Transmitted by the expert from HF-IRADS,
Member of the International Ergonomics Association (IEA)
(Note: it was not confirmed to the secretariat that this document is submitted by IEA)

Informal document No. 8 - September 2020 session of WP.1
Informal document **GRVA-07-65**
7th GRVA, 21-25 September 2020
Agenda item 12

Human Factors Challenges of Remote Support and Control
A Position Paper from HF-IRADS[1]

1. Introduction

This document is intended to provide guidance on the major human factors challenges to be considered when providing remote support and control to assist vehicle operation under automation. Such remote support could extend from the provision of assistance in the event of a breakdown all the way to full remote operation, i.e. a vehicle being driven on the public roads by a remote driver. This document has been developed to assist in the discussion of both WP.1 and WP.29 on the potential for remote assistance and control as assistance for manual and automated driving but also as its own means of vehicle operation. It can be acknowledged that not all potential human factors issues have been identified in this brief paper, but major known human factors concerns are covered.

Three major categories of remote support and control can be conceived. Table 1 provides some examples of each.

1. Remote assistance, e.g. by a service provider to provide support and breakdown assistance
2. Remote management, analogous to air traffic control, to allow a remote controller to assist when a vehicle requires authority to move or deviate from a prescribed path
3. Remote control, which could extend from limited path guidance (e.g. around road works) to full remote driving at low speed or even high speed

Many of the HF challenges can be transposed from the in-vehicle driving task. Thus, the remote operator would benefit from a well-designed human-machine interaction (HMI), a well-thought-out sequence for transitions of control — for both assuming and relinquishing control and potentially attention monitoring. Other challenges are, however, specific to the remote nature of the tasks. Those specific challenges are addressed here.

Road traffic presents a complex, ever-changing environment where safety should be the primary concern. The success of remote operation will, however, be affected by many inter-dependent factors specific to the remote nature of the tasks (Habibovic et al., 2020). For example, challenges related to situational awareness, hand-over, telepresence, change blindness and workload might, if not properly accounted for in the design of HMI, lead to risky situations as well as poor experience and work conditions for remote operators. Those specific challenges are highlighted and discussed in more detail here.

2. Management of the remote environment

Unlike some applications of teleoperation where each remote vehicle has one or more operators, a fleet of automated driving system (ADS) vehicles will likely require a method where each remote operator can manage many vehicles. Control of multiple remote vehicles or robots presents very different demands on operators than does control of a single vehicle (Chen et al., 2011; Lee, 2001). Military and search and rescue operations have worked to increase the number of systems a single operator can manage, sometimes termed “fan-out”. Fan-out (FO) depends on interaction time and neglect time (Goodrich and Olsen, 2003; Olsen and Goodrich, 2003). The interaction time (IT) is the time the remote operator must

[1] “Human Factors in International Regulations for Automated Driving Systems” (HF-IRADS) operates under the auspices of the International Ergonomics Association (IEA). It brings together human factors experts from across the world to support UNECE activities on the safety of automated driving systems.

spend interacting with the vehicle, and neglect time (NT) is the amount of time the vehicle can operate without attention from the remote operator, which combine to define fan-out (FO):

$$FO = (NT+IT)/IT$$

Although this equation seems to provide an easy way to calculate how many vehicles a remote operator can manage, the estimation of NT and IT is complex. For instance, interaction time depends on at least four factors: (1) vehicle monitoring and selection, (2) context switching, (3) problem solving, and (4) command expression (Olsen and Goodrich, 2003). Neglect time is equally challenging to quantify. With ADS failures, neglect time does not have a predefined duration or onset and so interaction time cannot be scheduled. Instead, it is a random variable. Further, neglect time of one vehicle is not independent of others—a thunderstorm might lead to many simultaneous ADS failures. The more system-paced, i. e. outside of the control of the operator, the monitoring requests are, the more they overlap in time for different vehicles, and the less they can be handled simultaneously by the operator, the fewer vehicles can be controlled by one operator without risking neglects. The consequence of neglecting a vehicle varies from simply adding a few minutes to a trip to potential additional crash risk for the passengers. Whether an operator can successfully intervene strongly depends on neglect time — whether an operator needs to respond in minutes to adjust a route or in seconds to avoid a collision. Although difficult to calculate, the fan-out equation provides a useful framework for understanding how human factors considerations combine with design choices to influence the safety and efficiency of remotely operated fleets.

