Driver Reaction and Behavior in a Motorway Environment Equipped with an Integrated VMS and On-Board RDS-TMC Information System

Antonella De Angeli, Danilo Fum, Walter Gerbino
Department of Psychology, University of Trieste (Italy)

and

Bruno Pani, Gino Parisatto, Gilberto Tognoni
AINE—Autostrade Italia Nord-Est (Italy)

Abstract

The paper illustrates the results of a research carried out at the Department of Psychology of the University of Trieste in the context of the EEC-funded, Drive-2 Area, GEMINI Project. The main goal of GEMINI was to evaluate the social opportunity, the technical feasibility, and the economical costs of the introduction of traffic-related information systems based on Variable Message Signs (VMS) and Radio Data System—Traffic Message Channel (RDS-TMC) technologies in motorway environments. Within this framework, the research focused on studying the impact on drivers behavior and attitudes of the information provided by an integrated VMS/RDS-TMC system. To this purpose, an experiment was performed in which the reactions of a sample of 96 expert users driving specially equipped cars through a motorway tract where VMS information was delivered were collected and investigated. The paper presents the general scenario of the experiment, illustrates the methodology used, and discusses the main findings.

INTRODUCTION

An important, and often neglected, point in the development of a new technology concerns the attitudes of the perspective users and their willingness to accept it. It is generally not sufficient to provide sound and reliable new methods for doing things better, cheaper, faster, or whatever. It is equally important to comply with the user expectations and needs, with their possible fears, and to be able to smooth the learning curve that the adoption of every new policy will inevitable require.

In the traffic domain, for instance, there is a tendency to provide drivers with increasing amounts of information concerning the vehicle flow, weather conditions, emergency situations. It is generally assumed that this kind of information will help to adopt more cognizant, mindful and sensible decisions. Very few attempts, however, have been made to evaluate the drawbacks that the information load will have on the drivers cognitive processes or to assess the influence of the information content on their behavioral reactions.

The EEC-funded, Drive-2 Area, GEMINI Project was aimed at studying the social opportunity, the technical feasibility, and the economical costs of the introduction of traffic-related information systems based on Variable Message Signs (henceforth VMS) and Radio Data System—Traffic Message Channel (henceforth RDS-TMC) technologies in motorway environments. In the evaluation phase of the project, a research has been carried out by the Department of Psychology of the University of Trieste in cooperation with one of GEMINI partners, the AINE (Autostrade Italia Nord Est), a consortium of three companies operating the motorway system in North-East Italy. The research focused on investigating the impact on drivers behavior and attitudes of information
provided by an integrated VMS/RDS-TMC system. To this purpose, an experiment was performed in which the reactions of a sample of 96 expert users driving specially equipped cars through a motorway tract where VMS information was delivered were collected and investigated. The paper presents the general scenario of the experiment, illustrates the methodology used, and discusses the main findings.

EXPERIMENTAL DESIGN AND METHODOLOGY

For the experiment, a factorial design with three factors was adopted: the salience of the message and the expectations towards the integration of the information provided by the VMS and RDS-TMC were manipulated as independent variables between the subjects. A third variable was constituted by the test site chosen for the experiment. Half of the subjects drove along the so-called East Ring (Villabona-San Donà di Piave) and half along the West-Ring (Villabona-Padova West) of the Italian A4-motorway (Torino-Trieste). The two test sites differed according to
- number of lanes: two lanes (plus emergency lane) for the East Ring, three lanes (plus emergency) for the West Ring;
- traffic flow (generally heavy traffic in the West Ring, normal traffic in the East);
- different density and type of the VMS panels (the West Ring was endowed with the EASY-DRIVER system of traffic monitoring and control while in the East Ring only normal panels were present).

The experiment therefore followed a 2 (salient vs. non-salient) x 2 (integrated vs. non-integrated) x 2 (East vs. West Ring) design.

