The Evolving Role of Automation in Transportation: Human Factors Lessons Learned from the Different Modes

Maryam Allahyar [1], Ensar Becic [2], Sheryl Chappell [3], Donald Fisher [4] (Panel Chair), Maura Lohrenz [4] (Panel Organizer), Chris Monk [5], Brian Philips [6]

[1] Federal Railroad Administration
[2] National Transportation Safety Board
[3] Federal Aviation Administration
[4] Volpe National Transportation Systems Center
[5] National Highway Traffic Safety Administration
[6] Federal Highway Administration

Automation is not only in our future, it is already here. This has long been the case for aviation (FAA). But it is increasingly the case for our highly connected systems of vehicles (NHTSA), highways (FHWA), and railroads (FRA). Clearly we must educate the operators about the capabilities and limitations of these new automated systems (NTSB). The purpose of this panel is to share, at this critical point in the development of automation, the knowledge that has been gained across the different modes of transportation about how best to develop systems that may help reduce the approximately 94% of crashes attributed to human error. The five presenters (Allahyar, Becic, Chappell, Monk, and Philips) come from the different modes and have been centrally involved in the efforts to understand the role of the human operator in automated systems. Active engagement with the audience is expected.

INTRODUCTION

Automated systems are rapidly evolving and surging into every mode of transportation, offering hope for ever-increasing levels of safety and efficiency. However, until all vehicles within a given mode are fully automated, humans will be in the loop. As long as humans are in the loop, careful attention must be paid to human behavior to ensure minimal harm is done.

This panel presents human factors lessons learned in transportation automation across several modes, from the earliest research in aviation automated systems to current and future research in connected vehicles, intelligent vehicles, and positive train control. The panel includes members of the U.S. Department of Transportation Human Factors Coordinating Committee (HFCC), including representatives from the Federal Aviation Administration (FAA), National Highway Transportation Safety Administration (NHTSA), Federal Highway Administration (FHWA), National Transportation Safety Board (NTSB), and Federal Railroad Administration (FRA). The HFCC was established to enhance awareness, understanding, application, and evaluation of human factors in transportation.

LESSONS FROM FAA

There are many landmarks as we take a flight down the memory lane of aviation automation. In the early days, Fitts' List (1951) defined which tasks are better performed by humans versus machines. But that type of task allocation evolved into more flexible and capable automation that the pilot could engage/disengage as appropriate. Then, as autopilots went from independently holding a heading, speed, and altitude, to flying a three-dimensional route, human factors scientists such as Wiener and Curry (1980) began to appreciate the difference in pilots' interaction with their aircraft. No longer could a pilot look at one instrument to determine whether the automation was doing what was intended. The control loops now had inner loops, and pilots were sometimes out of the loop. The question "what's it doing now?" was all too common on the flight deck. Concerns about mode confusion, loss of situation awareness, mistrust in automation, manual skill degradation, complacency, and others, all started being discussed and studied. There were automation workshops, summits, and policies. The aircraft manufacturers developed automation philosophies, as did the airlines and human factors scholars (Billings, 1991). Dr. Wiener gave us his laws of automation, such as, "Automation is dumb and dutiful."

Sheridan and Verplank (1978) defined 10 levels of automation from no automation to fully autonomous. More recently, scientists and practitioners have segmented automation by the function it supports or performs. Parasuraman, Sheridan, and Wickens (2000) identified four generic functions to be supported: information acquisition, information analysis, decision and action selection, and action implementation. Adaptive automation (Parasuraman & Riley, 1997) called for the automation to assist when needed and desist when not, keeping the pilot more engaged while managing high workload.

Along the way, there was a change in the specified role of the flightcrew. Now that the airplane was often in automated flight, the duties of the captain or first officer whose turn it is to serve as the pilot controlling the aircraft – the "pilot flying" – had to be further defined for when he/she was manually flying and when manipulating the autoflight system. The "pilot not flying" became the "pilot monitoring," to emphasize the importance of both crew members constantly ensuring the aircraft systems were performing as intended.