Both human remote operators and automated driving systems have their own intelligence and capability to act, and it is part of the task of remote operators to manage the automation (especially in the context of switching between vehicles of different capabilities). An ADS may fail, but failure of basic vehicle safety systems, including technologies such as AEB or ESC, is also a potential problem. Part of the role of the remote operator is to be aware of the capabilities afforded by such systems, and remote operation will benefit from having procedures in place to deal with such failures.

From numerous studies in automotive and other domains it is known that insufficient *situational awareness* leads to failure. In the context of remote operation, limited situation awareness could occur due to reduced sense of the vehicle and detachment from the action (i.e. *lack of embodiment*). The remote operator has no bodily feeling of the vehicle and the view outside, and even if communicated via camera and similar sensors, the sensation might provide only limited understanding of the conditions. In addition to this, physical detachment from the vehicle might also lead to *decreased feeling of urgency*, which in some situations could have negative consequences on the entire operation. There are also potential ethical concerns induced by physical detachment from the vehicle and traffic situation. That is, remote operators could *lack empathy and sensitivity* towards their surroundings, especially seen from the perspective of passengers of the vehicles being remotely controlled.

While various sensors available in automated vehicles might be able to "enrich" information provided to a remote operator as compared to an on-board driver, there is risk of *information overload* (which might be amplified due to the plurality of vehicles). In other words, replacing the bodily feel of the vehicle with sensor information could come with the trade-off of information overload, and remote operators could be exposed to too much information with the result that they would no longer have the capability to understand the situation. A related challenge is *change blindness* or failure to detect relatively large changes in visual scenes. For example, if remote operators are overloaded with information, or if they are engaged in continuous monitoring, they might fail to notice important changes in the scene.

In other domains, *boredom* of remote operators has been commonly reported. Also, it is natural to expect that *inattention* and *distraction* might occur as well. Depending on the design of workstation and the tasks of the remote operator, *motion sickness* might occur (similar to the motion sickness in driving simulators). To this end, it can also be added that there might be a need to monitor the remote operator. In a control room there is also the potential to move around more freely, so that the operator might not even be physically at the workstation when a call comes in. System design may benefit from asking questions such as: how to gain operator attention, how to allocate jobs to operators, how to ensure the operators are attentive.

Transfer of control (hand-overs/hand-offs) between the system and operator, as well as between operators at break times and at the end of shifts, is also a critical phase where risk of failure is increased, and therefore changing operators may benefit from planned and careful execution. In particular, evaluation of the process of hand-overs and collaboration between remote operators and "local" operators (i.e. those inside or in the vicinity of vehicle) may provide the most benefit.

On a general level, the question arises of whether an adequate, or optimal, remote driving station is a replica of the driver environment of vehicles of today or "something else". It might well be that a remote driver station and its HMI contain more and other functionality than is available to a driver of today. Best practice in operation centres is applied by analysing workflows of the real task and designing the remote operation centre around the workflows and the human operator. In other words, applying a user centred design focusing on factor such as *optimum seating distance, information presentation, task simplification, noise and light optimization*.

3. Training and personnel

The remote personnel are, by definition, professionals and therefore may be expected to have received specific, targeted training. Where they are able to remotely drive a vehicle, they might have to hold the appropriate driving licence for that vehicle category. As with other types of safety critical shift work, the organization and its employees can benefit from health checks, e.g. for sleep apnoea, especially when they may be operating a public service vehicle.

Depending on the nature of the remote support, remote personnel may need to be familiar with the prevailing traffic rules for the roads on which the vehicles are operating. There could be a case for handover from one controller to another at national, regional or state/province borders.

