How Well Do Drivers Adapt to Remote Operation? Learning from Remote Drivers with On-Road Experience

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***Abstract*— Remote driving is a promising strategy for helping Autonomous Vehicles (AVs) navigate many environments where edge cases may otherwise limit their abilities. For some companies, remote driving is an alternative to AVs altogether. Much remote driving research has taken place in simulated or controlled environments with novice operators, leaving the needs of operators with real-world experience under-explored. This research aims to understand if experienced operators are satisfied with current production remote driving systems, if they adapt to the difference in control, and how their job satisfaction compares to in-vehicle safety driving. This paper briefly overviews recent remote driving research and presents results from a questionnaire and a semi-structured interview with experienced teleoperators. The findings indicate that operators do adjust to the new domain, but latency and network reliability remain a challenge. Likewise, standardised training practices for operators are found to be lacking.**

***Index Terms*— Teleoperation, Remote operation, Remote driving, Human computer interaction**

I. Introduction

Autonomous vehicles (AVs) have faced hurdles that leave them insufficient in many driving scenarios and have usually required a safety driver to ride along with the vehicle. In public transportation services, such as taxis and buses, this limitation becomes apparent. An operator still needs to ride in each vehicle and monitor the system. To solve this, the idea has emerged of driving the vehicle over cellular networks in a process often called *teleoperation*, *remote operation*, or *remote driving* [1]. In this concept, the driver sits at a workstation often miles from the vehicle and may completely drive the vehicle or might only direct a vehicle once it asks for assistance.

Fatigue and job satisfaction concerns are prevalent in taxi, ride-sharing, bus, and heavy goods vehicle (HGV) operation [2], [3]. With any major shift in working style, the job satisfaction of employees must be considered to support this shift. Remote driving research has been mostly limited to simulations or novice operators, meaning research with experienced drivers who may have a different perspective on the task is lacking. To this end, this research aims to better explore the human factors challenges of real-world remote driving, prompting the following four research questions:

- After an adaptation phase, what anticipated challenges are still faced by remote operators?
- After an adaptation phase, what challenges and difficult situations emerge for remote operators?
- What are current training practices for remote drivers and what training is needed?
- What psychological safety needs do remote operators have?

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II. Related Works

A. Inception and Evaluation of Teleoperation

Robotic remote operation has been extensively investigated in hazardous environments such as nuclear cleanup [4], outer space [5], and bomb disposal [6]. However, remote vehicle operation on public roads differs from those domains for several reasons, mainly higher speed/reduced reaction times, the presence of other road users and pedestrians, and passengers potentially in the vehicle. These factors contribute to on-road remote operation having a high Level of Interaction (LOI) [7] caused by a low level of automation, high operation speed, and a relatively high task difficulty.

One work provides an extensive framework for evaluating general teleoperation interfaces [8], and other works have evaluated ergonomics, comfort, and emotions of teleoperation interfaces in other domains [9], [10], [11], [12]. Robotic teleoperation has been evaluated through gaze distraction, situation awareness, user workload, user experience, system usability, and level of telepresence [13], [14], [15], [16], [17], [18], [19], [20], [21]. From a results-driven perspective, one can evaluate teleoperation through task success rate, completion time, and number of states completed during the task [22], [23]. Remote driving performance can be measured using lane offset, task completion time, vehicle following distance, variation in following distance, emergency events reaction times, and speed variation [24], [25].

B. Teleoperation Network Technologies and Challenges

Extensive research has focused on improving the underlying networks of teleoperation and smoothing packet delivery [26], [27], [28]. Cellular networks often have latencies which are possible to smoothly operate on [29], [30], but total latency above 150 ms can create a sharp increase in workload [24]. At least 50 Mbps bandwidth has been proposed as a requirement for transmitting video data [31]. Latency variation can contribute the most to high workload, increase task completion time, and decrease lane-keeping accuracy [20], [21], [25], [17], [7].

