is generally low or very low. With models that link speed and geometric characteristics of curves (Louah et al., 2008; Sétra, 1986) the "safe" speed to clear the curve is estimated at 70 km/h. This value is confirmed by passages done with the "diagnostic vehicle" showing that for this speed (70 km/h), lateral acceleration reaches a threshold of 3 m/s^2 that is considered by most users as the acceptable limit in terms of comfort. Finally, the location of the speed detection was determined by a simple kinematic study which takes into account a reaction time equal to two seconds, an approach speed of the fastest users equal to 102 km/h, a "safe" speed in the curve equal to 70 km/h and a deceleration accepted by users equal to 2 m/s^2. It was set at about 150 m before the curve. Considering all these criteria, the speed used to trigger the warning device is fixed at 93 km/h (V85). Furthermore, this speed corresponds to an activation of the alert system for approximately 15% of the fastest users approaching the bend.

The choice of signaling media was based on an analysis of the literature about the necessity for a low-cost solution and on the operational feasibility. The literature showed that road signing was poorly perceived or not perceived at all (at least not consciously) (Drory and Shinar, 1982; Hughes and Cole, 1984; Shinar and Drory, 1983; Sprenger et al., 1999), which incidentally led certain authors to question the real effectiveness of road signing (Fischer, 1992; Johansson and Backlund, 1970; Knowles and Tay, 2002; Macdonald and Hoffmann, 1991; Summala and Hietamäki, 1984). As for other authors, they underlined the importance of context when considering signing awareness (Bazire et al., 2004; McKelvie, 1986) and individual risk perception as decisive criteria (théorie de l'homéostasie du risque, Wilde, 1994). But fixed signs, put in place to inform all drivers in all situations of a danger regardless of their driving behavior, are a matter of obeying the law rather than a decisional aid. All these factors taken into consideration, dynamic road signing would appear not only to be a means of alerting the driver, but also making him change from an automatic to a controlled behavior (Ranney, 1994); additionally, it would better inform him of the real risks than fixed signing would. The choice came down to flashing lights; this solution had

[2] Two other control loss types were studied (loss related to adverse weather conditions and loss related to visibility problems); these studies will not be presented here.

Fig. 1. Flashing beacons on a tri-chevron alignment.

the advantage of being legally authorized and having the ability to enhance curve perception in addition to being low-cost and easily reproducible (McGee and Hanscom, 2006). The warning system consists of flashing beacons on a tri-chevron alignment (see Fig. 1). The flashing beacons turn on for a speed higher than 93 km/h at the detection point and for a period of six seconds. If the driver slows down enough, the warning goes off before entering the curve; otherwise the lights remain on.

2.3. *Evaluation of the technological solution effectiveness in terms of speed*

2.3.1. *Method*

Two stations for speed measurements (electromagnetic loops embedded in the pavement) were installed on the experimental site. These stations were located ahead of the curve (250 m and 50 m before the turn) (Violette et al., 2009). The first station was used to trigger the device. The second allowed us to evaluate driver speed before the curve. In addition to speed, the timestamp and length of the vehicle were registered, this last factor allowed us to distinguish commercial trucks from light vehicles (only the speeds of light vehicles were taken into account, the alert system was not adapted to the kinematics of trucks, which is not the same as that of light vehicles). A computer recorded the data.

2.3.2. *Results*

We measured the speeds approaching the curve before the triggering of the device (reference period) to the speeds after the triggering of the device (experimental phase). Two days of reference period recording and two days of experimental phase recording were compared.[3] Finally, we were able to observe the speeds of 4392 vehicles during the reference periods and the speeds of 4697 vehicles during the experimental period.

As a result, the average speed is 74.59 km/h (SD = 8.98) for the reference period and 72.38 km/h (SD = 10.39) for the experimental period. So, there is a reduction of 2.21 km/h. This difference is statistically significant ($t(9087) = 10.83$, $p < .0001$). In other words, the commissioning of the device resulted in a decrease in the observed speed 50 m before the curve.

[3] Two days were selected randomly in the middle of the phase to be certain that the device would be at its optimal performance [0]. However, only the weekdays were used due to weekend traffic being particular and less problematic in terms of speed. At first, these two days corresponded to two user survey days (a link needing to be made among objective data–speed–and subjective data–questionnaires), but an equipment malfunction prevented us from accessing the magnetic loops. Therefore, we made the choice to resort to two randomly chosen days in the middle of the phase to ensure that the device operated at its maximum performance.

2.4. *Evaluation of the acceptability of the technological solution*

2.4.1. *Method*

In parallel to road experiments, two roadside surveys were conducted to obtain feedback from users on the device, both one month and seven months after its commissioning.

