Is your request just this? New automation paradigm to reduce the requests of transition without increasing the effort of the driver

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Abstract: The scope of this paper is to describe an innovative interaction paradigm between the driver and highly automated vehicles, developed in AutoMate EU project. This new interaction modality is based on the cooperation, i.e. the mutual support in perception and in action between the driver and the car. The cooperation aims to exploit and make concrete the complementarity of the human and the automation as part of a team. The concept has been tested by evaluating the system that more than others allows the driver to cooperate with the vehicle, i.e. the HMI. The results of the exploratory study show that the cooperation is well perceived, understood and accepted by the users. In particular, the Human to Automation support in perception, the most innovative concept proposed by the project, has shown the potential to reduce the effort requested to the driver to understand how to support the automation as well as the effort to actually support it to cooperatively deal with situations the automation cannot cope with.

1. Introduction

Vehicle automation is rapidly changing the role of the driver in the driving task. In the next years, semi-automated cars will be put on the market, with the aim of increasing the safety and reducing the traffic congestion [1]. However, evolving systems and technology change how humans interact with the vehicle and the environment, thus new human factors can arise and cause new, previously unknown, safety risks [2] [3]. In this perspective, these factors affect not only the safety, but also how the automation is perceived, trusted and consequently accepted by the users [4].

Driving task is made of control and monitoring. Highly automated vehicles control task has been described [5] as a sum of three different states:

- Static driving states, when one agent is exclusively in charge of the control task.
- Dynamic driving states, when the human and automation are jointly executing the same control task (e.g. shared control)
- Transitions, i.e. a shift of vehicle control from the human to the automation and vice versa

This paper describes the shift of paradigm developed in the H2020 Automate project: from an ADAS-like use of automation, where it is only designed and regarded to as a support to the driver towards a cooperative support, where the automation can explicitly ask for support to the driver to cope with complex traffic situations that may degrade its performance. The enabler of the cooperation is the HMI. The next paragraphs describe the rationale of the concept, the strategies developed to implement it and the results of the first evaluation of the implementation.

2. Project's concept

The top-level objective of the AutoMate project is to develop, evaluate and demonstrate the "TeamMate Car" concept as a major enabler of highly automated vehicles.

This concept consists of considering the driver and the automation as members of one team that understand and support each other in pursuing cooperatively the goal of driving safely, efficiently and comfortably from A to B. However, the cooperation requires an additional effort both for the HMI designer and the driver.

So, why is it needed?

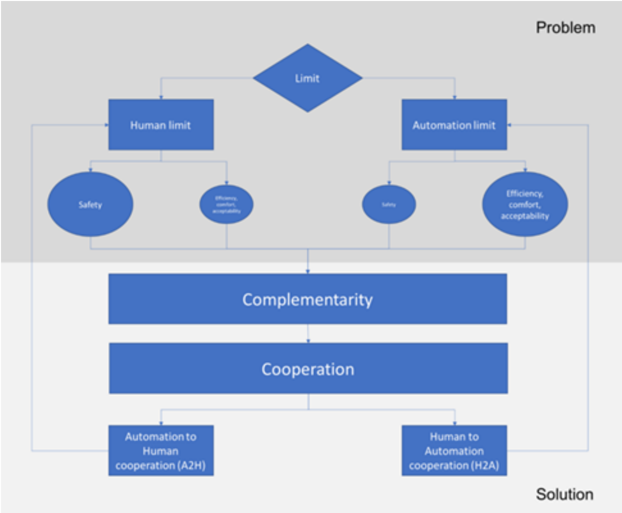

Figure 1 Schematic representation of the overall concept of the project

As shown in Figure 1, both the human and the automation have **limits** that can negatively affect the safety as well as the efficiency, the comfort, the trust and the acceptance of the autonomous driving.

For the human, the limits are often related to his/her driving performance (e.g. distraction, lack of observation, misinterpretation, etc..): they are likely to affect the safety, and cause accidents.