There is no argument about the safety benefits of automation. Automated flight is also more operationally efficient. However, along with these benefits are important lessons learned. Abbott (2015) presents nine:

1. Vulnerabilities exist in pilot interaction with automated systems;
2. Rather than automation as a whole, we need to consider the different types of automated systems, such as automated aircraft control, automation for the calculation, management and presentation of information, and the automation of management tasks;
3. Lack of practice can result in degradation of basic knowledge and skills;
4. "Levels of automation" is a useful concept for communicating ideas about automated systems, but can be hard to put into practice;
5. Operators should have a clearly stated flight path management policy for how the crews operate their aircraft;
6. Use of automated systems can reduce workload during normal operations, but may add complexity and workload during demanding situations;
7. Some of the vulnerabilities associated with automated systems are due to how complex they are, not to the automation itself;
8. Be cautious referring to automated systems as another crewmember; and
9. The contributions of the pilots and controllers must be recognized as they mitigate operational risk on a regular and ongoing basis.

As this panel addresses automation across transportation modes, the flight down the aviation automation memory lane can offer guidance on hazards to avoid and benefits to acquire.

LESSONS FROM NHTSA

The National Highway Traffic Safety Administration (NHTSA) is responsible for developing, setting, and enforcing Federal motor vehicle safety standards and regulations for motor vehicles and motor vehicle equipment in the United States. The purpose of the agency's safety programs is to reduce or mitigate motor vehicle crashes and their attendant deaths and injuries. There were 32,675 fatalities on our roadways in 2014. NHTSA is encouraged by the new automated vehicle technologies being developed and implemented by automakers and others. These technologies have the potential to reduce significantly the fatalities and injuries that occur each year as a result of motor vehicle crashes. In addition to safety, many other potential benefits come with automated vehicles, including increasing environmental benefits, expanding mobility, and creating new economic opportunities.

HF Evaluation of L2 and L3 Automated Driving Concepts

The purpose of this study was to investigate user interactions with Levels 2 and 3 (L2, L3) partially automated vehicles (Marinik et al., 2014). In L2, operators can remove both their hands from the steering wheel and their feet from the pedals for a period of time, but need to be actively engaged in monitoring the vehicle, since control could be returned at any time. In L3, the operator can disengage from active supervision of the vehicle. L2 and L3 are of interest because this is where the driver's role transitions to that of intermittent operator, and longitudinal and lateral control are ceded in varying degrees to the vehicle. For L2 and L3, the level of involvement by the human might vary. Therefore, we use the term operator instead of driver. The study focused on how these intermittent operators transition between automated and non-automated vehicle operation, and how this interaction is affected by the human-machine interface (HMI). Three experiments were performed with prototype partially-automated vehicles on controlled test tracks in mixed traffic. The findings suggest that the most effective hand-off strategies were those that incorporated nonvisual components. The driver engagement patterns observed in this study provide data and evidence that could support the future development of human factors design principles for L2 and L3 partially automated vehicles.

Naturalistic Study of L2 Automated Vehicle Functions

This research project, initiated in late 2015, focuses on 1) driver engagement, 2) driver performance, 3) system performance, and 4) driver-system interaction. One hundred and twenty drivers will be recruited from the Northern Virginia area and provided one of 5 different L2 leased models for everyday use. Insights that may also be gained from the outcomes of the project include issues related to driver-vehicle interface design, unintended use and consequences, the safety and security of L2 systems, system failures, and licensing and training requirements.

Small Business Innovation Research (SBIR)

Lastly, NHTSA is managing a Phase II SBIR project investigating driver status monitoring and driver engagement. The technology has the potential for improving the decision making dialog between the automation and operator. NHTSA continues to research the numerous key human factors issues involving automated vehicles.

LESSONS FROM FHWA

The Federal Highway Administration (FHWA) has been conducting research in vehicle – highway automation for over 25 years. FHWA's automation research goals are to improve overall roadway network performance, roadway safety, and mobility, and to reduce environmental impacts.

Automated Highway System (AHS)

In the 1990s, the AHS program focused on having a highly automated vehicle operate on an automated highway and take passengers rapidly to a desired destination. The driver would program in a destination and the vehicle would go to this location and exit the highway without driver intervention. While the project highlighted some critical human factors issues (e.g., how should transfer of control occur, and what role can the driver be expected to play when a system failure occurs?), the concept was a bit ahead of its time in terms of what the technology could support. One of the lessons learned was that automation (and technology in general), cannot be implemented before it is fairly mature (Cheon, 2003). In the case of AHS, the technology was too costly and immature to provide safe autonomous vehicle operations.

