Human Factors in Cybersecurity Incident Response Training for Autonomous Vehicle Operators

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1. Introduction

Most of the IoT (Internet of Things) and cyber-physical systems (CPSs) failures happen when systems are running in an atypical way. Vehicles are already extremely reliable and trustworthy by nature. It is complex to distinguish at first sight what is expected from the system and what would be a highly risky anomalous path from this gold standard. What cybersecurity approaches then could be thought for the 1st response team of autonomous vehicles in case of a cheap brand jamming equipment hidden in a bag? And what kind of abnormalities within the sensor data (temperature, cameras, LiDAR, etc.) could be explored to raise awareness to the autonomous vehicle operator? The question for the role of 1st responders in this new environment is also something to be well thought and somehow innovative. Is it plan A for autonomous vehicles to autonomously stall operations and wait for a human 2nd responder? Or somehow keep running simply because trips (at the discussable cost of security)?

Autonomous vehicles (AVs) have the potential to greatly increase benefits (e.g. decrease in road accidents, less energy consumption) or pose great challenges (e.g. ethical questions, traffic jam, labor market disruption) to today's society. However, a great concern from a security perspective is that connected vehicles could be severely affected by hostile attacks, whether it is about privacy, control, or sabotage. The combination of which is called CAVSs cyber-attacks over Connected and Autonomous Vehicles.

1.1. Definition and Overview of Autonomous Vehicles

The term "autonomous vehicles" and its abbreviation, "AV," are broad umbrella terms that encompass a wide range of different vehicle operation alternatives up to the zero level, with the potential to increase road safety and improve the mobility and quality of life of people,

the transport efficiency, and the profitability of companies working in this field. Nowadays, self-driving cars are classified according to their driving automation, on a spectrum of 0 (no automation) to 5 (full automation). Due to this, it is considered that there is the possibility of having unsafe conditions in some operational design domains.

An autonomous vehicle, as the word itself implies, can navigate and travel from one point to a second one without the need for human intervention on the steering wheel. The extreme case is the one in which the vehicle moves freely, with all its passengers attending a particular activity, such as a movie or game. By doing so, a number of distracting activities, such as chatting with friends, eating, or texting while in the tunnel, are established without modifying the performance of the driver in the driving task. It should be mentioned that a fully autonomous vehicle is unlikely to be available soon, taking into consideration that self-driving cars will require mastering the complex driving skills that human beings acquire gradually after years of driving experience.

2. Human Factors in Cybersecurity Incident Response

Responders in the field benefit from knowing that multiple types of information are being collected and will be available to them when they need it. First, information should give the responders an understanding of what the vehicle is perceiving, including its surroundings and, if deploying machine learning to classify objects or scenarios, an explanation of that computation. Second, data that sheds light on the vehicle's deliberative processes will help the responder understand why the vehicle is doing what it is doing. Third, data that shed light on the internal status of the vehicle is critical for understanding how "fringe" parts of the vehicle may be affecting the current performance or potential vulnerabilities. It is one thing to be able to tell that an AV is having difficulty with an object or driving scenario, while entirely another to understand why the AV is having difficulty. The value of sensor information is coupled with the comprehensibility of this information by an operator (and mitigated by potential perception overloads).

In addition to developing the necessary technology to protect vehicles from cyber-attacks, we need to consider the human factors involved in how cybersecurity safeguards are monitored and how humans intervene, accept, and comprehend when a cybersecurity breach occurs. Table 2 presents some of the requirements for effective human factor involvement in cybersecurity training in the context of autonomous vehicles.

2.1. Cognitive Biases and Decision Making

When we regard autonomous vehicles in terms of cyber resilience, another subset of biases can have effects on decision making, such as optimizing scaling bias: we are solving one problem to the detriment of another. We have the ability, but the need for immediate reward overtakes. Because the thinking moves to the subconscious part of the human brain, concepts such as "the obedience effect" in the case of autonomy, "the technical judgment" paradigm or simply the information-accuracy trade-off come into play. We observe the behavior of the human operator being compelled to act.

Many cognitive biases affect human decision making in risk-averse areas. It is well documented that in stressful situations affecting the fight-or-flight part of the human brain, the decision-making functions of the human brain can become impaired. Some well-known cognitive biases that have implications for security incidents are the sunk costs fallacy: "because we have invested so much energy, time, or money into an action, we cannot jeopardize these costs"; normalcy bias, often linked to the ambiguity effect which makes us think the problem involves us less, especially in crisis; optimism bias, linked with the false consensus effect "our popularity shapes our feeling of fear during risky activities, and people tend to overestimate the world's agreement on their point of view", and the illusion of safety.

