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## To cite this version:

Quentin Gadmer, Marie-Pierre Pacaux-Lemoine, Philippe Richard. Human-Automation - Railway remote control: how to define shared information and functions?. 16th Symposium on Control in Transportation Systems (IFAC 2021), Jun 2021, Lille, France. pp.173-178, 10.1016/j.ifacol.2021.06.022. hal-03407188

HAL Id: hal-03407188
https://hal-uphf.archives-ouvertes.fr/hal-03407188

Submitted on 27 Jun 2022

Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 54-2 (2021) 173–178

# HUMAN-AUTOMATION - RAILWAY REMOTE CONTROL: HOW TO DEFINE SHARED INFORMATION AND FUNCTIONS?

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**Abstract:** As it had already been observed in other domains, such as aircraft or automotive sectors, the development of fully automated driving systems in the mainline railway sector faces multiple technical and safety barriers. Before such an advanced system can be overcome, systems with intermediate and adaptive levels of automation must be considered and studied. In this context, human operators maintain a crucial role for the train driving activity and their interactions with technical systems and other agents must remain among the main focuses of the conception phase. These interactions are considered through a thorough Human-Machine cooperation model. The objective of this paper is to present a conception and evaluation method implementing this model in the development of assistance systems for cooperation with human operators. The method is currently being applied for train remote driving as part of the TC-Rail project, where the aim of the study is to focus on Human-Factors aspects. A second phase of development is currently in progress and has been complemented by the results of a first phase. Along with the conception method, the state of this second phase, as well as use cases for future tests that implement it, are presented in this paper.

***Keywords**:* Human-machine cooperation; Adaptive level of automation; Design and evaluation method; Teleoperation; Railway.

## 1 INTRODUCTION

The process of automation has led to the development of increasingly intelligent or capable assistance systems, aiming to share the ability to control a process with human operators, as recommended in multiple domains (Flemisch F., Abbink D., Itoh M., Pacaux-Lemoine M.-P., Wessel G., 2019). Such systems could be assisting, not exhaustively, with the analysis or the decision making during an activity, inducing strong interactions with human operators and the need to be able to communicate and cooperate effectively with them.

Unfortunately, research on automated systems is mostly technical, and often overlooks the human operators' role and their importance in the process control. This is especially true in domains where the literature is quite recent such as mainline railway driving, as companies often aim for perfectly functioning but immediately unachievable fully automated systems. Human operator's needs and interactions with assistance systems are rarely assessed, severely impairing their ability to cooperate with each other. Paradoxically, to speed up the research process and save production cost and resources, the development of partially automated systems will largely build upon what is already existing, effectively minimizing specific needs of the new activity for humans or machines. As a result, companies and industries sometimes re-use existing machines with different objectives, or different humans, or different environments, but even if the difference is very small, it can disturb the overall human-machine system and may lead to catastrophes, especially if the human and the machine are not able to communicate effectively.

Such communication difficulties are highly critical in a teleoperation context, which is carried out within the framework of Railenium's TC-Rail project (Railway Remote Driving). This project aims to develop a system of remote control for freight trains, identifying and resolving the technological limitations and scientific challenges. Other applications of remote driving are considered (management of technical routes between stations and maintenance centers or recovering an autonomous train), but not taken into account within the TC-Rail project. This work aims to contribute to the management of the impact of distance between the human operator and the controlled system in order to enable the human-machine system to achieve its objectives in complete safety. For more details on this project, you can consult Masson et al. (2019).

Human centered approaches when building assistance and cooperation systems for train driving are still scarcely documented in the literature, especially in the case of train teleoperation that is still only emerging. In our research for this

10.1016/j.ifacol.2021.06.022

project, we have applied and extended human-machine cooperation principles to this remote driving context, especially the method supporting these principles. This updated method, used to design and evaluate assistance systems and its interaction with human operator, will now be presented.

