# Human Factors Research Facilitates the Safe Application of Technology

***The science of human factors can help us better understand how people and technology-based systems interact. Human factors research not only identifies potential problems in system–operator interfaces but also can define human limitations in the use of technology to perform certain tasks. Engineers at the Human Factors Laboratory at the Volpe Center have been at the forefront of ergonomic research into systems and procedures design for both air and rail transportation systems. Their work will support the development of more user-friendly systems and lead to a reduction in accidents attributable to human error.***

The application of technology to the problems of today's transportation systems holds the promise of providing imaginative solutions to our most pressing issues. From automated systems that can help us create safety profiles of truck operators and air carriers, to intelligent transportation systems that can make our commute to work safer and more efficient, technology-based systems are the key to rebuilding our transportation infrastructure in the years to come.

Yet, as the use of advanced technologies in transportation becomes more widespread, we also must take into account how the human operator interacts with these systems. In the blink of an eye, technology can perform literally hundreds of tasks that would take a human operator hours to perform. Often, though, such systems are designed with only scant attention to how the people responsible for their operation interact with them. Systems designed without adequate evaluation of their human interface can lead to operator error and sometimes disastrous consequences.

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## The Origins of Human Factors Research

The field of human factors research deals with the interaction between people and systems, and attempts to understand how system design can influence operator performance. Human factors research also can help delineate appropriate functions for humans and machines, identifying work assignments that can be more efficiently handled by machines or other automated systems and those tasks which are best handled by humans.

Some of the earliest work in human factors research can be traced back to the interest in time-and-motion studies that were in vogue in industrial America during the 1930s and 1940s. Such research was seen as an important tool to identify inefficiencies in the automated assembly line. However, the primary objective of such research was to maximize worker productivity, and little attention was paid to the human component of the system or to the effects that increasing levels of productivity had on the workers themselves.

The scope of human factors research expanded during World War II, when specialists working with manned military systems found that the performance of systems and their operators varied widely based on the extent to which the systems were "user friendly." Today, the study of human factors continues to focus on how information is presented. It seeks to identify the factors that can enhance the operator's ability to process important information that is provided by the system.

Human factors engineering is an important component in the development and design of virtually every product we use, from automobiles to computers, even to the remote control device we use to turn our television on and off. The ultimate goal of modern human factors research is to help designers create products and systems

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that allow their human operators to achieve the greatest possible benefit with the least risk to their health and safety.

## Human Factors at the Volpe Center

Human factors engineers at the Volpe National Transportation Systems Center have developed guidelines for the design and evaluation of several types of advanced systems, including cockpit avionics, air traffic control systems, and high speed rail transportation. The guidelines help to ensure that these advanced systems minimize the possibility of human error. The human factors specialists at the Volpe Center are also actively involved in a number of research projects to identify how technology-based systems can be modified and improved to reduce operator errors and optimize system safety and performance. Their work also will help us to better understand the limits of humans' technological capability and define important human factors parameters for systems design in the future.

Under the direction of Dr. E. Donald Sussman, analysts have conducted important research on machine–operator interaction in air and rail systems. In addition to laboratory research, these specialists have also provided support to other Volpe Center divisions in their investigations of high-profile transportation accidents, such as the crash of an underground commuter train in Boston. These projects have contributed significantly to our understanding of the role that human factors plays in transportation systems and in the performance of system operators.

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## Human Factors in Aviation

Flying a plane requires a pilot to continuously monitor information from a number of sources. Pilots must constantly monitor their radio for instructions from air traffic control while also checking cockpit instruments that indicate the plane's air speed, altitude, and heading. In addition, pilots must examine their approach charts to obtain the local procedures for their destination airport. Researchers at the Volpe Center have developed ways of making these tasks easier and less prone to error by improving the approach charts that pilots use and developing guidelines for effective controller–pilot voice communications.

### Controller–Pilot Communications

With all that a pilot must attend to, the risk of misunderstanding Air Traffic Control (ATC) instructions communicated via radio is high and can have deadly consequences. According to the Federal Aviation Administration's (FAA) Operational Error and Deviation System, more than 70 percent of operational errors and pilot deviations are attributable to communications problems.

Correctly understanding ATC information provided by the controller is essential for safe flight. Funded by the FAA's Office of the Chief Scientific and Technical Advisor for Human Factors, Drs. Judith Burki-Cohen and Kim Cardosi have conducted numerous studies since 1993 to assess the error rate of communications between air traffic controllers and pilots. For example, three separate studies conducted by Cardosi evaluated more than 150 hours of tape recordings between air traffic control centers and pilots, using more than 25,000 controller-to-pilot transmissions, including instructions to maneuver or change routings, requests for clearance to take off and land, and transmissions dealing with other flight issues.

The majority of the transmissions analyzed in these studies contained one, two, or three pieces of information that were transmitted and acknowledged by a full or partial "readback" (communications between controllers and pilots are routinely confirmed by reading back to the transmitting party the instruction or the request just received). However, some transmissions contained as many as five or more pieces of flight-critical information.