For the automation, the limits are mostly at perception and decision level and may affect the efficiency and the comfort of the trip, and then, in turn, the acceptance of the automation.

Therefore, the cooperation is needed to overcome the limits of both agents (driver and automation) in order to cope with the complexity of the real world.

In particular, while the Automation to Human support (A2H) is used to complement the human's limits, the Human to Automation support (H2A) is implemented to allow the automation to ask the driver for support and use his/her support to overcome its limits.

The complementarity between the driver and the automation is the conceptual solution to compensate the reciprocal limitations, while the cooperation is how the complementarity is implemented. Figure 2 shows how both the A2H and the H2A cooperation can be implemented in perception (state A and B) and in action (state C and D).

The innovative solution developed in AutoMate is to provide a means to allow the automation to ask the driver for a support in perception instead of a request of transition (i.e. a disengagement, that is much more critical in terms of safety).

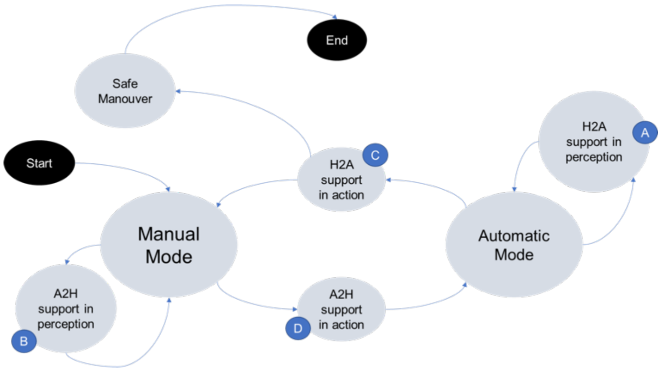

Figure 2 State machine that shows how the cooperation is implemented

3. How the enablers support the cooperation

The TeamMate car concept defined in AutoMate is implemented by developing enablers for the cooperation, i.e. a set of building blocks that, integrated and combined with each other, help to compensate both the human and automation limits.

Table 1 How the enablers support the cooperation

Enabler ID	Enabler	Type of cooperation enabled
1	Sensor and communication platform	A2H in perception
2	Probabilistic driver modelling and learning	A2H in perception
3	Probabilistic vehicle and situation modelling	A2H in perception
4	Adaptive driving manouver planning, execution and learning	A2H in action
5	Online risk assessment	A2H in perception and in action
6	HMI	A2H in perception (warning-based), H2A in perception and in action (negotiation-based)

The technical enablers (enablers 1-5, cfr. Table 1) support the cooperation from the Automation to

the Human (i.e. they implement the traditional automation approach). Since the human limits can lead to safety issues, these enablers have the aim to compensate these limits and increase the safety, supporting the driver when he's not able to deal a situation.
The HMI (enabler 6), instead, also enables the support in both directions, by allowing the cooperation between the two agents. Since the limits of the automation (both in perception and decision) can mainly lead to comfort and acceptability issues, this direction of support is followed in order to increase the effectiveness and the efficiency of the trip and, consequently, the acceptability of the system. The strategy to allow an effective interaction through the HMI is described in the next paragraph.

4. How the HMI supports the cooperation

As stated before, the HMI is the enabler that more than others allows the mutual support and, therefore, the cooperation. In fact, through the HMI the vehicle is able to **inform** the driver about a potential risk (A2H support) or to **ask** the driver either for support in perception and in action (H2A).
To cover all levels of information needed and ensure an effective cooperation, different HMI elements have been designed.
Each element has been placed on the most suitable device in the vehicle, according to a structured HMI strategy. As a general approach, the driving related information (and in particular the information related to the cooperation) have been placed on the instrument cluster, while non-driving related information have been placed on the central display (or on a separated device, i.e. on a nomadic display like a tablet).
Other elements of information have been used as a means to improve the comprehension of the message or to reduce the cognitive workload requested to the driver. These elements are:

- **Ambient lights**, that have been used to reinforce the comprehension of the cooperation and to discriminate the type of cooperation (in perception or in action). They have been also used as a means of concurred abbreviation [6]. The so called "concurred abbreviations" are personalized patterns of interaction that can also employ implicit multimodal signals (e.g. gestures, speech, haptics and actions) and are used to improve the communication and relationship between human(s) and automation. Inspired by psychological theories of social behaviour, they are based on common patters of interaction between humans: increased levels of intimacy and trust (i.e. friendship) are associated with personalized explicit and implicit protocols of communication. They facilitate the cooperation and further foster the sense of belonging to a team that has common objectives and values.
- **Augmented Reality (AR)** functionalities, used to inform the driver about the vehicle's intention (e.g. the intention to overtake)
- **Head-Up Display (HUD)**, as alternative to AR, used to inform the driver about a possible danger or an imminent request of transition of control

In order to carry out the different information and to adapt the communication to the message, two different HMI have been conceptualized, designed and implemented:

- When the direction of the support is **from the human to the automation (H2A)**, the communication is **negotiation-based**.
- When the direction of the support is **from the automation to the human (A2H)**, the communication is **warning-based**;

4.1 Human to Automation (H2A) Support

As represented in the state machine shown in Figure 2, the Human to Automation support occurs when the car is in Automated Mode. In order to ensure an effective support, the vehicle should be able to explain its limit and make the driver aware of the needed support.
Through the negotiation-based HMI the automation **requests a support from the driver**. In particular when the request of support is in perception, the interface is used to ask a sensorial help to the driver to compensate its sensorial limits. The HMI state that represents this request is the state A - Human to Automation support in perception.
In order to adapt the information to the complexity of the situation, different elements (instrument cluster, audio messages, ambient lights) have been combined into an integrated HMI designed to make the driver aware of a 5-level information:

1. The **current state** of the automation;
2. Which of the two agents (the human or the automation) has a limit, to be aware of the **direction of the cooperation**;
3. What is the **"meta-message",** i.e. if the vehicle needs support in action or in perception;
4. What is the **message**, i.e. what is the requested/offered support;
5. What is the **next HMI state** after the support.

An example of the negotiation-based HMI is shown in Figure 3.

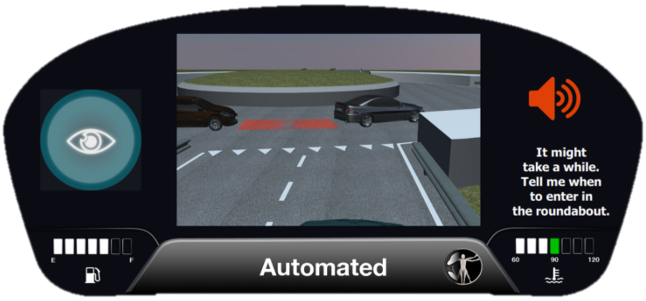

Figure 3 Negotiation-based HMI (state A)

Therefore, the experiment to evaluate this direction of cooperation has been oriented to measure the comprehension of the suggestion that, in this example, is a real negotiation of the upcoming manoeuvre (i.e. H2A support in action). The HMI to enable the H2A support has also been tested in the "H2A support in perception" modality, since this mode is the most innovative concept deployed in the project. In fact, it is expected to reduce the number of disengagements (i.e. when the cars unexpectedly hands over the control to the driver, that represents a well-known safety critical condition) with a minimum effort of the driver (both in terms of understanding the type of support and in terms of actual support provided to the automation).

4.2 Automation to Human (A2H) Support

The Automation to Human support starts from Manual Mode. When the cooperation occurs in this direction, the vehicle to human communication approach is warning-based, thus the emphasis should not be placed on the explanation of the manouver, but on the possible consequences of the human limits.

Through the warning-based HMI the automation **offers a support to the driver** (in perception or in action). This interface has a more typical structure, since the automation-to-human support is the archetypal paradigm used in automotive HMI industry and research. An example of warning-based HMI in Manual Mode is shown in Figure 4.