Propensity of remote drivers to motion sickness is a concern. Already in 1949, Birren warned of the negative performance effects of motion sickness. This has been particularly studied in the naval context (e.g. Bos and Bles, 2000; Colwell, 2002).

4. Controls and displays

Operator performance is best supported when controls and displays are aligned with the specific duties of the remote operator. The requirements for controls and displays might be very different when a remote operator only needs to verbally assist a person inside a vehicle with some simple advice that is not safety-related versus a situation when a remote operator is controlling a vehicle at high speed.

When thinking about the physical controls that a remote operator may have, options could include traditional vehicle controls such as a steering wheel, brake and accelerator pedal, as compared to a joystick or head-slaved controls. Joystick operation is already a feature for (local not remote) safety driver control in certain shuttle vehicles, but this is limited to very low-speed operation. Vehicle motion control is much more of a challenge in high-speed driving. For more limited vehicle control, buttons or a kill switch may be sufficient.

Currently, much literature is focussing on remote control of robots, for instance for search and rescue, tele-surgery, advice from a distance etc. Although this has hardly been studied in driving, the sense of telepresence is very important when an operator is physically separated from the vehicle. Based on experience from those domains, it seems reasonable that extending the visual feedback with force feedback in driving controls could be able to improve performance, since it may help the remote operator to better perceive the information from the remote environment and its constraints, hopefully contributing to the prevention of dangerous collisions. In their study on a control joystick to avoid collisions with airborne vehicles, Alaimo et al. (2011) showed that adding haptic cues to provide a sense of urgency of the impending collision (actually offering support) helped improve performance. The type of haptic feedback (direct or indirect) also affected performance.

An important question also remains whether a remote operator should always be able to fully control the vehicle and initiate any action, or whether the driving automation system supporting that vehicle should protect the operator from error by prohibiting specific control actions or asking for a confirmation ("Are you really sure you want to…?").

From studies of operator performance in driving simulators, it is well known that, in addition to haptic feedback, the provision of motion feedback greatly assists vehicle control, particularly in deceleration and curve driving (Carsten and Jamson, 2011).

The display element of the HMI for remote operators plays a crucial role. This is because, unlike with direct vehicle-based HMI, the operator has only indirect access to the in-cab or driving environment, and is therefore much more reliant on the visual medium for information acquisition, interaction, feedback and control.

It may be useful to categorize two types of display in this context, one set showing the operator what is going on in and around the vehicle, and another set to be used by the operator to interact with the vehicle when the automated system requests assistance. However, to ensure that operators achieve acceptable performance, the interfaces should not overwhelm the operator with too many devices (e.g. displays and controls) that simultaneously request a high level of cognitive and motor skills.

Van Erp and Padmos (2003) studied the effects of indirect viewing on driving performance. They identified the critical image parameters of such systems on vehicle control, both in simulated and in real world driving. Important parameters were magnification factor and field of view. In addition, image resolution was important, with low resolution leading to overestimation of distances and reduced quality of lateral control. A literature overview by Van Bakker et al. (2000) in the military domain showed that restriction of peripheral vision (i.e. smaller field of view) can degrade control of vehicle path, speed estimation, and time to contact estimates. Degraded foveal vision (contrast and resolution) can affect lane keeping and object detection.

Thus the following aspects of display provision all need to be considered:

- Resolution (pixel density)
- Field of view and provision of mirrors
- The possible need for stereo vision to provide depth sense, thus helping to judge the positions of targets and possible obstacles in the remote environment
- Contrast and brightness

To reduce communication load, it may be possible to create a synthetic or semi-synthetic view of the remote scene, for example through a combination of HD maps and augmented reality. Virtual reality may have a role here.

Remote operator eyepoint will affect speed perception and the possibility of detecting vulnerable road users. Eyepoint height differs from one vehicle to another, and operators may need to adapt to this as they shift from controlling one vehicle to control of another.