HF for Limited Ability Autonomous Driving Systems (HF4LAADS)

HF4LAADS was an important project (2009-2011), for which FHWA and General Motors were key stakeholders. This project investigated the ability of vehicles using Adaptive Cruise Control (ACC) and Lane Centering (LC) to follow a single freeway lane on a test track. One key issue investigated was the impact of reduced driving workload on drivers' ability to respond to emergency situations. A key finding was that drivers were more likely to engage in secondary tasks when the driving automation afforded the opportunity to do so. This study set the stage for additional human factors studies investigating Level 1 (L1) automation research at FHWA, and L2 and L3 automation research at NHTSA (see above).

Evolutionary automation

Since the AHS and HF4LAADS projects, both infrastructure and autonomous vehicle technologies have matured considerably. Vehicle automation features have started to appear in an evolutionary fashion in many vehicles available today. Some lower level automation features now available include lane departure warning systems, blind spot monitoring systems, ACC, and LC systems. But human factors and safety concerns still exist even with lower level automation systems. For example, LC systems and lane departure warning systems often use cameras to detect the lane line stripping and to determine when the vehicle is not centered in the lane, or is crossing over into the adjacent lane. Better coordination is needed between manufacturers and FHWA to establish the specification for lane line salience that vehicles need to perform at safe levels.

FHWA has also taken an evolutionary approach to automation; e.g., FHWA's research into Cooperative Adaptive Cruise Control (CACC), which combines three driver-assist systems: 1) conventional cruise control, which automatically maintains the speed a driver has set; 2) ACC, which uses radar or LIDAR sensors to automatically maintain a gap the driver has selected between the driver's vehicle and a vehicle ahead; and 3) dedicated short-range communications (DSRC) to transmit and receive data with surrounding vehicles (i.e., vehicle-to-vehicle (V2V) communications) so that the system can more quickly respond to changes in the speed and location of other CACC vehicles, even vehicles that the driver cannot see (Jones, 2013). One goal of CACC is to enable strings of equipped vehicles to travel at higher speeds with smaller gaps (for increased throughput), while affording greater safety than is possible without CACC technology.

Several FHWA CACC human factors experiments appear to have yielded evidence of a safety benefit. We are conducting two experiments to verify whether drivers with CACC would effectively monitor the system's longitudinal control and override the system in the event that greater braking authority was needed than the system was designed to provide. Preliminary results of these experiments suggest that auto-braking and an auditory alarm are necessary to achieve a crash reduction benefit, although the alarm alone may promote less severe collisions. The results of these studies and similar research reinforce FHWA's approach of "Connected Automation" (Figure 1). This approach uses automation to leverage the power of wirelessly connected vehicles to share safety information that will help the vehicles within a certain area (~1000 foot radius) know the intentions (speed, trajectory, acceleration, braking, etc.) of all other vehicles within that radius. Therefore, connectivity supports automation, and shared information facilitates better situational awareness and decision making, for increased roadway safety.

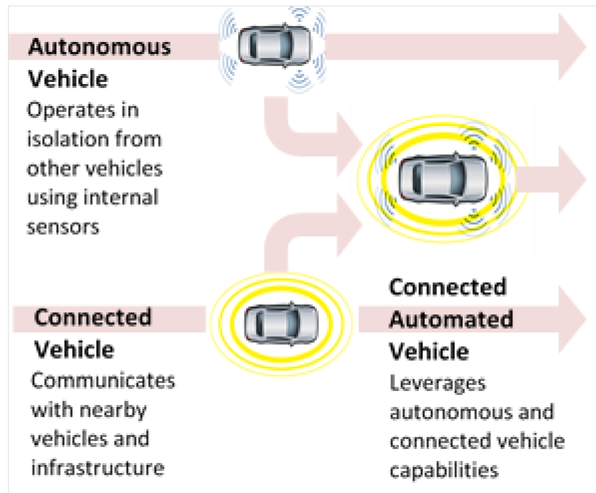

Figure 1. Connected Automation yields greatest benefits

LESSONS FROM THE NTSB

For at least the past decade, autonomous vehicles have been viewed as the future of surface transportation. While automation has been an integral component in other modes, particularly aviation, it has taken several decades to make autonomous vehicles a feasible reality on our roadways. Much of the current spotlight discussion on autonomous vehicles focuses on implementation and their safety benefits. However, anticipating negative aspects of automation and developing potential countermeasures to those has to occur concurrently. Failures in human-machine interaction, especially those related to driver understanding and expectations of the system, are of particular interest.