2.4.1.1. Population. In the first survey, 68 people were interviewed (35 women and 33 men). They had an average age of 46.71 years (SD = 14.46) and had an average of 26.19 years of driving experience (SD = 13.66). In the second survey, there were 31 participants (12 women and 19 men) whose average age was 48.68 years (SD = 16.05) and average number of years of driving was 28.29 (SD = 15.07). In both cases, about three quarters of surveyed users are drivers who regularly spend time on the road (at least several times per week).

2.4.1.2. Material and procedure. Each survey was conducted over the course of one day between 9:30 a.m. and 5:30 p.m. with a break between 12:00 a.m. and 2:00 p.m. All vehicles on the experimental site were stopped by General Council employees and drivers were asked to answer a short questionnaire. Volunteers then parked at a rest area. Non-volunteers were free to leave. After the investigator gave a brief presentation on the subject of study, he gave the driver a questionnaire. The driver had all the time he needed to answer. Once completed, the interviewer took the questionnaire and answered all the respondent's questions.

The questionnaire began with an open question about the function (role) of the flashing lights: "In your opinion, what is the function of the flashing lights installed on the blue traffic sign?" This sentence was accompanied by an image of the traffic sign with lights above it to remind drivers of the signing that was in the curve. The questionnaire also included usual demographic questions (sex, age, number of years of driving, driving frequency).

2.4.2. *Results*

In the first survey, one month after commissioning the device, the analysis of the open ended answers about the function of the flashing lights shows that only 4 out of 68 people (less than 6%) understood the dynamic and individualized aspects of the device activation (lights triggered based on vehicle speed). Examples of answers were: "the lights are triggered at night," "the lights are triggered when there is a vehicle in front of them," "the lights turn on when a vehicle approaches the turn," and so on. In the second survey, seven months after the commissioning, there was a better understanding since the analysis of answers shows that 13 out of 31 people (42%) understood the dynamic and individualized function. The breakdown of responses is statistically different based on the timing of the questionnaire (either one month or seven months after the device setup) ($\chi^2 = 17.01$[4], df = 1, $p < .0001$). This result indicates that users have learned the purpose and use of the device

2.5. *Conclusion*

The installation of the technological device has made it possible to observe a reduction in average speed when approaching a curve, proof that the tri-chevron alignment sign with flashing beacons is effective and that it could be a low-cost solution for curve safety, something that has not been demonstrated before (even in the case of a general alert, that is to say with flashing beacons in place for all drivers) (McGee and Hanscom, 2006).

[4] Yates's correction.

However, the roadside analysis revealed a poor comprehension of the system's workings in that users did not understand the individual nature of the alert. Although we observe a learning phenomenon (as a reminder three quarters of surveyed users drive regularly, at least several times per week) as users seem to have discovered the use of the device, 58% of surveyed drivers still have a poor understanding of it after seven months of use. The hypothesis, however, was that an individual alert should lead the user to modify his behavior through making him aware of an immediate danger compared to a general alert which only serves to enforce legal regulation.

3. Spiral 2: Studies to develop explanatory sign

3.1. Planning and action

The results from this first spiral prompted our decision to test the impact of an improved comprehension of the individual nature of the alert and led us to seek a solution for making people better understand how the device works; we retained the idea of installing a roadside explanatory sign. Therefore, the second spiral consisted in developing a fixed sign in the laboratory which aimed to notify users that they would come across dynamic signing indicating that they would receive a personal message based on the speed at which they approach the curve.

3.2. Action

Different models were created taking into consideration concepts developed in cognitive ergonomics and more precisely signing ergonomics (visibility and legibility, see Castro and Horberry, 2004). Therefore, we intentionally chose to present the deployed road signing in picture (tri-chevron alignment sign with flashing beacons). Many studies have in fact pleaded in favor of pictures over texts (Ells and Dewar, 1979; Potter and Faulconer, 1975; Sperber et al., 1979; Whitaker and Stacey, 1981). This appeared all the more relevant as the users were not accustomed to seeing this type of individualized dynamic road signing. These prototypes also needed to respect French regulation regarding road signs.

3.3. Qualitative analyses of the models

3.3.1. Qualitative analysis 1

3.3.1.1. Method. In total, 30 students from University Rennes 2 were interviewed either individually (22 people), or within a focus group (two groups of four people). They viewed a slide show presenting seven models: three showed a message with only activated flashing beacons and four showed both scenarios (activated and non-activated lights). The flashing beacons with a tri-chevron alignment sign were shown either alone, or with an image representing the curve. Moreover, for approximately half of the participants, the images were associated with the term "flash" (which is the common term) and for the other half, the images were associated with the term "flashing beacons" (the technical term). We also used a variation of the terms "activated" and "lit." Finally, four different messages were proposed while the flashing beacons were activated: "You are driving too fast," "Excess speed," "Danger," and "Slow down." When the lights were presented as non-activated, three messages were tested: "your speed is appropriate," "appropriate speed," and "speed limit respected."