Figure 4 Warning-based HMI (state D)

5. Experiment and results

Due to the small sample selected for the experiment, no statistical inferences can be made for the study. However, it was meant to provide a preliminary feedback to evaluate the comprehension of the HMI, and to measure how it affects the workload of the subjects.

The scope was to collect useful information to guide the next step of the design, and to evaluate the concept by measuring how the highly innovative solution of the H2A support in perception is perceived by the users.

The warning-based and negotiation-based strategies used to communicate with the driver are evaluated separately to compare the comprehension of the message conveyed by the corresponding HMI.

For the specific H2A support, the objective of the experiment is to assess

1. if the support in perception is perceived as less cognitively demanding than the support in action (i.e. does the driver understand that the automation is asking for a support *only* in perception?)
2. if the support in perception, preventing the request of transition of control, is also perceived as less demanding in terms of action requested to the driver (i.e. does the driver understand that he/she has *only* to use his/her perception in place of the sensors of the automation and provide a feedback, instead of taking back the control of the vehicle?)

Moreover, the use of ambient lights to increase the comprehension and improve the effectiveness of the expected support has been tested during the experiment.

5.1 Methodology

The experiment was designed as a repeated measures design, meaning that each participant drove every condition. It was divided into two parts: the first part to evaluate the integrated HMI, the second part to evaluate the quality of the interaction with ambient lights in addition.

In order to ensure a depth comprehension of the results, the HMI has been tested in different scenarios. The other experimental requirements were:

- To test the HMI in both **directions** of the cooperation (H2A and A2H support),
- To test the HMI in both **types** of cooperation (support in perception and in action).

The test was performed on the instrument cluster because, according to the HMI strategy used to design the interface, it is the main system in which the cooperation is shown. The participants were asked to look at the HMI in the instrument cluster, and then to answer some questions to measure the level of comprehension of the message.

The message was reinforced with audio, i.e. vocal communication in natural language from the vehicle to the driver, to adapt the communication to the complexity of the scenario.

Since, as stated before, the HMI (especially when the cooperation is from the human to the vehicle) has five levels of information, the same levels of comprehension were measured with a customized questionnaire:

- The **current state** of the car before the request (or offer) of support;
- The **direction** of the support, i.e. who has the limit to be compensated;
- The **meta-message**, i.e. the type of support needed (in perception or in action);
- The content of the **message**;
- The **next state**, i.e. if there is or not a transition of control

The NASA-TLX questionnaire for workload measurement [7] was administered after each part of the experimental scenario.

Moreover, qualitative data on the comprehension of the support, based on the think-loud protocol [8] have been collected during the experiment.

The second part of the experiment had the aim of evaluate the ambient lights as a means of concurred abbreviation.

This phase of the experiment was performed to collect two different pieces of information:

- The most effective **color** of the ambient lights;
- The usefulness of this means of concurred abbreviation, i.e. if this HMI is able to **improve the comprehension of the cooperation** reducing the user's workload.

The users were asked to see two scenarios with ambient lights, and to express their opinion on the color selected to communicate the cooperation. In fact, the ambient lights have been used to improve the **request of support** from the automation. Therefore, they have been used only when the direction of the support is H2A.

The colors selected to suggest the cooperation are:

- Blue, for H2A support in perception;
- Yellow, for H2A support in action.

The experimental setup of the Ambient lights validation is shown in Figure 5.

Figure 5 Experimental setup of the experiment with ambient lights

In order to measure how this module is able to improve the effectiveness of the communication, the NASA-TLX questionnaire has been administered again on selected scenario that have been modified with the addition of the ambient lights.

The **H2A support in perception** has been measured with **blue ambient lights**, comparing its

results with the score of the test performed with the same scenario without lights.
The **H2A support in action** has been measured with **yellow ambient lights** to assess how this enabler can improve the effectiveness of the take-over request's comprehension.
The objective of these information is to assess that the user-centered design approach has achieved its purpose.