3. Training Methods and Techniques

- Teaching Training to Past Knowledge: One of these principles is "Teaching Points to Past Knowledge", that is, previous knowledge should be used for the learning process. Those who understand the previous knowledge can take in new information more efficiently and can make a logical connection between learning and previous knowledge. It is crucial to connect information to be learned to existing neural circuits in the brain to record learned information in different cranial lobes. This principle can be adapted to AV learning by either focusing on past driving abilities or by focusing on using previous trainings given in the organizations. In the first solution, both current knowledge about vehicles and vehicle adaption process will be grounded based on this past knowledge, and in the second solution, trained output will address both the standards used within the organization and will emphasize cybersecurity concerns related to those standards.

There are several principles in learning and teaching that must be followed when training individuals on a task. These principles can be adapted to train future vehicle operators on standards and threats related to autonomous vehicle systems.

3.1. Cybersecurity Incident Response Training Principles

3.1. Simulation-based Training

An event simulator called Cyber War Net was extended for the vehicle cybersecurity domain and integrated with a MOTCP spectrum analyzer and a vehicle data logger for such purpose. In addition, an incrementally complex simulator gradually easing the novice users was presented as a training tool for teaching the cybersecurity risk factors in a highly dynamic vehicle system affected by software vulnerabilities. In another work, a zero-impact and non-intrusive virtualization-based approach was used to design a simulation setup called RAVEN. This development required the integration of a vehicle message simulator and a high dynamic range and high-speed communications to replay the physical world's attached ECUs. The integration of virtualization capabilities allowed for hosting a physical machine and guest OS for real-time messages and virtual ECUs on a real controller, allowing the training of automotive engineers into the vehicle's cybersecurity realm.

According to the literature, simulation-based training in the cybersecurity domain is effective in imitating real-world incident response situations. The simulation-based approach brings the benefits of enabling the operators to repeatedly practice their incident response skills, which is essential to achieve performance improvement in suspected and actual cybersecurity events. The simulation-based approach also enables trainees to practice in a safe environment by mimicking incidents in a controlled and repeatable way. Such a controlled environment guarantees the safety of the trainees while ensuring that they are not causing any damage to the other working systems. The replication of real-world problems and the duplicated high security of the impacted systems/vehicles are the paramount advantages of simulation-based training.

4. Case Studies and Real-world Examples

This section provides an overview of examples where our guiding principles were deployed to develop training for a broad range of mission contexts. This is not an exhaustive list, as it would be impossible to catalogue all of our training interventions and examples of research

practice, nor do we intend to provide detailed case examples for every aspect of our approach. Rather, this section illustrates key concepts using multiple examples to show both the breadth and depth of our approach and understanding. The purpose is to impart the philosophy and principles that guide our research, as well as the iterative nature of the problem-solving processes in which we engage. The case examples illustrate the applicability of the HFCRIT principles across multiple diverse problem domains. Despite differences in specific characteristics associated with each case along our research trajectory, common threads inform our understanding about operator performance and the HFCRIT development process.

The previous sections provided guidance on how to design effective cybersecurity incident response training, including an overview of relevant human factors research, an approach to structured task analysis to identify training requirements, and techniques to represent unfamiliar task repertoires, including cognitive work analysis and macrocognitive modeling. In addition to our team's extensive experience in operator training for diverse domains, including law enforcement, emergency response, defense, and international peacekeeping, we have collaborated with colleagues across these domains to improve training design and delivery. This experience was invaluable when applying the HFCRIT approach to develop training for autonomous vehicle operators.

4.1. Incident Response in Autonomous Vehicle Cybersecurity

Autonomous vehicle (AV) cybersecurity includes a wide range of increasingly intriguing scenarios such as cyber-physical attacks (e.g., reckless driving, stop-and-go inducing traffic jam, etc.), privacy attacks (e.g., tracking someone's vehicle movements), and information attacks (e.g., obtaining sensitive information related to passengers). AVs offer a new context to apply and study the human factors. Incidents in AVs could have higher consequences compared to those occurring in manned vehicle scenarios. Understanding that vehicles act without human intervention, which may prevent their presence and actions, such incident response should be part of the AV's cybersecurity approaches. Contextual information results from research can be used as a guideline to assist the development of cybersecurity incident response procedures and human factors designs, helping AV operators to deal with AV incidents. The knowledge extracted from the studies could provide a baseline to prepare operators to take proper actions in the event of AV incidents that occur with a small number of vehicles compared to manned vehicles.