## 2 METHODOLOGICAL APPROACH

User-centered design methods aim to evaluate the ergonomics of systems. They provide knowledge about the design and evaluation of interfaces, e.g. usability and models of human-machine interaction based on cognitive behavior (Gould and Lewis, 1985; Nielsen, 1993). Nevertheless, other methods exist, originating from different domains, such as the method presented in social acceptability (Brangier, Hammes-Adelé and Bastien, 2010). The authors underline the interest in exploiting complementarities between humans and machines. This is also the objective of the method proposed by Millot, the so-called method in "U" (Millot and Roussillon, 1991). This method aims to propose an easier way to design and evaluate system than the V-cycle proposed by Royce (Royce, 1970), and moreover, it does take into account humans and their interactions with assistance systems. The method in "U" has the objective to balance human involvement with machine involvement in the control of the process in a cooperative manner. Firstly used in telerobotic domain (Millot and Roussillon, 1991), other domains applied this method like in automotive domain to design and evaluate driving assistance systems (Pacaux-Lemoine and Crévits, 2010; Pacaux-Lemoine, Simon and Popieul, 2015). Fig. 1 presents the new version of the method. Indeed, details about human and machine representations, their interactions through a Common Work Space (CWS), and the multi-level aspects of cooperation enrich the previous version, to converge towards Human-Machine System Integration method.

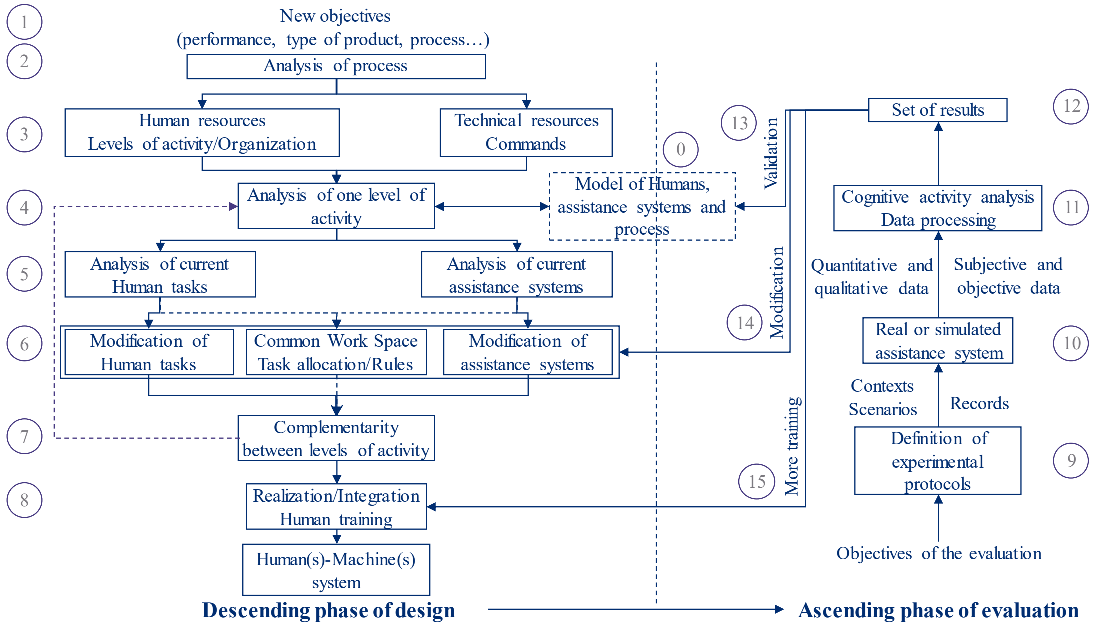


Fig. 1. Method in "U", extended from (Millot, 1995)

In this method, a descending phase designs Human(s)-machine(s) system and an ascending phase evaluates it.

First, designers need to know the objectives of the human-machine system they have to design (cf. Fig. 1-1). In the TC-Rail project, the objective is to design the remote control, i.e. the augmented work position of the train driver, as well as the augmented train. Safety is of course the main performance to control, but train schedule and driver acceptability must be taken into account too. Therefore, designers must correctly identify and understand objectives with discussions with managers, experts and current/future train drivers. Models of current organization, current tasks and functions, and detailed description of drivers' activity exist and already provide interesting information about the prescribed tasks (cf. Fig. 1-0). However, in addition to existing models, designers may study human and technical resources (cf. Fig. 1-3), and conduct analysis of current activity (e.g. being in cabin with drivers). Such points of view are sometimes different from the point of view of managers (cf. Fig. 1-2). Ergonomic and social fields help analyze human resources, extracting cognitive and physical constraints linked to activities, as well as constraints from the social organization.