5.2 Participants

As stated before, the study was preliminary and a small sample of users were involved. The number of participants selected for the test was 9. The gender of the subjects was balanced to avoid possible biases: 5 males and 4 females were recruited.
The average age of participants was 29,44 years.
Only participants with valid driving licence were considered for the test. They have had driving license since 10,77 years and they travel for 18.200 kms/years on average.
The experimental setup is shown in Figure 6.

Figure 6 Experimental setup of the experiment

The HMI was installed on a laptop and the subjects were asked to answer the questions after viewing each part of the experimental scenario; an experimenter supported the subjects for every clarification and was in charge of administering the questions and collect real-time subjective data.
Before the test, the experimenter briefly introduced the project to the subjects and showed a video to describe the project's concept.
All the users were asked to sign an informed consent form to participate in the test. No other user requirements were considered for the experiment.

5.3 Results

As stated before, the integrated HMI assessment concerned the five levels of information offered to ensure an effective communication between the driver and the automation.

All hypothesis have been successfully validated:

a) 100% of the participants were able to understand the initial state (automation or manual driving)
b) 100% of the participants were able to understand the direction of the cooperation
c) 96,3% of the participants were able to understand the type of support needed, i.e. the difference between cooperation in perception and in action
d) 96,3% of the participants were able to understand the message explained through the HMI
e) 100% of the participants were able to understand the state in which the car would have been after the cooperation

Since the radical innovation of the approach used in AutoMate is to enable the support from the human to the automation, the deep research question was to evaluate if the support in perception is less demanding then the support in action (that correspond to the request of transition), both in terms of understanding and actual support.
The results of the NASA TLX questionnaire show that the support in perception is less demanding then the support in action, confirming the hypothesis and giving strength to the approach established in the concept. In fact, the overall workload perceived by the users was lower for the support in perception than the support in action ($\Delta = 0{,}73$).
In particular, the support in perception proved to be effective in improving the perceived performance ($\Delta = 1{,}05$), reduce the effort ($\Delta = 0{,}88$), and reduce the frustration ($\Delta = 1{,}25$).

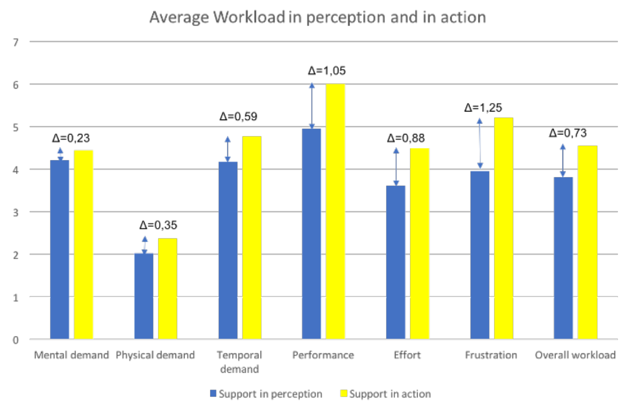

Figure 7 Average workload in perception and in action

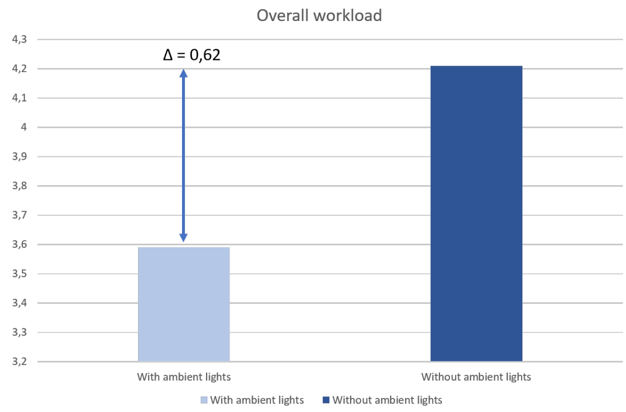

Figure 8 Comparison of overall workload with and without ambient lights

Although the HMI for H2A support in perception (negotiation-based) is more complex than the warning-based HMI (to adapt the amount of information to the complexity of the situation), the users perceive less effort when the cause of the need (i.e. the limit) of cooperation is explained.