5. Future Trends and Recommendations

Vast and efficient incident response performed in a sequence of planned steps is required for training autonomous vehicle operators in the proper reactions and responses that mitigate the potential severity of accidents or operational incidents, decreasing damage or charges of life. Incident response sequence and steps we are considering and basic competencies are preliminarily classified and mapped to job competencies from the national occupational skill standards or occupational requirements of the various countries. These job competencies do not specifically represent the qualifications for autonomous vehicle operators since the standards are not mature when conducting the research. However, they do provide a starting point for developing the autonomous vehicle operator incident response competencies. Moreover, we are working with authoritative organizations in the autonomous vehicle industry to develop a more accurate, current set of qualifications, competencies, and tasks required in the future.

Informed by the results of the exploratory study, the ultimate goal of the research program is to generate knowledge in human factors and conduct applied research to support addressing the training of autonomous vehicle operators at a practical, tactical, and contingency level. Training materials that are delivered with the integration of human factors principles and the results from this research study should be especially helpful in improving autonomous vehicle operator incident response performance, making advanced training more effective in real-world incidents that autonomous vehicles face. To achieve the goal, this research program is proposed and divided into several stages of research and a series of studies. According to the exploratory results, this research program applies the proposed research framework to study the knowledge in human factors and propose the training design with the full considerations of human factors.

5.1. Integration of Artificial Intelligence

The literature also provides evidence that AV operators need to be trained in AI for the purpose of incident response. In the academic domain, investigated the effects of the linguistic label representation of confusion matrices on the learning performance of deep neural networks for the applications of autonomous driving. applied a novel structure from motion camera calibration algorithm to a low-cost outdoor mobile robot system. reported on the issues in the development of swarm robotics of a Robot Operating System (ROS) based surveillance system designed to monitor a defined environment continuously for any

anomalous activities, and the lessons learned. These lessons were: malicious entity detection should be able to flexibly integrate with different scouting behaviors and robust alerting strategies with the goal that the surveillance system can actively and figuratively monitor the surrounding environment, identify situations suspicious of malicious behaviors, control different forms of video support depending on the location, type of event, and the environment (e.g., sound detection, odometer reading, image capture, video streaming in the entire environment), locally manage the list of suspicious events to ensure that it triggers a selective alarm only when the domain of influence (DOI) moves within the predefined range of coverage.

The literature discusses integrating AI into AVs. For example, developed an AI-SDN-based autonomous vehicle control architecture where an Artificial Intelligence rule engine is employed to perform judgment making. introduced AutoLearn, a holistic AV-to-cloud framework for improved utility in real-world applications. developed an AI-centric edge, fog, and cloud computing enabled deep learning cloud platform for AV communications. proposed a micro-grid based voltage stabilization approach for autonomous cars in a data center environment using soft computing algorithms. described a secure and efficient design to regulate the platooning of AVs upon their encounters at a cross intersection controller, in such a way to avoid crashes and/or queuing as well as guarantee specific minimum clearance between the vehicles.

6. Conclusion

The strength of this dissertation lies in the position it takes, which is that cyber-physical systems are phenomenologically different from other systems with physical and cognitive functions, and that recognizing and understanding these differences support the development of model-based IR education and training for CSPs. This perspective, and the insights that arise from it, are under-represented in the literature outside the problem domains of nuclear command-and-control at large and very large distributed environments. Although the SCADA/ICS literature is in many cases more applicable than the cybersecurity literature, it remains implicitly based on physical network presence and control instead of the physical control function. Model-based training is also presented in a more nuanced way, and applied to a field of universal relevance. The study also identified a coherent and generalizable set of

use-cases that its primary subjects should be able to recognize and respond to, regardless of what an autonomous vehicle-specific challenge might be.

Nearly all prior literature on cybersecurity incident response training proposes training on manual intervention, or concludes with suggestions to manually intervene. We argue that, in fact, training for autonomous vehicle cybersecurity should be developed assuming the allowance of manual intervention is a fall-back failure case, not a recommended response to a cybersecurity incident with an autonomous vehicle. We presented six scenarios that are instructive for the development of such an autonomous vehicle cybersecurity IR course. We articulated an undergraduate TLO responsible for implementing and developing a three-week, fifteen-hour course that conforms to industry's gap in anticipating future cybersecurity challenges related to the implementation of autonomous vehicle technology for everyday purposes. This TLO was careful to avoid mentioning a handful of functions specific to the autonomous vehicle. Doing so would be equivalent to providing a list of sensitive points that an intruder would exploit.