The method highlights the interest in extracting the levels of activity and layers of cooperation from the organization (cf. Fig. 1-4). The designer has to then identify tasks and sub-tasks of humans and machines at each level (cf. Fig. 1-5): - the operational level concerns the control of the train speed (train driver, ground staff), - the tactical level concerns the line knowledge and the forecast of next speed limits (train driver, traffic supervision), - the strategic level concerns the itinerary of the train (train driver, traffic planners and schedulers). At each level, the designer suggests modifications of current tasks or creations of new tasks for humans and machines, as well as the definition of rules for task allocation between humans and machines involved in the level, and the Human-machine interface to support the common workspace (cf. Fig. 1-6). Next step is the identification of cooperative tasks between these layers of cooperation (Pacaux-Lemoine M.-P., Flemisch F., 2018). An iterative procedure proposes the analysis of activity level by level, as well as complementarity between levels (cf. Fig. 1-7). Tasks or functions deal with individual and cooperative activities, therefore, Know-How (KH) and Know-How-to-Cooperate (KHC) functions of train driver and several assistance systems may be analyzed through a grid presented in the next part with the use case presentation (cf. §3).

The ascending phase starts when the designer has identified a minimum of humans and assistance systems' functions to be evaluated. The objectives of the evaluation must answer the questions raised by the stated hypothesis. What do we want to highlight with the evaluations? How can the proposed new human-machine system be assessed and prove its usefulness? Experimental procedures and protocols must answer such questions, with the definition of contexts, scenarios and recorded data (cf. Fig. 1-9). Context deals with whole or part of the process in which the human-machine system takes part. Scenarios aim to encourage users to complete some tasks by asking them (and the assistance systems) to reach goals despite triggering unexpected events. Regarding data, experimenters must find the right compromise between recording many data and spending a lot of time cleaning, selecting, and analyzing data, or selecting the most appropriate data and the way to analyze them.

The 10th step of the design and evaluation method describe the way assistance systems are implemented in a real or simulated experimental environment. After technical tests aiming to evaluate the system robustness, tests of usability and acceptability must be conducted, and assistance systems can be evaluated at different levels and for different kinds of system maturity (Boy, 2018). Designers may fully program functions or simulate those functions using technics such as the Wizard of Oz method (Pacaux-Lemoine and Loiselet, 2002) or the theater method (Schieben *et al.*, 2009). However, in that case, specific interfaces must be developed to manage the simulated functions. However, that can be time and cost consuming. The 11th step of the method deals with data processing. Many methods exist to analyze data, however few methods exist that are able to confront subjective, objective, quantitative and qualitative data. Moreover, few methods help experimenters to understand data and provide explanations or justification of results. The model of a cooperative agent may support such an analysis. The idea is to use a coding of agents' activity done according to the model of cooperation to highlight interactions between agents (cf. Hoc J.-M., Pacaux-Lemoine M.-P., 1998). The 12th step of the method is the result of all the previous steps. Experimenters may describe the experimental HMS results. Then, three main feedbacks aim to update boxes of the design phase. The first round of feedback (13th step of the method) validates the HMS and updates current models of human operators, assistance systems and processes according to new achievements. The second round of feedback (14th step of the method) highlights unsuitable aspects in the design of the HMS. Therefore, designers must modify such aspects that may deal with new human tasks, or new assistance system tasks, or new CWS, or new organizations. The third round of feedback (15th step of the method) underlines the necessity for participants to have more training with their new tasks, regarding their cooperation with assistance systems, or with the activity.

This method was used in the TC-Rail project. A first loop of a descending and ascending phase was completed, and the project is currently in its second descending, design phase.