Multiple displays, as with a "driver" view, an external birds-eye view of the scene, and a screen showing vehicle system status, may create new demands on the operator and task-switching requirements. Which screen is to be prioritised? Modality of information to and support for the operator needs to be carefully considered. Operator workload could be very high, leading to a need for more rest periods or shorter shifts.

5. Communications channels

Reliable and appropriate communications are an essential element in any remote support for vehicles equipped with automated driving systems. Poor communications may compromise task performance, even if the remote operation is conducted by experts. The remote worker in the control centre benefits from communications in appropriate modalities. For remote assistance, auditory communication might be sufficient with relatively low demand on bandwidth. But moving to the higher levels of remote support (categories 2 and 3) places greater demands on communications. For category 2, video linkage will likely be required, most likely between the AV's camera and the remote controller. There will also be a need to pass vehicle diagnostic information to the remote workstation. Very low latency may not be a requirement, but assurance of robust communications is likely to be important to support human performance.

With remote operation, the situation becomes far more demanding. There will probably be a need for a high-resolution video and audio feed from the vehicle, possibly in stereo (see section 4). The greater the pixel resolution and the greater the field of view required, the more the demand on bandwidth. Lags and judders in communication also become critical. If there is a one second delay in a remote operator receiving the remote scene and further half second delay in the transmission of a control command to the subject vehicle that would add 1.5 seconds to the normal one-second reaction time of a driver to an event, which in many situations would incur a major increase in risk. Control of the vehicle would also become erratic. Many studies (e.g. Sheridan and Ferrel, 1963; Lane et al., 2002) have shown that fixed time lag can be a problem for remote operation, but Davis et al. (2010) found that variability in lag was even more of a challenge to good performance in remote operation than lag itself. This indicates that *consistency* of transmission could be a basic requirement.

Reaction time is linked to, and often enhanced by, operator expectations. If a remote operator is working in a denuded environment, without perception of the traffic and roadway ahead, then that operator will not be primed by the circumstances to react fast, and will likely have a delayed response.

6. Passenger needs and requirements

Confidence and trust in these systems is important for their adoption. Users (passengers, drivers) may be comforted by the idea of remote human support yet not be accepting (or be afraid) of remote human operation. Visual (and possibly auditory) monitoring inside and outside the vehicle may be necessary to support remote operation, but such constant personal monitoring raises issues of surveillance and privacy and these data must be handled appropriately. Some remote operation solutions may be acceptable while others may not and this may vary by user group.

Passenger needs will differ depending on the type of ADS and the form of remote interaction and support that is provided. When a driver is in the vehicle, a remote operator may be engaged for a brief duration to resolve a specific situation or for a longer period as required. The remote operator may assume full control of the vehicle or only partial control with the driver's permission. In all instances an effective HMI and protocol supports safe operation by supporting the communication and interaction between the driver and the remote operator.

The needs and expectations of passengers riding in fully automated buses and shuttles need to be met when there is no operator/driver on board. Although automation will perform the driving task, it may not perform some of many additional functions usually performed by on-board human drivers (e.g. Salmon, Young and Regan, 2011). Remote operators may become responsible for these functions.

As an example, prior to closing the door, it is important to confirm that all waiting passengers have boarded. Before moving the vehicle, passengers should be safely seated or in an appropriate standing position.

Some passengers may require assistance, others may attempt to board beyond the vehicle load limit, an unruly passenger behaviour may require intervention, or cargo may come loose and present a safety risk, just to name a few possibilities.

Medical emergencies and crashes pose the most serious safety concerns. These are time-critical and require accurate perception, comprehension, an effective response and action. They require stopping and securing the vehicle, attending the injured, coordinating passenger emergency exit and on-board communication with dispatch and emergency crew. These are complex coordinated actions that may require the coordination of multiple remote operators.