Various prototype systems have been developed in research settings to mitigate the feeling of latency [32], [33], including predictive displays and delay compensation methods [34], [25], [17]. A similar "frame prediction" display method has been shown to lower workload and improve performance and controllability by reducing mental demand, temporal demand, effort, and vehicle lane offset [18]. However, these methods do not seem to be used in practise by most companies which motivates the need to study how experienced drivers feel about their current systems.

C. Expert Insights on Remote Driving

One prior work conducted a closed-course remote driving session with industry experts and found 6 categories of challenges: lack of physical sensing, human cognition and perception, video and communication quality, remote interaction with humans, impaired visibility, and lack of sounds [1]. The study then developed a prototype remote operation interface to address these concerns. A report from the UK Law Commission finds no express legal requirement for a driver to be inside the vehicle on UK roads [35]. The report also suggested that remote drivers should only be located within the country of the vehicle they are driving and recommends that drivers be given specific training to deal with teleoperation challenges. Regular health checks and frequent breaks are also recommended. Safety challenges include loss of connectivity, stringent network requirements, risk of remote driving failures, lack of situational awareness for drivers, and deprivation of force feedback and acceleration. The report warns of detachment and loss of concern for the physicality of actions. It is recommended that the remote operation centres have their own proper safety in case of distractions, fires, or intruders.

III. Methodologies

To better understand real-world remote operation challenges, we recruited participants whose primary job title was remote driving. All operators had completed their company's training and had real-world experience. Participants were not compensated for their responses, and all participants and their companies were kept anonymous.

A. Questionnaire

Participants first completed a questionnaire about general factors of remote driving containing a quantitative section and a qualitative short-answer section. We recruited participants through online methods including Google, LinkedIn, and Twitter searches. In total, we reached out to 35 participants from 8 companies and 1 university and received 16 completed responses. Participant responses came from 5 companies and ranged between the ages of 28 and 47. 81% of participants were male (13) and 19% were female (3). Countries of remote operation included Germany (10), the USA (8), the UK (3), and Sweden (1). As the numbers indicate, some participants operate in multiple countries. Eight participants had bachelor's degrees, 3 had a master's degree, 1 had a PhD, 1 had a high school diploma, and 3 had vocational training or some college education. Drivers had held licenses for a mean of 14.6 years (SD = 7.0, min = 3, max = 29). All participants operated passenger vehicles except one participant who operated HGVs.

B. Semi-Structured Interviews

The second research phase consisted of semi-structured interviews with remote operators to explore topics that emerged from the questionnaire. We conducted 4 interviews (3 male, 1 female) across 3 companies. Interviews lasted around thirty minutes and audio from interviews was recorded with a smartphone and transcribed using Microsoft Office. Data was handled in accordance with the University of Oxford central privacy and ethics approval.

IV. Results

A. Questionnaire Results

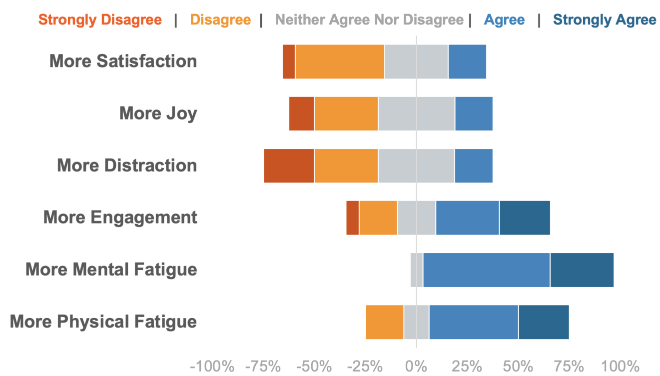

Fig. 1. Percentage agreement with statements about remote driving factors compared to in-vehicle safety driving.

1) Stress: Compared to in-vehicle driving, 69% of participants stated that remote driving was more stressful, and no participant stated that it was less stressful. Several participants reported that they simply felt more aware. Commonly mentioned stressors are reported in Fig 2. Some other mentioned stressors were restricted field of vision, motion sickness and fatigue, poor weather conditions, sensor malfunction, distance/speed perception, unexpected traffic situations, vehicle agility, and decreased spatial awareness. Stress included worries that an accident may have a large negative effect on the company and the entire industry.