The salience of the message was manipulated by presenting different kinds of messages to the subjects. In the salient condition the messages delivered by the on-board RDS were relevant both in their absolute (since they referred to events which could critically influence the drivers behavior) and in their relative content (since they referred to facts or events that were happening within the test site). The non-salient messages were constituted, on the other hand, by irrelevant information since they were dealing with unimportant events that were happening outside the test site. The information delivered by VMS was manipulated in the same way. Moreover, the subjects in the salient condition encountered during their trip an obstruction to the traffic flow (works in a lane) whose presence was regularly indicated by the information systems. No obstacles were experienced by the subjects in the non-salient condition. It was hypothesized that the salience of the messages would influence the behavior and the attitudes of the drivers toward the information delivered by the VMS and the RDS-TMC systems.

The expectations towards the integration were manipulated by presenting the subjects with different instruction sets. In the integrated condition the on-board RDS-TMC and the VMS panels were described as components of the same information system. The instructions stressed the interdependence and complementarity of the two system components. The subjects were explicitly invited to evaluate the congruence of the information provided by the two sources and the coordination between them. In the non-integrated condition the instructions did not mentioned the VMS panels and the subject attention was focused only on the evaluation of the on-board radio set.

In order to enhance the sensitivity of the experiment, a simulative technique was used. The experimental RDS prototypes (purposefully developed for the GEMINI project) which were
available could non assure a precise synchronisation with the VMS panels. To overcome this problem, the messages on board were produced by a simulator that was operated, unknown by the subject, by an observer sitting on the rear seat. In this way it was possible to reproduce exactly the same situation for every subject allowing the delivery of the same message at the same point, and to obtain a perfect coordination between the information provided by the VMS and the on-board RDS-TMC. According to the results of the debriefing session that followed the experimental phase, no subject was aware that the messages were produced on board and not broadcast on the air and received by a real RDS-TMS system.

It is important to emphasize how, for contingent and pragmatic reasons, it was impossible to manipulate orthogonally all the factors. In fact, while it was possible to reproduce a genuine high-integration x salient situation, the condition high-integration x non-salient was spurious since the messages delivered by the VMS panels and the radio set were not identical: the messages on board dealt with potentially relevant events that were happening outside the test site while the panels delivered neutral or unimportant messages. The difference between the conditions was caused essentially by two facts:

— The set of messages that were received on board (codified by the ALERT-C protocol) did not allow to deliver irrelevant information. All the messages of ALERT-C refer in fact to potentially significant events. In order to differentiate the non salient and salient messages the former had to deal with (fictitious) events happening in locations outside the test site.

— While it could be technically feasible to deliver this (untruthful) information through the VMS panels—which were seen by all the people driving along the motorway and not only by the subjects—for safety reasons this was not allowed by AINE officials. All the messages delivered by the VMS system in the non-salient condition had therefore a neutral character.

Evaluation Tools

In order to evaluate the drivers reaction and to record their attitudes toward the information systems, the following tools were employed:

— Italian Driver Behavior Questionnaire
— Driver Personality Inventory
— System Evaluation Questionnaire
— User Satisfaction Questionnaire
— Driver Observation Grid.

These tools are briefly described.

*Italian Driver Behavior Questionnaire*. It constitutes the Italian version of the Driver Behavior Questionnaire (DBQ) developed by Reason, Manstead, Stradling, Baxter, and Campbell (1990) (1). The questionnaire is composed by three parts. The first one aims at eliciting self-descriptions concerning the driving habits of the subject. The second part is formed by 16 items derived from the DBQ which cover a variety of bad driving behaviors. The subjects are requested to evaluate, on a five points scale, the frequency according to which they make the mistake or violation. The last part of the questionnaire asks the drivers to evaluate their own driving style in terms of expertise, security, compliance with the traffic regulations.