## 3 APPLICATION WITHIN THE TC-RAIL PROJECT

### *3.1 "First loop"*

During this first loop, a first demonstrator has been developed. The first step was to understand the activity of a railway driver, to determine the changes that must be applied, in terms of taking information or modality of information presentation so that the driving activity can be carried out remotely. Specific choices were made for this first demonstrator to limit the scope of the study:

- The activity was limited to the braking and traction tasks, to focus on the applicability of remote driving on a simpler system;
- It was assumed that remote drivers would initially also be former drivers. This greatly influences their knowledge of the driving activity, even from a remote perspective;
- The intelligence brought into the systems was kept as low as possible for this first phase, to reduce experimental variables.

In this context, the analysis of the prescribed activity in cabs and working groups with drivers (steps 1 to 5 of Fig 1.) has led to the definition of several recommendations for the design of Human Machine Interfaces (HMI) for train remote driving (steps 6 to 8 of Fig 1.). Some of these have been integrated into the phase 1 remote cabin.

In addition to the first demonstrator, on a real train, further tests were performed on a simulator (steps 9 to 12 of Fig 1.) with sixteen freight train drivers. In both environments, the choice was made to reduce information gathering to a single information channel (visual) in order to identify the problems caused by the lack of other channels. The objective of this choice was to identify situations and sources of information that must be considered when transitioning towards remote driving. It emerged that the visual channel alone is not sufficient and leads to visual fatigue and increased cognitive workload. The test results helped identify sequences of the activity where the acquisition of information from several sensory channels is essential, effectively enhancing our model of the activity and the human operator. For example, drivers noticed the absence of proprioception, which greatly participates in building a proper sense of presence and understanding of the train's movements. We believe this lack of information will have a negative and potentially important impact in situations such as the tensioning of the train's coupling before the departure of a freight train or the problematic of slipping/sliding. It is not be possible to reproduce all the sensory sources (kinesthetic, auditory...) in an identical way to reality and when it is possible to provide such information, the latency between the remote driving system and the telecommunications network must be considered, making the information difficult to rely on.

Because of the multiple discrepancies between on-board and remote driving and the altered perception ability of the remote driver raised during the first loop, it seems essential to provide more developed assistance systems (step 14 of Fig 1.). The next parts of section 3 explain the method used to define the allocation of tasks to the different agents presented (Fig. 2) and proposes an illustration on the slipping and sliding use case.

### *3.2 Use case*

Since every situation of the train driving activity cannot be considered in a single design phase, our study is limited to only a reduced number of specific use cases. The use case defines the scope of our study by setting the different actors, human and assistance systems that have a goal in the process, their role in achieving this goal, notably the assistance system's role in aiding the remote driver and conditions specific to the use case. To illustrate the application of the method and the model, in this paper we have focused our examples on the management of wheel-rail adhesion issues, such as slipping and sliding and see how to build assistant systems for these situations.

In this context, the remote driver is facing multiple issues as the detection of sliding or slipping is now much more difficult. Indeed, due to technical restrictions of remote driving and the lack of information, motion parallax or proprioception, it is harder for a remote driver to properly estimate the train's speed and feel the effects of traction and braking efforts. As a result, they rely mainly on speed indicators, subject to latency and inaccuracy, and their knowledge of the train line to notice or anticipate such issues. Moreover, the detection of adhesion issues is essential as it can potentially affect the train's acceleration, its braking time and can sometimes damage the infrastructure or the train itself, resulting in the need for a repair services intervention. Moreover, an increased braking time is dangerous as it adds up to latency and increased reaction time due to remote driving.

During the second descending phase of the extended Method in "U", the cooperation model was updated from the first evaluation phase's feedbacks and the needs specific to the chosen use cases. In the following part, we will present the current state of the model and how it is used in this use case to develop assistance systems.

### *3.3 Updated cooperation model*

In (Pacaux-Lemoine M.-P., Gadmer Q., & Richard P., 2020), we have presented in detail the cooperation model, extending already existing Human-Machine Cooperation principles and previous models used by Dr. Pacaux-Lemoine (Pacaux-Lemoine M.-P., Flemisch F., 2018) to more than two agents and adapting its use towards train remote driving. In this framework, we have identified four agents directly taking part in the driving activity: the remote driver, the train and two Advanced Driver-Assistance Systems (ADAS), one on-board, that has more control over the train and its environment, and one within the remote-control cabin that can easily communicate with or monitor the remote driver. These agents cooperate with each other to successfully complete the driving activity mission and their interactions are the main focus of our study. For each of them, we aim to define their KH, the inner ability of the agent to control and interact with the process and their KHC, the ability to communicate and share functions with other agents.