2) Adaptation and Immersion: Some drivers felt they adapted to latency after 1-2 drives while others felt they adapted after 6 to 8 weeks or a couple of months. One driver estimated it took about 500 kilometres. These estimations highlight the subjectivity of what drivers feel means to be adapted to the task. One driver mentioned that although immersion was lower compared to in-vehicle driving, concentration was higher perhaps because concentration takes over when immersion is harder to achieve. When asked what could improve immersion, participants most commonly reported additional peripheral views, haptic feedback, more audible feedback, and decreased work environment ambience. Drivers mentioned that immersion occurred after a period of time ranging from a few minutes up to 60 minutes.

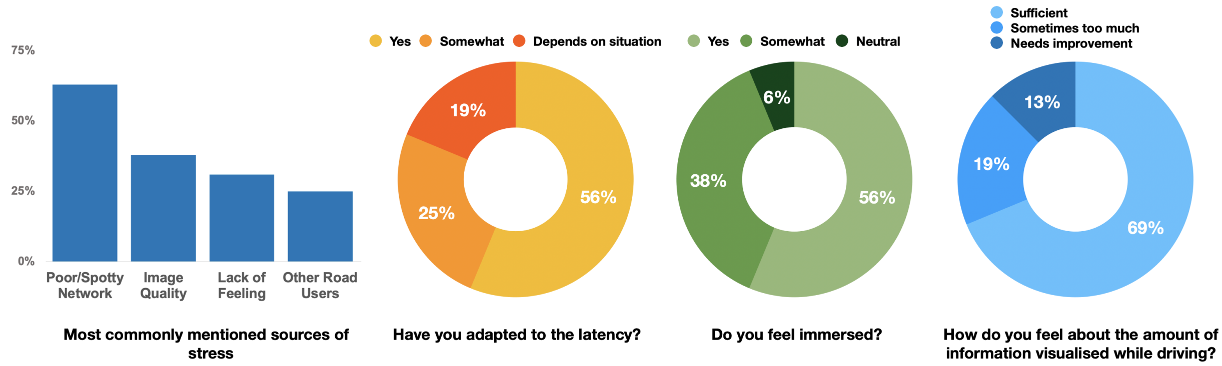

Fig. 2. Driver responses to sources of stress, adaptation to latency, immersion, and visualisations.

3) Work Hours, Breaks, and Environment: When asked about breaks, 69% stated that breaks usually lasted 10 to 15 minutes, once per hour. Drivers felt encouraged to take breaks whenever needed and that frequency will vary by person. 63% percent of drivers reported that they worked 6 to 8 hours a day, while one driver reported they sometimes worked up to 10 hours. Not all of this time is spent driving on public roads, with many of the longer days involving training or testing new technology in closed environments. The majority of participants stated that they never drove for more than 2 hours at a time, with 1-hour sessions being preferable. Sometimes experienced drivers could have longer sessions lasting up to 5 hours. Driving session lengths are generally much shorter on public roads due to higher workload. Participants reported a good sense of community within their companies and felt that they had an impact on system designs by working closely with engineers. Drivers also felt they were drawn together by the difficulty of the job, further increasing a sense of community.

4) Job Perception and Public Interactions: Drivers were asked about the public perceptions of their job and interactions with pedestrians and any passengers (if applicable). The most commonly reported perception was unawareness of the technology. Once aware, people were mainly curious, fascinated, excited, or interested. Some people would wander up to the car and pose with it. A couple of participants mentioned rare instances where pedestrians would act irrationally around the vehicle. Some rare negative emotions from the public were disbelief, distrust, confusion, worry, and scepticism. One driver stated that the general public seemed to have more trust in remote driving than AVs, but still less trust than conventional driving. Drivers reported that traditional signalling methods to other road users (such as turn signals, hazard lights, or high beams) worked sufficiently well.