Initially, we invited the participants to freely study the slide show and then asked them to express what they understood. Secondly, we gave them precisions on the objectives of the sign and with these precisions we asked them to give their points of view again. Finally, they had to give preferences in terms of which signs seemed to best transmit the dynamic and individualized nature of the signage.

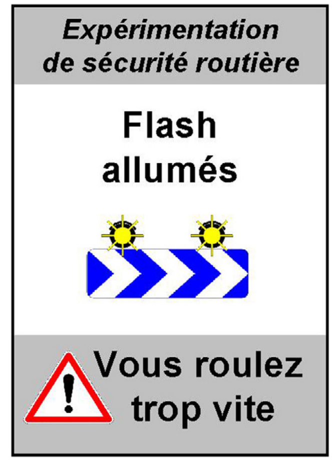

Fig. 2. Explanatory sign.

3.3.1.2. Results. The qualitative analysis of these open ended opinions demonstrates a better understanding of the term flash by the subjects and an association between this term and the dynamic nature of the signal. The term lit was preferred over the term activated, even though the latter was judged more dynamic. Finally the personalized messages (e.g., you are driving too fast or slow down) were preferred over other messages (e.g., danger or appropriate speed). As for as format is concerned, the participants say that they better understand the message if the flashing lights are displayed as both on and off; the display of the flashing beacons with a tri-chevron alignment sign presented alone is preferred over the signing presented with an image of the curve. Despite these responses, this first analysis did not allow us to determine which sign best conveyed the necessary information. Consequently, we planned a second analysis.

3.3.2. Qualitative analysis 2

3.3.2.1. Method. In this second stage, 11 students individually underwent the same procedure as in the first analysis. We created five models based on the first set of results; the flashing beacons condition was removed. Participants were invited to analyze the terms activated/lit, the messages you are driving too fast/slow down/excessive speed (for the switched on lights) and your speed is appropriate/appropriate speed/speed limit respected or safe speed (for switched off lights).

3.3.2.2. Results. The information relating to the personalized nature of the signing is that which incites the largest response among participants. Six out of eleven participants judged the message you are driving too fast as the most effective (the others were divided between the other two messages). Ten out of eleven people prefer the term lit over activated. Only four people thought one sign was enough (lights switched on), the others opted for having access to both pieces of information (lights on and off) whether they be on the same sign or two different signs.

4. Spiral 3: Road-test to measure the impact of an explanatory sign

4.1. Planning and action

In consideration of the analysis done in the spiral 2, we conceived an explanatory sign (see Fig. 2). Despite the participants declaring a preference for having access to both pieces of information (lights on and lights off), in accordance with the technical work package, we chose to create a single sign displaying only one piece of information (lights on). The geometric configuration of the road was not suitable for the set up of two successive signs while the set up of one sign displaying two pieces of information would not have been optimal from a cognitive point of view, that is, in terms of reading time.

In order to measure the impact of installing this sign, two new roadside experiments were planned, one to measure the impact on speed and the other to evaluate the comprehension of how the device works. The explanatory sign was installed about 500 m before the flashing beacons with the tri-chevron alignment sign. The objective was to give users the time to see, read and understand the explanatory sign before approaching the device.

4.2. *Evaluation of the effectiveness of the explanatory sign*

4.2.1. *Method*

The method used to collect vehicle speeds was identical to the one used in spiral 1: the speed measured 50 m before the curve is taken into account. As previously done, two days of measurement were carried out. In total, the speeds of 3393 light vehicles were recorded.

4.2.2. *Results*

The average observed speed was 64.53 km/h (SD = 11.50). If we compare this average to the speeds observed in spiral 1, it would appear that it is statistically different from the speed observed before the installation of the device (M = 74.59 km/h, SD = 8.98, $t(7783) = 43.34$, $p < .0001$). It is also statistically different from the speeds observed after the installation of the device (M = 72.38 km/h, SD = 10.39, $t(8088)$ = 32,303, $p < .0001$). In other words, the installation of the explanatory sign made it possible to observe a greater reduction in speed than with the installation of the technological device alone.

4.3. *Evaluation of the comprehension of the device operation*

In order to evaluate the impact of the installation of the explanatory sign in spiral 2 on the comprehension of the device function, a roadside survey was carried out based on the same principle as the one in spiral 1.

4.3.1. *Method*

4.3.1.1. Population. As in the first survey, users were stopped alongside the road and invited to respond to a questionnaire. In total, 52 drivers agreed to participate (30 women and 21 men, one person did not answer the question). They had an average age of 46.77 years (SD = 14.40) and had an average of 27.12 years of driving experience (SD = 14.31). Finally, 58% of them drive at least several times per week.