Passengers need solutions to communicate and initiate emergency stops as well as regular stop requests (Automated Vehicle Safety Consortium, 2020). Unexpected events such as ADS-initiated trip interruptions will need to be properly communicated to avoid passenger confusion. HMI solutions are needed between passengers and remote operators to support communication and interaction for both typical daily and emergency operations.

7. Service design

The human factor challenge varies depending on the service design. Definition of the Operational Design Domain (ODD) for a service determines complexity of interaction of the service vehicle with other road users. When the service is established within an isolated dedicated track, the interaction is restricted to that with other service vehicles and the human factor challenge is minimised. On the other hand, when the service is established in a mixed traffic environment, the interaction can be with other cars, bicycles, and pedestrians. This can generate complicated situations where the remote operator needs to intervene. When the service is designed to slow down or stop the vehicle after notifying the remote operator to intervene, the remote operator is given more time to handle the situation than if taking over a running vehicle. When the number of service vehicles for one remote operator increases, the human factor challenge becomes larger, because management of operator's attention among the vehicles becomes more complicated. There are other service design factors that influence human factor challenges.

8. Conclusions

Remote control and operation is complex. It should not be assumed that remote handling constitutes a viable backup for problems encountered by vehicles under the control of an ADS, or that remotely controlled driving of a vehicle is feasible in busy environments or on high-speed roads.

Thorough investigation of different use cases is needed. A safety case should be prepared for each specific application of remote support and control. Low speed remote operation may be easier in simple vehicle control terms than high-speed operation, but it should be remembered that low-speed environments tend to be the busiest, and that, in interactions in urban traffic, accurate perception of the surroundings and very fast reactions are typically needed. Currently, there is a lack of evidence that remote vehicle operation on public roads can be performed safely.

The proper design of the work environment for remote control and operation is also important. For management, lessons can be learned from air traffic control; for control, the driving environment imposes demands beyond those encountered in other transport modes.

9. Implications for UNECE WP.1 and WP.29

Both WP.1 and WP.29 have adopted principles and guidance on road vehicle automation. The WP.1 *Resolution on the Deployment of Highly and Fully Automated Vehicles in Road Traffic*, adopted in September 2018, states that an *Automated Driving System* "refers to a vehicle system that uses both hardware and software to exercise dynamic control of a vehicle on a sustained basis." The resolution states that Automated Driving Systems should make road safety a priority, monitor and safely interact and tolerate road user errors with surrounding traffic. It further states of the term *Highly automated vehicle* that: "[It] refers to a vehicle equipped with an automated driving system. This automated driving system operates within a specific operational design domain for some or all of the journey, without the need for human intervention as a fall-back to ensure road safety." No mention is made of any possible assistance from or fallback to a remote centre. In a new version of this text, there should be consideration of the possibility of remote support, and thus the definition of an Automated Driving System may need to be expanded so as to encompass any required remote support.

The WP.29 *Revised Framework document on automated/autonomous vehicles*, adopted in 2020, states that "an automated/autonomous vehicle shall not cause any non-tolerable risk" and then lays out a number of key issue and principles that need to be addressed as priority items by the subsidiary bodies of the Working Party. A definition of "automated/autonomous vehicles" is not provided, but there is no mention of remote support as means of assistance, and remote support is not listed in the priority items. It is therefore suggested that a whole system approach be adopted in GRVA and its sub-groups and that remote support be added to the list of priority issues to be addressed.

HF-IRADS will continue to examine the issues discussed here, monitor relevant research activities and support the UNECE in its efforts.

References

Alaimo, S., Pollini, L. and Bulthoff, H. (2011). Admittance-based bilateral teleoperation with time delay for an unmanned aerial vehicle involved in an obstacle avoidance task. AIAA Modelling and Simulation Technologies Conference, Portland, Oregon.

Automated Vehicle Safety Consortium (2020). AVSC Best Practice for Passenger-Initiated Emergency Trip Interruption. AVSC00003202006. June 2020. https://avsc.sae-itc.org/principles-03-5471WV-44491AM.html.

Birren, J.E. (1949). Motion sickness: Its psychological aspects. In: Human Factors in Undersea Warfare. National Research Council, Washington, D.C.