5) Safety and Maintenance: Drivers reported that any near-miss situation would be logged and there would be a debrief. Safety procedures were routinely reviewed and updated, with driver input. In case of an accident, drivers had a team that would be called to the scene in addition to local emergency services. Drivers had a daily pre-flight checklist of the vehicle and the teleoperation station. Driver overrides, communication channels, sensor feeds, and safety-critical system responses were all checked. The drivers had regular experience sharing sessions and training practice.

B. Interview Results

1) Stress and Workload: One driver was able to roughly quantify remote driving workload, estimating that there was a factor of 10 compared to in-vehicle safety driving, i.e. that 100 kilometres of remote driving at 25 km/h in a dense, complex environment felt like driving 1000 kilometres at 250 km/h. While this is simply one driver's estimation, it demonstrates how much drivers can feel that their concentration needs to be substantially higher. Time to react in remote driving is similar to the lower time to react when driving in-vehicle at high speed. Reported stressful situations for experienced drivers included poor intersection visibility, illegal manoeuvres of other vehicles, quick cyclist lane changes, pedestrians emerging from between parked cars, erratic behaviours of cyclists and pedestrians, and interactions with animals. Nevertheless, drivers felt that their current views and alerts were sufficient for detecting these situations. One driver stated that stressful situations, ”aren't really different than when you're a normal driver, but your reaction times are slowed so that can make them difficult.” One driver discussed how the interpretation of their legal responsibility in the country of operation affects their stress. They stated, ”If it was a technical failure at that moment, if I was to teledrive in the States doing 20 miles an hour... if something [technical component] fails and I am to run someone over, I'll be the one going to jail. In the EU you have different legislation.”

2) Network: Although vehicle emergency manoeuvring systems can handle a complete network loss event, the driver could still feel ”completely disempowered” and anxious until communication resumes. One driver reported that having a secondary telephone link to transmit audio is helpful in a cellular data loss scenario to communicate with passengers or law enforcement officers. Likewise, poor network conditions can lead to video compression that makes it more difficult to discern the environment and increases strain.

3) Training and Safety Procedures: There are currently no standardised processes for remote operator training, and procedures are not shared among companies. One operator reported that it took 6-8 weeks of training to feel completely comfortable with remote operation. One driver reported that it was "really up to 6 months until your brain is fully re-programmed." Adjustment to the task took long because depth perception is altered and speed estimation is difficult because of the modified field of view and lack of g-force. Drivers reported that daily driving was essential for maintaining skill, especially in the beginning but also as an expert. As for training structure, drivers mentioned that evasive manoeuvres and reaction time tests are important which can be measured with a safety driver in-vehicle. Remote operators should train communication protocols with any in-vehicle safety driver to ensure clear, succinct communication in safety-critical moments. Drivers felt that local knowledge of the streets was essential to help them focus on the driving task and prepare for hazardous areas that might include increased road user presence, spotty network connections, or difficult intersections. The interviews highlighted that the training must include psychological aspects. One driver stated, "...it's really really important that you can drive and also can handle pressure and stress situations." Currently, it seems that remote driving training largely lacks psychological training both in the form of improving mental fortitude and in screening out those who may be at high risk for developing adverse psychological reactions.