The ambient light colours selected for this validation phase did not meet the user requirements, i.e. the results are below the success criteria. This information will be used to improve the HMI in the next project cycle (according to the user centred design approach used in the project) and other colours will be considered according to the participant's comments and feedback.

As regards the second part of the experiment, the important result achieved is that ambient lights have been considered a useful means to improve the effectiveness of the communication when the support needed is from the human to the automation.

This factor was also confirmed by the comments of the users, and above all by the objective results of the NASA TLX. These results show how the HMI, with the addition of the ambient lights, is able to reduce the driver's workload, and improve the comprehension of the expected cooperation.

The results of NASA TLX repeated on the same scenario without the ambient lights and then with ambient lights are shown in Figure 8.

5.4 Qualitative results

The comments collected through the think aloud protocol highlight that the cooperation is well understood, and the elements designed on the instrument cluster are visible and do not require too much attention to be interpreted.

Several comments on the interaction style was collected. Some users considered the messages too peremptory (*"I don't want that car to tell me that I'm distracted, I'd rather prefer that it tells me that it's better than me in doing something and it can help me"*) or too informal (*"I would prefer a more formal communication"*).

One user felt that it might take a bit of training to learn the expected cooperation and to discriminate the different types of cooperation.

The ambient lights were well accepted and considered as a useful support to simplify information comprehension. However, the color of the ambient lights has been object of discussion: the blue was selected as the color for H2A support in perception since this color was considered neutral enough to avoid confusion in the driver [9]. From the comments of the users it emerges that for some of them the color was too neutral and therefore not useful for attracting attention.

Also for H2A support in action some of the users felt that yellow ambient light was not clear enough to explain the expected cooperation. While not necessarily implying a safety related situation, the request of support in action has been considered a critical event, and two users would have preferred a more intense color (*"since I have to take control, and I could be out of the loop, I would have preferred an orange blinking light").*

These comments will be used as cues to drive the design in the next project's cycle.

5. Conclusions

This paper describes how the concept of cooperation developed in AutoMate project has been implemented through the HMI and tested to assess its consistence.

In particular the concept of cooperation, as an implementation of the complementarity between the human and the automation, has proved to be a promising solution to increase both safety and acceptability issues arising from the increasing vehicle automation.

The results of the experiment show that the most innovative direction of support (i.e. H2A, when the automation requests a support to the driver) is well understood and accepted by the users.

Moreover, the H2A support in perception has been measured to be less demanding then the support in action (the transition of control). This factor can be considered one of the most relevant concept emerged during the project.

In fact, although the HMI for H2A support in perception (negotiation-based) is more complex than the A2H warning-based HMI (i.e. the archetypal paradigm used in automotive HMI industry and research), the users are able to understand it and correctly perceive the reduced requested effort compared to the H2A support in action (i.e. the request of takeover).

The H2A support in perception has highlighted a reduction of perceived mental workload and frustration, and an increase of perceived performance compared to a support in action. This is of particular interest, since this type of cooperation seems to be able to reduce the number of requests of transitions (i.e. disengagements) and potentially to improve the relationship between the driver and the automation (i.e. the trust and acceptance), as the driver is aware of the minimum effort requested to effectively support the automation and cooperatively cope with the complexity of the real world to drive safely, efficiently and comfortably from A to B.

The findings emerged during this study are likely to be used as a basis to design effective Human Machine Interfaces for highly automated vehicles. Since the AutoMate project is made of cycles, the next activities will be to evaluate the results gained through the cooperation with the integrated building blocks, in order to demonstrate how the features (modules, tools and models) developed in the project can improve the safety and the comfort of the driving experience.

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