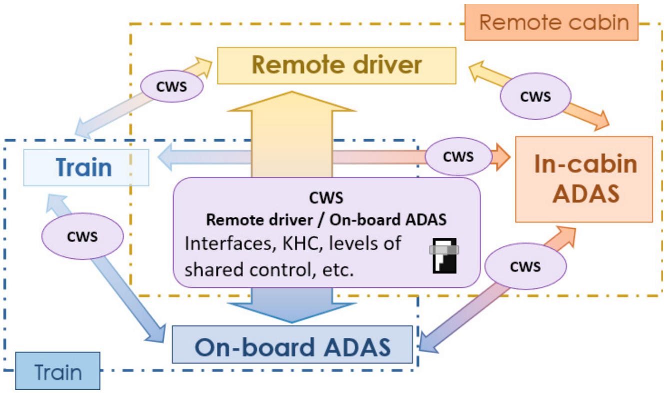


Fig. 2. Simplified cooperation model for train remote driving

The KH can be divided into four subfunctions, being Information Gathering (IG) on the process and the environment, Information Analysis (IA), Decision Making (DM) and the Action Implementation (AI). The KHC is also divided into four subfunctions, dealing with Information Gathering (IG) on other agents, the Detection and Management of Interferences (ID & IM), and the Function Allocation (FA) between agents. The support for this cooperation is known as the Common Work Space (CWS), which provides means of communication between agents and tools to interact with the process (communication networks, user interfaces, controller, etc.).

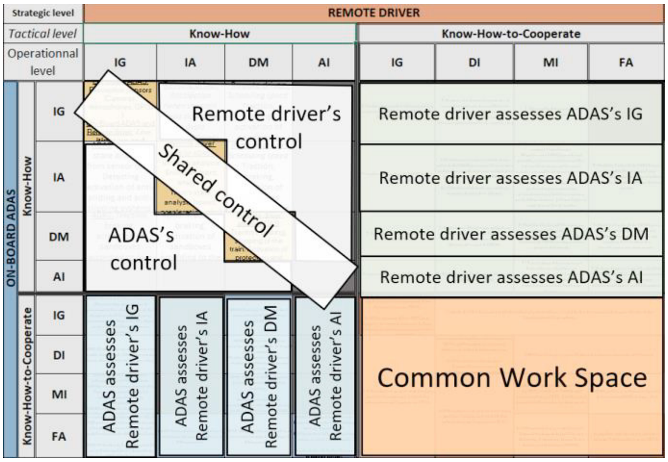
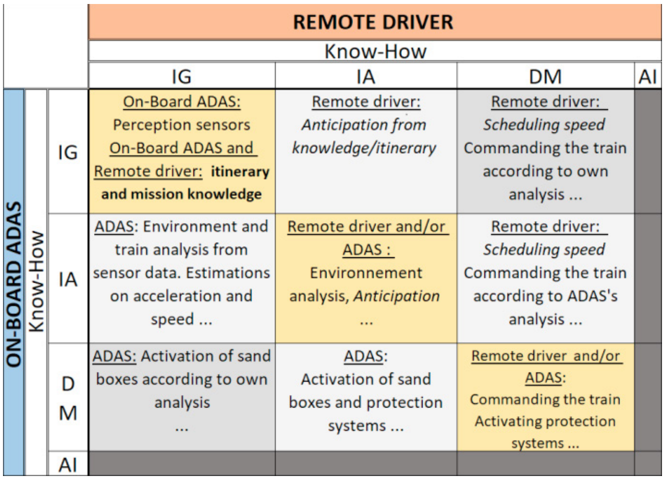


Fig. 3. Cooperation table detailing the model's functions for each pair of agents