*Driver Personality Inventory*. It is formed by 20 items (adjectives) chosen from the Italian taxonomy of personality traits developed by Di Blas and Forzi (1994) (2) according to the lexical
approach. For every adjective, the subjects had to evaluate on a five-points scale how truthfully (they think) the adjective describes a trait of their personality.

**System Evaluation Questionnaire.** It is formed by three parts. In the first one the subjects were asked about the number and the content of the messages received through the on-board RDS and delivered by the VMS panels. A literal recall of the messages was stressed. The second part of the questionnaire requested the subjects to evaluate the perceived integration between the two systems. They were explicitly invited to emphasize any incongruity or discordance between the information received through the systems. The last part of the questionnaire requested the subjects to compare explicitly the systems according to their reliability, efficacy, robustness, and their potential distracting effects.

**User Satisfaction Questionnaire.** It was used to evaluate the subjects attitudes towards the information delivered by the information systems. The first part asked the subject to evaluate the on-board RDS-TMC according to several criteria (usefulness, novelty, easy of learning, etc.). The second part dealt with the evaluation of the information provided by the VMS and RDS-TMC by using a scale based on the semantic differential technique. (3)

**Driver Observation Grid.** In order to record the behavior during the driving session, an observation grid was built which covered the different maneuvers (change of lane, overtakes, etc.) made by the subjects during the driving session. The grid comprised also a series of summary items which recorded the general behavior of the subject during the session (average speed, safety distance, preferred lane etc.).

**Experimental Procedure**

At the beginning of the session the subjects were welcomed and informed about the goals of the experiment. Following the standard practice used in man-machine interaction research, they were assured that the object of the evaluation was not their personal characteristics but some of the information systems features. The subjects were then requested to fill the Italian Driver Behavior Questionnaire and the Driver Personality Inventory. They were then invited to read the instructions which manipulated the subjects set toward the expected integration between the two systems.

After the initial briefing, the subjects got into a specially equipped car and the driving session began. The drivers were taped during the entire session and their glances were recorded. Their behavior was also monitored, following the grid items, by two on-board observers. In the first half of the session the drivers were requested to execute a secondary task (in addition to the primary task of driving) i.e., to verbally report the content of every sign encountered during the trip. To make the subjects perform a secondary task is a classic method which is used to evaluate how much attention remains available after the execution the primary task. A decrease in the performance of the secondary task following the presentation of messages by the on-board set or VMS panels would indicate that the messages interfere with the subject attention. The observer seated near the driver monitored the accuracy of the secondary task while the observer in the rear seat monitored the driving behavior (and operated the simulator). In the second half of the session the subjects were engaged in the execution of only the primary task and their behavior was monitored by both observers.

After the driving session was completed, the subjects were interviewed by a third experimenter and requested to fill the System Evaluation Questionnaire and the User Satisfaction Questionnaire.
While the subject was busy executing this task, the observers completed the Driver Observation Grid with the items summarizing the driver behavior, checked their judgements—which were normally highly congruent—and discussed any remaining differences. The whole session lasted approximately an hour. A sub-sample of one fourth of the subjects were given an in-depth interview in order to get impressions and suggestions not directly collected through the questionnaires.

The Sample

In the experiment 96 employees (84 male and 12 females) of the AINE consortium were used as subjects. Their age was in the range 20-55 years (mean = 37 years). The years since obtaining the driving license ranged from 2 to 36 (mean = 18). On the average, the subjects reported to travel 27.000 km per year. The subjects were randomly assigned to the experimental conditions.

RESULTS

Separate analyses were performed on the dependent variables collected during the experiment. Due to space limitations, only the main findings are reported.

Glance Analysis

Three different analyses were performed on the glances of the subjects engaged in the driving behavior.

The first analysis was aimed at determining what the driver was looking at when he was diverting his attention from the road. One fourth of the glances were given to the on-board RDS-TMC monitor, more than half of the glances to one of the two rear mirrors, the remaining glances to the dashboard instrumentation. The percentages were the following:

- instrumentation 16.3%
- RDS monitor 25.1
- external mirror 41.3
- rearview mirror 17.3.