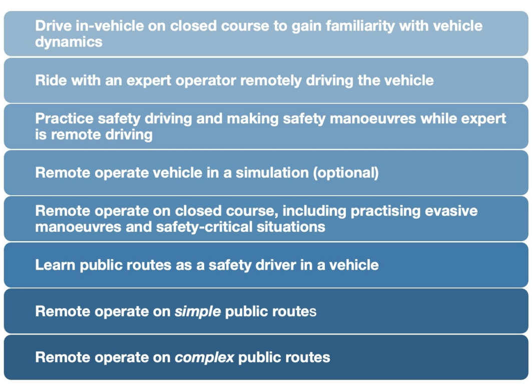

Fig. 3. Recommended stages of remote driver training

4) Visualisations and Interfaces: A centrally-placed camera felt natural and provided good viewing angles. Camera views were generally simple, with camera views in similar positions on the screen to where mirrors would be in a car. Lens distortion with wide angle cameras can be problematic and cause a greater cognitive burden. One driver stated that it would be better to have multiple cameras with narrow fields of view stitched together but this could increase installation, maintenance, and compute cost. Drivers reported there are some situations where the views are even better than conventional driving, requiring less head movement to see around the vehicle. However, there were also situations where not being able to move one's visual perspective makes the task difficult. For instance, drivers reported that T-intersections could be difficult. One driver felt that augmented reality visualisations should be a top priority for remote driving developers. Solutions like object detection could help mitigate camera distortion issues, and overlays could help visualise expected acceleration and braking. HGV operators preferred having some form of alert if the vehicle started to roll, which can be difficult to perceive over a camera stream. Drivers were conflicted about the use of audio. Three drivers found audio useful, stating it "...gives you more safety, and you feel you can control the car better." Drivers still report that all information coming through the visual channel inherently makes the driving task more difficult. Drivers still miss the feeling of acceleration and force feedback through the steering wheel.

5) Work Hours, Environment, and Breaks: Remote driving offers a safer and more comfortable work environment. Breaks are more flexible as another driver could take over the vehicle, removing the need to find a place to park. They expressed that women felt safer remote driving because they were not exposed to threats that a passenger or other people in the environment can pose. However, being in an office can bring its own challenges, particularly distraction. If a nearby driver goes on break, that driver must ensure that they are not distracting others. The office must be arranged so that the sun does not shine in the operators' eyes or cause glare on screens. Concerning the risk of feeling disengaged, one driver stated, "We don't have that sensation. Ever." Other drivers echoed this statement.

Building on the driving session length questionnaire results (max 2 hours, 1 hour ideal), drivers stated that long or especially stressful sessions can cause headaches, eye strain, back pain, stiff neck and shoulders, poor circulation in the legs, and altered perception. One driver stated that there is immense eye strain when trying to make out small objects (even with high resolution) because everything is 2-dimensional. Drivers reported that fatigue was clearly higher than when driving in-vehicle. This fatigue seemed to reduce as drivers gain experience but remains high. One driver reported that they felt physically exhausted after a 6- or 7-hour day spent remote driving, even with breaks scattered throughout. One driver stated that there should be no more than three 2-hour sessions in a day. Drivers emphasised the importance of having a company culture of speaking up when feeling unwell. Attention tracking was mentioned as potentially useful for helping a driver recognise when they need a break. However, concern over feeling monitored could arise. It was proposed that companies should be legally required to keep track of their operator hours to ensure that operators are not overworked or encouraged to work long hours for extra pay. One driver stated that they couldn't imagine a situation where they would want to change drivers on the fly, as orienting oneself to the environment can take time.

6) Other Road Users: Drivers felt that they always drove more defensively than they would in-vehicle. Other cars are considered more stressful than pedestrians because other drivers are often aggressive. People often think remote driving vehicles are AVs. Unfortunately, one driver stated that a pedestrian had once assumed the vehicle was an AV and jumped in front of it just to see if it would stop, which it safely did. Other pedestrians did not notice the cars were unusual because remotely driven cars generally have small sensors. For this reason, drivers worried that other road users may think it is a runaway car and suggested that improving public recognition of the technology would reduce driver stress. Drivers reported positive interactions with law enforcement officers and that their defensive driving was appreciated. Streaming audio from the vehicle can aid with emergency vehicle detection, however, one driver mentioned that software-based detection could be worth researching.

7) Network Requirements: Current network conditions in major cities are sufficient for remote driving, and drivers are able to keep up with traffic speed. Normal operating speeds were under 35 miles per hour. On current networks, it is best for the vehicle to have a maximum speed which adjusts automatically based on real-time network conditions. One driver reported that they felt a 4G connection was not suitable for highway speeds. The issue of blackspots in 5G beamforming was mentioned, potentially necessitating a backup 4G link (or multiple) if the 5G connection drops.