We use the model to determine the capacity of the agents regarding each of these functions and list them in a grid table featuring each pair of agents such as Remote Driver – Train This grid was used by Dr. Pacaux-Lemoine in (Pacaux-Lemoine, M.-P., Simon, P. and Popieul, J., 2015) and is useful to comprehend the KH and KHC's of agents, and how they use the CWS to support their interactions. The table serves a complete and rigorous study in raising as many questions as possible on the agents' capacities and in avoiding overlooking any element of the process. Fig. 3 presents the main elements of this tool, that will now be developed. The first, upper-left square, in white and yellow, shows the agents' KH, detailing the aspects of each of the KH functions for both agents. Then, the two adjacent squares, in blue and green, show their respective KHC with the other agent. The last, lower and right square, in orange, details the use of the CWS by the agents to communicate and justify, for example, their analyses or decisions.

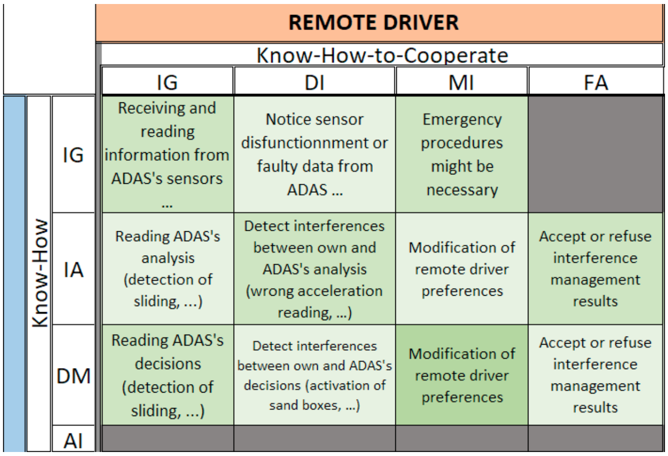
In Fig. 4, we can see how the on-board ADAS's KH complement that of the remote drive to help with the detection and prevention of wheel-rail adhesion issues. For clarity and readability purposes, the cells content has been reduced to show only a few examples. The remote driver relies on the ADAS's information gathering abilities for their analyses and might anticipate an issue from their knowledge of the train line (incoming slopes, weather constraints, etc.). The ADAS can analyze the train's behavior and then alert other agents as part of its KHC (see Fig.5). In this use case, the ADAS's speed and acceleration analysis can be compared with the estimation of the train's behavior through a digital simulation, helping in detecting wheel-rail adhesion issues. Finally, with an increased authority, the ADAS can control the train's speed if necessary, or manage the opening of sand boxes when rails are too slippery. In this pair of agents, the Action Implementation (AI) function cases were left empty for both agents. This is because the remote driver and the on-board ADAS's decisions are transmitted to the train through a controller that will activate the train's actuators. The AI authority is thus left to the train agent which will implement other agents' decisions.



| | | | **REMOTE DRIVER** | | | |
|---|---|---|---|---|---|---|
| | | | Know-How | | | |
| | | | IG | IA | DM | AI |
| **ON-BOARD ADAS** | Know-How | IG | On-Board ADAS:<br>Perception sensors<br>On-Board ADAS and Remote driver: **itinerary and mission knowledge** | Remote driver:<br>*Anticipation from knowledge/itinerary* | Remote driver:<br>*Scheduling speed*<br>Commanding the train according to own analysis ... | |
| | | IA | ADAS: Environment and train analysis from sensor data. Estimations on acceleration and speed ... | Remote driver and/or ADAS :<br>Environnement analysis, *Anticipation* ... | Remote driver:<br>*Scheduling speed*<br>Commanding the train according to ADAS's analysis ... | |
| | | DM | ADAS: Activation of sand boxes according to own analysis ... | ADAS:<br>Activation of sand boxes and protection systems ... | Remote driver and/or ADAS:<br>Commanding the train<br>Activating protection systems ... | |
| | | AI | | | | |