Figure 1 shows the distribution of glances as a function of the traffic conditions (heavy vs. light). A contingency analysis showed that this factor had a statistically significant effect on the subjects ($\chi^2 = 36.45$, $p < .001$). In both conditions most of the glances were given to the mirrors. With heavy traffic, however, the number of glances given to the on-board RDS monitor was twice the number of glances given to the instrumentation while the proportion is almost the same when the traffic is light. This result allows an interesting observation: while the subjects are heavily engaged in a driving behavior, they resort to the RDS monitor to get some help in monitoring the environment. This behavior does not diminish the attention they dedicate to the direct control of the traffic (glances to the mirrors) but it happens at the expense of the glances dedicated to the instrumentation.
Figure 1: Frequency of glances as a function of traffic conditions.

A second analysis took into account the glances given to the on-board RDS monitor immediately after having seen a VMS panel. Three quarters of the subjects looked at the VMS panels but only a quarter looked at the RDS monitor afterwards. This distribution does not depend on the saliency of the message or on the degree of integration. In order to evaluate this finding it is necessary to consider the fact that the secondary task was quite demanding. This could explain why the subjects in the integrated condition, who—according to the instructions—should have checked the congruence between the on-board and VMS messages, did not follow this suggestion.

In the third analysis the relation between the message salience and the glances toward the RDS monitor was investigated. It is important to highlight that a message was delivered by the RDS system according to two different modalities: audio and video. While the message was uttered only once it remained available on the screen until the arrival of a new message. The number of gazes given to a message was divided into two classes: glances within the first two minutes of appearance and glances in the following interval. As reported in Table 1, while in the first two minutes there was no difference in the number of glances given to the monitor between the salient and non salient condition, in the next period the salient messages attracted a significantly ($\chi^2=1.30$, p<.001) higher proportion of glances. This means that the subject attention to the non salient message declines very quickly while they continue to pay attention to the messages that are potentially significant for their behavior.

Table 1: Frequency of glances given to the RDS-monitor

<table>
<thead>
<tr>
<th></th>
<th>Salient</th>
<th>Non Salient</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 — 2'</td>
<td>153</td>
<td>142</td>
<td>295</td>
</tr>
<tr>
<td>2'— next message</td>
<td>170</td>
<td>122</td>
<td>292</td>
</tr>
<tr>
<td>Total</td>
<td>323</td>
<td>264</td>
<td>587</td>
</tr>
</tbody>
</table>
Driving Behavior

The subjects drove at an average estimated speed of 114 km/h. This value was not influenced by any of the experimental factors (salience, integration, test site). There was an interesting, even if partially expected, positive correlation ($r=0.282$, $p=0.006$) between speed and answers to the Driving Behavior Questionnaire. The drivers who got higher scores on the proclivity to violation subscale of the questionnaire are those who tend to drive at a higher speed.

Through the Driver Observation Grid some interesting indexes of the drivers behavior were collected. In fact the number of violations to the traffic rules made by the subjects or the dangerous behavior they were engaged in were very small, with the exception of changes of lane changing without appropriate signalizing. The following analysis therefore concentrates only on this behavior.

The main result concerns the effect of the test site. The number of lane changes was significantly higher for the subjects who drove along the East ring, both for correct lane changes ($F(2,93)=17.59$, $p=0.000$) and inappropriate changes ($F(32,93)=5.54$, $p=0.005$). This data confirm the difference between the two test sites. Driving along the East ring (two lanes motorway with medium traffic) stir a higher number of changes in comparison with the West ring which had three lanes but a higher volume of traffic.