The National Transportation Safety Board (NTSB) has advocated for the use of collision warning (CW) and ACC systems in both passenger and commercial vehicles since 2001. This advocacy has been accompanied by recommendations to conduct educational campaigns to inform the public about the benefits of these systems, but also to train commercial drivers about their proper use. Such training would be beneficial to all drivers; the NTSB views education as a necessary component, even for systems that only aid a driver. The functionalities of CW and autonomous emergency braking (AEB) systems may differ from one generation to the next, requiring a change in driver expectations. While CW and AEB systems are not designed to replace any aspect of driving performance (e.g., monitoring the environment, steering), but are rather intended to only aid a driver, overreliance and misinterpretation may still be a concern. The misinterpretation may be a concern particularly when the functionality of one system is dependent on the activation of another, as could have been the case in the crash that the NTBS investigated in Cranbury, New Jersey (NTSB, 2015).

When it comes to vehicles with partial automation, in which one aspect of a driving task is automated (e.g., lane keeping), the distinction between system and driver responsibility may not be as clear. An expectation of automating a single driving task may include redistribution of driver's newly available cognitive resources toward another driving-related task, such as monitoring pedestrians. However, as partial automation research conducted on test tracks has shown (drivers operating vehicles with lane keeping automation exhibited overreliance on the systems and in some cases prioritized the completion of a non-driving task), this may not always be the case (Blanco et al., 2015). Compared to a lane keeping system, which is continuous, CW and AEB systems are discrete and usually infrequent, and as such, may be easier to perceive as systems that only aid driver's performance.

A clear distinction between system and driver responsibility emerges only in L3 autonomous vehicles (see explanation of L3 systems, above). While we may expect a driver in such a vehicle to be less engaged in the driving task, the minimum level of engagement required for safe vehicle operation is still unclear.

Automated vehicles, with varying degrees of automation, have the potential to improve efficiency and increase safety, although obtaining their full benefits will require an educated driver with full understanding of the functionalities and limitations of those systems, reminiscent of the lessons learned from the FAA (Abbott, 2015).

LESSONS FROM FRA

The introduction of automation to railroad systems has the potential to improve safety and efficiency while reducing operator workload, but it can also change the role of the operator and introduce new sources of error (e.g., Parasuraman et al., 2012). The Federal Railroad Administration (FRA) is currently overseeing the railroads' implementation of Positive Train Control (PTC) systems, which introduce more automation in the locomotive cab to improve safety and efficiency. PTC systems are not intended to replace engineers; PTC is a backup system. The engineer still has full responsibility for operating the train in a safe manner.

With the insertion of new technology into rail systems, how such technology upgrades and innovations will impact dispatch and operations centers are not well understood. To date, no holistic modeling methods adequately capture how changes in rail dispatch/operations technologies will change workflow, manning requirements, or human performance.

During this panel, FRA will describe a systems theoretic computational model that quantitatively models rail engineers and their rail dispatch/operations center to help FRA proactively address the issue of crew size as automation is introduced into the locomotive cab. This model will answer questions such as:

- How would the insertion of new technologies (e.g. PTC, new scheduling decision aids, and additional rail lines) affect the workload of individuals and teams in the dispatch/operations center?
- Where could the insertion of these new technologies increase human error?
- How should a center plan for its future workforce in terms of size and skill level as current technologies are upgraded and new ones are introduced?

In addition to the very specific benefits the rail community will gain from the development and dissemination of such a model, there is a significant contribution to the larger human factors and systems research community. This modeling effort demonstrates how to represent both individual and team behaviors and workload (including communication, coordination and process losses/gains as a direct result of team performance), all in the presence of emerging and changing technology.

SUMMARY

These lessons learned from the various modes might be compiled into several cross-cutting themes:

System safety, security, alerting and readiness

- There is a need to address safety and security concerns related to automated systems (NHTSA).
- Pilots and controllers (cross-modally, operators) must mitigate risk on a regular and ongoing basis (FAA).
- Automation (and technology in general) cannot be implemented before its fairly mature, in terms of functional safety and reasonable cost-benefit ratios (FHWA).
- With CACC, auto-braking and an auditory alarm are necessary to reduce crashes (FHWA).

Operator-system interaction and transfer of control

- Vulnerabilities exist in operators' interactions with automated systems (FAA).
- There is a need to mitigate failures in human-machine interaction, especially with operator understanding and expectations of the system (NTSB).
- The distinction between system and operator responsibility may not be clear, especially with partially-automated vehicles (NHTSA, NTSB). In particular, it is unclear what role the driver should play when an automated system fails (FHWA).
- We must consider operator-vehicle interface design issues, especially with L2 and L3 vehicles (NHTSA).
- The most effective hand-off driving strategies incorporate nonvisual components (NHTSA).