Fig. 4. Remote driver and on-board ADAS's KH's complementarity

A few examples of the remote drivers' KHC with the on-board ADAS are shown in Fig. 5 (a close-up view of the upper right square in grid in Fig. 3). For each function of the KH, the grid lists the information received by the remote driver from the ADAS. Raw data from the ADAS's sensors, such as cameras or GPS is read on the remote cabin which serves as CWS between the two agents. For the remote driver, they appear on the physical interface on screens or through sound and haptic signals. This user interface is also used to transmit information regarding the ADAS's analyses and decisions. Interferences might then appear between the remote driver and the on-board ADAS regarding their analyses. For example, the remote driver can find a decision from the ADAS inadequate according to their own analysis. To avoid potentially dangerous conflicts in decisions and following actions on the process these interferences must be handled. In Fig. 5, the remote driver can do so by accepting, negotiating, or imposing their analysis/decision and ultimately modifying preferences regarding the ADAS's assistance level.



| | | | **REMOTE DRIVER** | | | |
|---|---|---|---|---|---|---|
| | | | Know-How-to-Cooperate | | | |
| | | | IG | DI | MI | FA |
| | Know-How | IG | Receiving and reading information from ADAS's sensors ... | Notice sensor disfunctionnment or faulty data from ADAS ... | Emergency procedures might be necessary | |
| | | IA | Reading ADAS's analysis (detection of sliding, ...) | Detect interferences between own and ADAS's analysis (wrong acceleration reading, ...) | Modification of remote driver preferences | Accept or refuse interference management results |
| | | DM | Reading ADAS's decisions (detection of sliding, ...) | Detect interferences between own and ADAS's decisions (activation of sand boxes, ...) | Modification of remote driver preferences | Accept or refuse interference management results |
| | | AI | | | | |

Fig. 5. Remote driver's KHC with the on-board ADAS

This framework is used to find solutions to complement the remote driver's abilities with other agents' support. It raises multiple questions regarding their ability or inability to perform certain tasks and allows us to fully comprehend the activity. This model is currently being enhanced by the results from the first phase of the project and further investigations on human factors and teleoperation. Multiple steps remain for the project to close the "second loop" of this conception cycle.

## 4 FUTURE WORK

Following the completion of the revised model, the next steps for the project is the implementation of new assistance systems according to the previous analysis. These solutions, which were found out using the framework, should help the remote driver in the context of the aforementioned use case. Since these systems must be conceived while factoring in the ascending evaluation phase afterward, and due to time restrictions and technical constraints, some solutions cannot be implemented and must be left for further studies and tests. Additionally, interfaces between agents be conceived, especially for the remote driver. These interfaces will allow agents to exchange information and communicate instructions. A communication network can support data exchanges between assistance systems, but the remote driver needs a physical interface in the remote driving cabin. Thus, a driving desk has been crafted. It includes screens for visual information such as the train's speed, braking efforts, or the train's front view from embedded cameras as well as all controls to command the train.

Then, the new ascending phase will aim to test the applicability and the efficiency of these assistance systems. Since only a limited number of features can be tested on a physical demonstrator, on a real train, the remaining functions will be implemented on a virtual environment. Again, the feedback from these tests' participants will enhance the cooperation model, confirm or invalidate hypothesis and should ideally highlight interactions or capacities that have been overlooked or misjudged in the current model.

## 5 CONCLUSION

In addition to testing the applicability of train remote driving, the objective of the previously introduced TC-Rail project is to lay the foundation for a more human-centered approach for the development of semi-automated systems in the railway sector. We believe that a fully automated railway system is not necessarily ideal or even desirable in every case and keeping human operators in the loop is the key for safer and more controlled automation. However, this assertion assumes that said human operators must be considered as a central point of the study, as to not overlook their needs or abilities and to build assistance systems adapted to them with which human operators can efficiently cooperate with.