For the subjects driving along the East ring, the kind of task (driving vs. driving plus secondary task) influenced the number of correct lane changes ($F(1,44)=42.13$, $p=0.000$). When the subjects are concentrated in performing the secondary task, the correct lane changes are more frequent. Generally speaking, the number of changes without signalizing is positively correlated with the violation propensity index ($r=0.31$, $p=0.002$). This could mean that the subjects did not signal the lane change deliberately and not because they did not remember to do it.

There were no differences among the groups in the dangerous maneuvers made by the subjects.

Finally, in the execution of secondary task (signal monitoring), 33 subjects (34.4%) gave a perfect performance while other 42 (43.8%) forgot to mention only a signal. This means that four subjects out of five were capable of giving a perfect or very good performance in this task. The arrival of messages on the on-board RDS-TMC did not diminish the subjects attention. There was no interaction between the execution of the secondary task and the other factors.

System Evaluation

VMS And RDS-TMC Integration

The judgements given by the subjects about the integration of the information provided by the VMS and the RDS-TMC depend on the message salience ($F(1,95)=47.6$, $p=0.000$). The subjects in the salient condition evaluated the integration as quite good (mean = 3.52 where 1=extremely bad and 5= extremely good). The subjects in the non-salient condition evaluated the integration as unsatisfactory (mean = 1.96). The fact that the salience of the message plays a significant role in the system evaluation was revealed by a Logit analysis which used salience and integration as independent variables and the subjects answers to the question whether VMS and RDS-TMC could be considered as components of the same system or as different information systems as dependent
variable. The only significant factor was saliency ($Z=4.58, p<.05$): in the salient condition the subjects evaluated more frequently the VMS and the RDS-TMC as two components of the same information system. The motivational variable, as it was manipulated by the instruction set, did not have any effect on the integration assessments made by the subjects.

**Direct Comparison Between VMS And RDS-TMC**

The on board RDS-TMC system was considered more robust than the VMS panels by the subjects of every experimental condition. There was however a significative interaction ($F_{(1,95)} = 4.1, p=.037$) between integration and robustness judgements: in the non-integrated condition the RDS was considered much more robust than the VMS.

According to the subjects, VMS and RDS-TMC do not differ in the distraction they could induce. There was however a significant interaction between saliency and integration ($F_{(1,95)} = 4.2, p=.043$). In the salient x integrated condition the on board radio set is considered as more distracting than the panels. In the non-salient x non-integrated condition, however, the reverse was true with the panels being judged as more likely to divert the subjects attention.

No differences were found on the reliability judgements about the systems. There was an almost significative interaction ($F_{(1,95)} = 3.4, p=.068$) according to which in the salient x non-integrated condition the on-board RDS-TMS is considered more reliable than the panels while in the salient x integrated condition its reliability decreases.

**User Satisfaction**

The reactions of the subjects toward the on-board RDS-TMC were quite positive. The system is generally considered as innovative (mean=4.06 on a five-points scale). The 13.7% of the subjects said that it compared lower, the 69.5% at the same level, and the 16.8 higher with the expectations induced by the instructions. The user satisfaction was negatively correlated with driving expertise ($r = -.232, p=.024$): the more expert drivers were the less satisfied.

The subjects think that the on-board radio set could slightly improve the safety of driving (mean 5.43 with 1= safety highly damaged, 7 = safety highly improved) and that it does not divert the subjects attention (mean = 5.375 with 1 = maximum distractibility, 7 = minimum distractibility).

**CONCLUSIONS**

The research showed a general positive attitude of the subjects towards the VMS and RDS-TMC systems and confirmed that the introduction of this technology does not require excessive cognitive or behavioral costs. A critical element for their acceptance is constituted by the meaningfulness of the messages provided. Since the drivers are operating under conditions of systematic information overload, the saliency of the messages constitutes one of the primary conditions for the positive evaluation of the systems. In other words, the delivery of useless alarms or irrelevant information represent real risks for traffic information systems. The drivers need to receive only relevant information and only when they need it.

**ENDNOTES**