4.3.1.2. Material and procedure. The implemented survey methodology was identical to the one used in Spiral 1 except for an open ended question that had been added in order to more accurately assess the understanding of how the device operates. So people were asked: "Why are these flashing lights triggered?"

4.3.2. *Results*

Concerning the operation of the flashing lights, the analysis of user open-ended responses reveals four types of answers. For 18 out of 49 people (36.73%) the lights indicate excessive speed for entering the turn; for 15 out of 49 people (30.61%), the purpose of the lights is to make people slow down; for 14 out of 49 (28.57%), the lights are to help anticipate or warn of danger; and two people gave atypical answers. Analysis of the open ended answers concerning the operation of the flashing lights shows that for 43 out of 48 people (89.58%) excessive speed triggers the lights, 3 (6.25%) think that the lights warn of danger and 2 (4.16%) believe that the lights are triggered by a passing vehicle. In other words, 89.58% of the users (43/48) understood the dynamic and individualized workings of the device. If we compare these results to those observed in spiral 1, where only 42% (13/31) of drivers understood the operation, we notice that subject distribution is statistically different between the two measurement periods ($\chi^2 = 3.83$, df = 1, $p = .05$).

4.4. *Conclusion*

The results from this third spiral highlight a speed reduction before the curve when an explanatory sign is put in place. A parallel should be drawn between these results and the comprehension of the device operation, namely the dynamic and individualized aspect. This indicates that comprehension of the device leads to a better respect for the alert signal and therefore a greater acceptability of the intended message.

5. Discussion

The objective of SARI was to study the possibility of new technological solutions to road safety problems. These innovations needed to respond to economic constraints (low-cost solutions) and the need to find new sources of road safety measures while taking user-infrastructure interaction into consideration. The methodology put in place was based on the principal of action research. Within this framework, three successive spirals were carried out. Each spiral led to the following one. This methodology made it possible to show that a technological solution could be more efficient if it were the object of user acceptability. This acceptability is examined through several dimensions including comprehension. The results showed that the speed reduction expected from the installation of a roadside device was maximized by not only the comprehension of the dynamic signing put in place but also by the comprehension of how the device works. In order to improve this comprehension, an explanatory sign needed to be installed before the equipped curve. Not only did this sign clarify the message delivered by the device, but as it turns out, it also made it possible for users to understand how the device works. With the delivered message being individualized based vehicle dynamic characteristics; it cannot be understood unless the device operation is as well. These results were particularly significant in obtaining behavioral modifications in favor of road safety.

In the end, if the driver processes the information delivered to him on the road, he only changes his behavior if the message is minimally comprehensible. Thus, while signing is dynamic and individualized, it needs to be made comprehensible through the use of a message explaining that the signal emitted from the device arises from the behavior of the user to whom it is addressed. The user needs to have sufficient explanation for understanding that the message is an individual driving aid and not simply an element of regular road infrastructure.

Also along these lines, are other results from SARI focusing on other types of vehicle control loss (through visibility loss or adverse meteorological conditions) and other communication media (variable message signs). They show that dynamic and individualized signing is not immediately understood and that this poor comprehension disturbs the expected effects (Bordel and Somat, 2010). However, this first set of results would be worth replicating, especially in other contexts, before considering a real deployment of these technologies. A longitudinal study would equally inform of the more long term learning effects. Finally, it would be interesting to study how the delivered message is represented with regard to the perceived risk (as opposed to objective risk). In another study, we were able to show that the acceptability of the delivered message (this time inside the vehicle) varied depending on the user's perception of risk and well as the gap between the objective risk and the subjective risk (Bordel and Hautière, 2011). A case in point would be risk related to loss of grip, which for the user is related to rain (and wind-shield wiper performance.) Whereas for an engineer, this risk is related to the height of water on the pavement, the geometric parameters of road and the characteristics of its surface.

In any case, dynamic and individualized signing seems to be a serious avenue for improving road security. Thanks to this technology, a communication process between the user and the infrastructure can be deployed. Consequently, we must equip ourselves with the means to respect some principles relating to human communication, as was done within the framework of the human-machine interface (HMI, Hoc, 2000, 2001). The first objective will be to respond to the questions of "who says what, to who, and how?" (Lasswell, 1948) before asking questions about maximizing the usefulness of the delivered message. This usefulness will be evaluated not only from an individual standpoint (through respect for ergonomic principles) but also through the consideration of social acceptability. Based on this latter view, the logic is to examine the representations, attitudes and norms which the driver is invariably subjected to. From this point of view, the installation of new dynamic and individualized infrastructures should systematically result in following the methodological groundwork recommended by Terrade et al. (2009). According to these authors, under the principle of mutual collaboration between engineering sciences and social sciences, designers should take the user into consideration from the conception to the deployment of a new technological device.

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