In this paper, we have presented multiple tools to be used conjointly to study and design human-machine systems in a Human-centered context. The extended method in "U" (Fig. 1) is a design and evaluation method in two phases. The first phase aims to support the conception of human-machine systems through a thorough study of human factors and assistance systems and through the application of human-machine principles, evoked in this paper. The second phase aims to evaluate the systems built to further enhance the model and subsequent systems. This two-phase process should be applied multiple times to reach a satisfactory level of comprehension of the human model, their needs, and interactions with assistance systems and those of said systems. We build these models according to a human-machine cooperation framework with four agents, the train remote river, the train and two assistance systems. The model gives a global understanding of the agents' roles and interactions. The agents' capacities regarding their KH and KHC and how they use their respective CWS to cooperate with each other are then gathered and listed in a unique grid table featuring each pair of agents that completes the model. These tables point out the complementarity between agents' KH and KHC and orients the research process by raising specific questions on the agents' abilities and the functions they share together.

## 6 ACKNOWLEDGEMENT

This research is part of the TC-Rail project co-financed by a public and private consortium (Railenium, SNCF, Thales, Actia Telecom, CNES). We wish to thank every industrial and academical partner involved in the realization of this project.

## REFERENCES

Flemisch F., Abbink D., Itoh M., Pacaux-Lemoine M.-P., Wessel G. (2019). Joining the blunt and the pointy end of the spear: towards a common framework of joint action, human-machine cooperation, cooperative guidance and control, shared, traded and supervisory control. Cognition Technology and Work, 21 (4), pp. 555-568

Boy, G. A. (2018) 'Human-centered design of upcoming human missions to Mars', Journal of Space Safety Engineering, 5(1), pp. 9–13. doi: 10.1016/j.jsse.2018.01.001.

Brangier, É., Hammes-Adelé, S. and Bastien, J. M. C. (2010) 'Analyse critique des approches de l'acceptation des technologies : de l'utilisabilité à la symbiose humain-technologie-organisation', *Revue européenne de psychologie appliquée*, 60(2), pp. 129–146. doi: 10.1016/j.erap.2009.11.002.

Gould, J. D. and Lewis, C. (1985) 'Designing for usability: key principles and what designers think', *Communications of the ACM*, 28(3), pp. 300–311.

Masson, É, Richard P., Garcia-Guillen S. and Morral-Adell G. (2019). TC-Rail: Railways Remote Driving. *12th World Congress on Railway Research (WCRR).* Tokyo, Japan.

Millot, P. and Roussillon, E. (1991) 'Man-Machine Cooperation in Telerobotics: Problematic and Methodologies', in *in Proc. of the second Symposium on Robotics*. Gif -sur-Yvette, France.

Nielsen, J. (1993) *Usability Engineering*. London: Academic Press.

Pacaux-Lemoine M.-P., Flemisch F. (2018). Layers of shared and cooperative control, assistance, and automation. Cognition, Technology & Work

Hoc J.-M., Pacaux-Lemoine M.-P. (1998). Cognitive evaluation of human-human and human-machine cooperation modes in air traffic control. International Journal of Aviation Psychology, 8, pp. 1-32

Pacaux-Lemoine, M.-P. and Crévits, I. (2010) 'Methodological approach and road safety system evaluation', in *IFAC Conference on "Analysis, Design and Evaluation of Human-Machine Systems"*. Valenciennes, France.

Pacaux-Lemoine M.-P., Gadmer Q., & Richard P. (2020). Train remote driving: A Human-Machine Cooperation point of view in IEEE ICHMS Conference. Rome, Italy (2020): Human-Centered Cyberphysical System.

Pacaux-Lemoine, M.-P., Simon, P. and Popieul, J. (2015) 'Human-Machine Cooperation principles to support driving automation systems design', in *3rd International Symposium on Future Active Safety Technology Toward zero traffic accidents (FAST-zero'15)*. Gothenburg, Sweden.

Pacaux-Lemoine, M. P. and Loiselet, A. (2002) 'A common work space to support the cooperation into the cockpit of a two-seater fighter aircraft', *Cooperative Systems Design: a Challenge of Mobility Age*, pp. 157–172.

Royce, W. (1970) 'Managing the development of large software system', in *in Proc. IEEE Western Computer Conference*. Los Almitos, CA: IEEE computer Society Press.

Schieben, A. *et al.* (2009) 'The theater-system technique: Agile designing and testing of system behavior and interaction, applied to highly automated vehicles', *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications, AutomotiveUI 2009*, (September), pp. 43–46. doi: 10.1145/1620509.1620517.