7. References

1. L. M. D'Arcy, "Human Factors in Cybersecurity: Examining the Impact of Training on Incident Response," IEEE Access, vol. 8, pp. 196748-196758, 2020.
2. J. St. Clair, "Autonomous Vehicles and Cybersecurity: A Human-Centered Approach," IEEE Transactions on Intelligent Transportation Systems, vol. 22, no. 3, pp. 1474-1483, 2021.
3. Vemori, Vamsi. "Human-in-the-Loop Moral Decision-Making Frameworks for Situationally Aware Multi-Modal Autonomous Vehicle Networks: An Accessibility-Focused Approach." *Journal of Computational Intelligence and Robotics* 2.1 (2022): 54-87.
4. C. Liu and M. Yu, "Cybersecurity in Autonomous Vehicles: A Focus on Human Factors and Incident Response," IEEE Internet of Things Journal, vol. 8, no. 4, pp. 2323-2333, 2021.
5. Vemori, Vamsi. "Towards Safe and Equitable Autonomous Mobility: A Multi-Layered Framework Integrating Advanced Safety Protocols, Data-Informed Road

Infrastructure, and Explainable AI for Transparent Decision-Making in Self-Driving Vehicles." *Human-Computer Interaction Perspectives* 2.2 (2022): 10-41.

6. A. K. Singh, "A Survey on Human Factors in Cybersecurity for Autonomous Vehicles," IEEE Communications Surveys & Tutorials, vol. 23, no. 1, pp. 146-164, 2021.
7. B. Zhao and J. Wang, "Developing Effective Cybersecurity Training for Autonomous Vehicle Operators," IEEE Transactions on Transportation Electrification, vol. 6, no. 4, pp. 1481-1491, 2020.
8. F. Martinez, "Enhancing Human-Centric Cybersecurity for Autonomous Vehicles: A Training Perspective," IEEE Transactions on Intelligent Vehicles, vol. 5, no. 3, pp. 456-465, 2020.
9. K. M. Kim, "Human Factors Engineering in Cybersecurity Training for Autonomous Vehicles," IEEE Access, vol. 9, pp. 11532-11542, 2021.
10. N. Ahmed, "Incident Response Training for Autonomous Vehicle Operators: A Human Factors Approach," IEEE Transactions on Systems, Man, and Cybernetics: Systems, vol. 51, no. 11, pp. 6961-6971, 2021.
11. D. Johnson and L. Liu, "Integrating Human Factors into Cybersecurity Training for Autonomous Vehicles," IEEE Transactions on Cybernetics, vol. 52, no. 5, pp. 3011-3020, 2021.
12. Tatineni, Sumanth. "Cloud-Based Reliability Engineering: Strategies for Ensuring High Availability and Performance." *International Journal of Science and Research (IJSR)* 12.11 (2023): 1005-1012.
13. G. Rodriguez, "Human Factors and Cybersecurity Incident Response in Autonomous Vehicles," IEEE Transactions on Intelligent Transportation Systems, vol. 23, no. 1, pp. 546-556, 2022.
14. P. Chen and Q. Zhang, "Cybersecurity Incident Response Training for Autonomous Vehicles: A Human Factors Analysis," IEEE Transactions on Industrial Informatics, vol. 17, no. 3, pp. 1947-1957, 2021.

15. L. Wu, "Human-Centric Cybersecurity Training for Autonomous Vehicle Operators," IEEE Transactions on Learning Technologies, vol. 14, no. 2, pp. 151-161, 2021.

16. A. Brown, "Cybersecurity and Human Factors in Autonomous Vehicle Operations," IEEE Transactions on Intelligent Vehicles, vol. 6, no. 2, pp. 289-299, 2021.

17. C. G. Atkin, "Effective Cybersecurity Training Programs for Autonomous Vehicle Operators: A Human Factors Approach," IEEE Transactions on Vehicular Technology, vol. 70, no. 5, pp. 4971-4981, 2021.

18. V. Patel, "Human Factors and Cybersecurity in Autonomous Vehicles: Training and Response," IEEE Transactions on Automation Science and Engineering, vol. 18, no. 2, pp. 643-653, 2021.

19. K. R. White, "Cybersecurity Training for Autonomous Vehicle Operators: Integrating Human Factors," IEEE Transactions on Human-Machine Systems, vol. 52, no. 4, pp. 589-599, 2022.

20. M. Gonzalez and E. Martinez, "A Human Factors Approach to Cybersecurity Incident Response in Autonomous Vehicles," IEEE Transactions on Intelligent Transportation Systems, vol. 24, no. 1, pp. 123-133, 2023.