Operator monitoring, engagement and workload

- Issues still exist related to driver status monitoring and driver engagement (NHTSA).

- Drivers are more likely to engage in secondary tasks when automation affords them the opportunity (FHWA).
- Drivers operating vehicles with lane-keeping automation were found to be less engaged, or even completely disengaged, from the driving task (NTSB).
- We still need to better understand driver operation of L1 vehicles, since these systems are now more widely available in the light vehicle market (FHWA).
- Automated systems can reduce workload during normal operations, but may add complexity and workload during demanding situations (FAA)
- A systems-theoretic computational model can represent operator/team behaviors and workload in the presence of emerging and changing technology (FRA)

Operator education and training

- Lack of practice can result in degradation of basic knowledge and skills (FAA).
- Education is a necessary component of automated systems, even for systems that only assist a driver (NTSB).
- There is a need to address issues related to unintended use and consequences (NHTSA).
- While CW and AEB systems are not designed to replace any aspect of driving, overreliance and misinterpretation may still be a concern (NTSB).
- Licensing and training requirements must be developed (NHTSA).

This is certainly not a comprehensive list of issues to be addressed as automated systems permeate our transportation system. However, by tapping into the experiences of each mode, we hope to learn from each other and find new ways of mitigating the potential risks and reaping the most from these new systems, for increased public safety, transportation efficiency, and environmental benefits. The purpose of the panel is to provide a forum for a broad, cross-modal assessment of the common problems that all face now and in the near future.

REFERENCES

Abbott K. (2015). Some lessons learned about pilots and flight deck automated systems. Retrieved on February 1, 2016 from http://www.skybrary.aero/bookshelf/books/2921.pdf.

Billings, C.E. (1991). Toward a human-centered aircraft automation philosophy. *International Journal of Aviation Psychology*, *1*, 261-270.

Blanco, M., Atwood, J., Vasquez, H.M., Trimble, T.E., Fitchett, V.L., Radlbeck, J., Fitch, G.M., Russell, S.M., Green, C.A., Cullinane, B, & Morgan, J. F. (2015, August). *Human factors evaluation of level 2 and level 3 automated driving concepts*. (Report No. DOT HS 812 182). Washington, DC: National Highway Traffic Safety Administration.

Cheon, S. (2003). *An Overview of Automated Highway Systems* (*AHS*) *and the Social and Institutional Challenges They Face*. Berkeley, CA: University of California Transportation Center.

Fitts, P.M. (1951). *Human engineering for an effective air navigation and traffic control system*. Washington, DC: National Research Council.

Jones, S. (2013). *Cooperative Adaptive Cruise Control: Human Factors Analysis*. McLean, VA: Federal Highway Administration.

Marinik, A., Bishop, R., Fitchett, V., Morgan, J., Trimble, T., & Blanco, M. (2014). *Human Factors Evaluation of Level 2 and Level 3 Automated Driving Concepts: Concepts of Operation* (DOT HS 812 044). Washington, DC: National Highway Traffic Safety Administration.

NTSB. (2015). *Multivehicle work zone crash on Interstate 95: Cranbury, New Jersey*. (Report No. NTSB/HAR-15/02). Washington, DC: National Transportation Safety Board.

Parasuraman, R. & Riley, V. (1997). Humans and automation: Use, misuse, disuse, and abuse. *Human Factors*, *39*, 230-253.

Parasuraman, R., Sheridan, T.B., & Wickens, C.D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans*, *30*, 286–297.

Parasuraman, R., Elsmore, G., Isaacs, M., & Fisher, D. (2012). Reducing major rule violations in commuter rail operations: The role of distraction and attentional errors. *Proceedings of the Annual Human Factors and Ergonomics Society's 56th Annual Meeting*. Boston, MA: Human Factors and Ergonomics Society.

Sheridan, T.B. & Verplank, W. (1978). *Human and computer control of undersea teleoperators*. Cambridge, MA: Man-Machine Systems Laboratory, Department of Mechanical Engineering, MIT.

Wiener E.L. & Curry, R.E. (1980). Flight-deck automation: Promises and problems. *Ergonomics*, *23*, 995–1011.