Bos, J.E. and Bles, W. (2000). Performance and sickness at sea. RINA Conference Proceedings, Human Factors in Ship Design and Operation, 27-29 September 2000, London.

Carsten, O. and Jamson, A.H. (2011). Driving simulators as research tools in traffic psychology. In: B.E. Porter (ed.), Handbook of Traffic Psychology, pp. 87-96. London: Academic Press.

Chen, J.Y.C., Barnes, M.J. and Harper-Sciarini, K. (2011). Supervisory control of multiple robots: human-performance issues and user-interface design. IEEE Transactions on Systems, MAN, and Cybernetics Part C: Applications and Reviews, 41: 435-453.

Colwell, J.L. (2000). NATO Questionnaire: correlation between ship motions, fatigue, seasickness and naval task performance. RINA Conference Proceedings, Human Factors in Ship Design and Operation, 27-29 September 2000, London.

Davis, J., Smyth, C. and McDowell, K. (2010). The effects of time lag on driving performance and a possible mitigation. IEEE Transactions on Robotics 26(3): 590-593.

Olsen, D.R. and Goodrich, M.A. (2003). Seven principles of efficient human robot interaction. IEEE International Conference on Systems, Man and Cybernetics.

Habibovic, A., Andersson, J., Castor, M., Meiby, L. and Rizgary, D. (2020). Human Factors of Remote Control. SAFER prestudy report.

Lane, J., Carignan, C., Sullivan, B., Akin, D., Hunt, T. and Cohen, R. (2002). Effects of time delay on telerobotic control of neutral buoyancy vehicles. Proceedings of the IEEE International Conference on Robotics and Automation, 2874-2879.

Lee, J.D. (2001). Emerging challenges in cognitive ergonomics: managing swarms of self-organizing agent-based automation. Theoretical Issues in Ergonomics Science, 2:(3): 238-250.

Olsen, D.R. and Goodrich, M.A. (2003). Metrics for evaluating human-robot interactions. PerMIS: Proceedings of the Workshop on Performance Metrics for Intelligent Systems.

Salmon, P.M., Young, K.L. and Regan, M.A. (2011). Distraction 'on the buses': A novel framework of ergonomics methods for identifying sources and effects of bus driver distraction. Applied Ergonomics, 42: 602-630.

Sheridan, T.B. and Ferrel, W. (1963). Remote manipulative control with transmission delay. IEEE Transactions on Human Factors in Electronics, 4(1): 25-29.

Van Bakker, N.H., Erp, J.B.F. and van Winsum, W. (2000). Driving with head-slaved camera systems: a literature survey. Report TNO-TM-00-A041. TNO Human Factors Research Institute, Soesterberg, The Netherlands.

Van Erp, J.B.F. and Padmos, P. (2003). Image parameters for driving with indirect viewing systems. Ergonomics, 46(15): 1471–1499.

Table 1: Examples of types of remote support

	Remote Operation Functions (Remote Human)	Examples
Remote Assistance	○ Provide information (e.g. passenger inquiry), support and assistance (service provider) ○ On-board monitoring (visual and auditory?)	○ Information requests, breakdown assistance (tow Truck) (e.g. On-Star) ○ Stop request, emergency request, ACN communications ○ Monitoring for safety and security (e.g. on a shuttle)
Remote Management	○ Assistance for hazard detection; scan environment ○ Authority to resume movement (or stop, partial or full control ○ Authority to deviate from fixed path ○ Limited path guidance in special situations ○ Provides perception/detection; has some authority to resume movement; based on human perception, intervention and action	○ Hazards in roadway that are unexpected such as uneven road, new construction, roadway blockage….
Remote Operation	○ Temporary or full control (DDT) under normal, unexpected or emergency conditions ○ Full remote driving – slow speed ○ Full remote driving – high speed	○ Dealing with failure modes, MRM ○ Intervening and guiding shuttles on a path or road at low or high speeds