8) Hardware Limitations: The need for certifiably safe hardware is one important theme that emerged. One driver mentioned, "You see a lot of marketing videos of people online using gaming equipment for the same task [teleoperation] which always scares...us a little bit." Hardware in the loop of the system needs to be functionally safe in line with ISO 26262 [36]. In addition to the maintenance mentioned previously, drivers reported that it was best to have error checks on the cameras and manual inspection of the camera lenses for debris. Drivers mentioned the trade-off between more vehicle sensors and increased operating costs due to routine maintenance and alignment. Companies must choose high-quality cameras which can rapidly change exposures when the vehicle enters bright or dark environments (e.g. entering/exiting a highway overpass).

V. Discussion

Our first research question asked about challenges still faced by remote drivers once they have gained real-world experience. Latency remains the largest challenge, and stress and fatigue remain high despite drivers feeling comfortable with operation (usually in 6-8 weeks). Concerning challenges that emerge for remote drivers, fear of communication loss is substantial. It is unclear if companies install a data recorder on workstations, but this could be useful for investigating near misses, accidents, or communication loss events. Self-imposed speed limits emerged as a necessity for the varying network conditions of a real-world environment compared to a test track. Workspaces should be free from distractions and have some sound isolation between drivers. Companies which solely use remote control should avoid frequent vehicle driver switching, as immersion takes some time. The UK Law Commission [35] and UNECE 2020 [31] have warned of feeling detached when driving remotely, however, our results suggest that the increased feeling of responsibility felt by drivers kept them hyper-aware. Drivers stated that they better managed this feeling over time, however the feeling did not go away.

Considering current training procedures, most training has relied on driver estimation of their own ability. Standardised procedures are needed to improve training efficiency and ensure a high safety standard for all companies. This could be a consortium of companies agreeing on practices or it could be enacted through regulation. Drivers echoed the desire for companies to share training for everyone's benefit.

Our final research question concerned the psychological safety of operators, and remote operation can provide a positive sense of community. Working hours and breaks are generally respected but standardisation of work hours is needed, and ideal break intervals should be studied empirically. Drivers reported comparable levels of joy when driving remotely. Nevertheless, higher workload and greater worry for passenger safety do raise concerns for long-term burnout and satisfaction. Drivers face an underlying fear of complete network failure, even in the presence of backup systems. Reported physical challenges such as stiff shoulders are common with in-vehicle safety driving, but nevertheless highlight the need for continued ergonomics research.

VI. Limitations and Future Work

All participants' jobs were remote control rather than remote supervision or remote assistance. These operators were chosen because remote control exhibits high workload, but remote supervisors and assistors may face unique difficulties. Another limitation is that the sample size of operators was small, simply due to the limited, but growing, size of the field. Most of the companies are young and naturally concerned about maintaining competitive advantage and positive reputation. Despite promising anonymity, some drivers were hesitant to partake in a study that could highlight negative factors of teleoperation. A final limitation is that our study had insufficient input from HGV drivers (one participant in the questionnaire and one in the interview). Future work could benefit from performing in situ remote driver experiments that collect both physiological and psychological responses to understand how fatigue and distraction change in the remote environment.

VII. Conclusions

Existing remote driving research has lacked insights from drivers with experience on public roads which are characterised by higher speeds, unpredictable roadway conditions, and interactions with road users. Our results indicate that drivers gradually adapt to teleoperation challenges with regular practice. However, some hurdles still remain to making the task feel natural. In general, drivers are often quite excited and satisfied with their work, feeling they are part of a future technology that prioritises a human in the loop. Remote operation offers new possibilities to improve transportation and logistic efficiencies. Nevertheless, if we are to support drivers as they enter this new field, there is still work to be done to ensure a safer experience, both physically and psychologically, for all stakeholders.

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