Cardosi's research consistently determined that fewer than 1 percent of all exchanges between controllers and pilots resulted in an erroneous readback of instructions.

Predictably, the rate of communication errors increased with the complexity of the transmission and with the number of pieces of information communicated.

To minimize the potential for readback errors by pilots and controllers, Cardosi concluded her study by outlining a number of recommendations, including the following items:

- Pilots should always use their call sign when responding to clearances;
- Pilots should ask for clarification, rather than expect a controller to catch readback errors;
- Pilots should always read back critical information;
- Controllers should provide no more than four instructions per transmission; and
- Controllers should avoid issuing "strings" of instructions to different aircraft.

Cardosi's work has been followed by additional investigations into the specific practices that can affect the probability of a communication error. Dr. Burki-Cohen conducted a laboratory study on the effect of message complexity on communication error. She also examined the effect of presenting numbers to pilots in sequential format (i.e., "climb to one seven thousand") to the effect of presenting the same information in grouped format (i.e., "climb to seventeen thousand").

In this study, 24 professional pilots were tested individually to evaluate their responses to tape recordings of air traffic control transmissions. Asked to assume the role of the pilot communicating with air traffic control, the pilots listened to control instructions over a headset, read back the information into a microphone, and adjusted the settings of a mock-up mode control panel in the laboratory. Each transmission contained from three to five

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pieces of information, and altitude and frequency information was presented in either sequential or group format. To prevent the pilot from anticipating instructions, transmissions were deliberately sequenced to avoid any similarity with an expected flight routine.

While Burki-Cohen's research found no significant correlation between error rates and the use of either a sequential or a group format, she did find a direct correlation between the complexity of the message and the rate of readback error. Error rates rose with the amount of information in a single transmission. These laboratory findings supported the findings of the tape analysis; controllers should limit the amount of information communicated in a single transmission.

Based on these findings, analysts at the Human Factors Laboratory are now evaluating what effect the rate of speech has on errors attributable to the format and complexity of the transmission. And, rather than continuing to rely on instinct and anecdotal information for the causes of communications errors, pilots, controllers, and aviation officials now have access to scientific data that can help minimize future miscommunications.

### Cockpit Human Factors

Other aviation human factors research conducted at the Volpe Center has focused on the the interaction between the pilot and navigation information. Dr. M. Stephen Huntley developed a cockpit simulator of a typical twin-engine private plane. In this laboratory environment, analysts can directly observe how pilots interact with experimental navigational devices and measure how modifications to those devices improve or impede pilot response. The devices can then be further evaluated in actual flight by pilots working in conjunction with the Center.

*This simulated mode control panel helps Volpe Center researchers evaluate communication errors in controller–pilot transmissions.*

Huntley, Colleen Donovan, and their colleagues have been working for the Air Transport Assocation to develop instrument approach charts designed to assist pilots on instrumentation landings. The maps include detailed information on approach altitudes at various distances from the airport as well as the proper radio frequencies for communication with controllers, providing the pilot with a virtual script for an instrument landing.

In another project, Huntley has worked with the FAA to develop guidelines and evaluation criteria for so-called "moving map displays." These computer generated displays overlay the actual position of the plane as derived from navigational satellite readings onto electronic versions of the traditional maps used by pilots to chart an anticipated flight path. Huntley and Donovan have also developed human factors guidelines for evaluating Global Positioning Systems (GPS) receivers. These receivers provide the pilot with navigation information that is much more precise than the information available from other instruments. This work on moving map displays and on GPS receivers represents a significant step toward reducing navigation errors by providing pilots with precise information that is easy to interpret.

## The Role of Human Factors in High-Speed Rail Operations

The human factors issues facing locomotive engineers and dispatchers in the operation of high-speed trains are somewhat different from those facing pilots and air traffic controllers. However, the failure to account for human limitations in the development and deployment of navigation systems for high-speed trains can result in the same tragic consequences as those resulting from controller–pilot communication errors.

The system–operator interface issues for high-speed rail travel stem from the need to keep the engineer actively involved in running the train—even during highly automated operations—to ensure that rapid human intervention is possible in the event of system instability. Research conducted by Burki-Cohen included an in-depth investigation for the Federal Railroad Administration (FRA) of how operators of other high-speed rail systems around the world address these issues in the design of their systems.

In these investigations, the Volpe Center conducted on-site reviews of the TGV rail system in France, the ICE system in Germany, and the Shinkansen in Japan. They found that, while each of these systems uses a different approach, all depend to a large degree on automated systems inside the cab to provide locomotive engineers with vital signaling information instead of relying on the engineer's ability to visually identify hazards or other traditional wayside

*High speed rail transportation presents a unique set of operator–system interface issues, and requires system designers to rethink their views about the balance between automated and manual systems.*

*Antiquated locomotive cab design allows poor ventilation and unacceptable levels of noise, leading to engineer fatigue and workplace injuries.*

information outside of the train. Each system also incorporates technology into the design of its engineer's cab that continuously monitors the alertness of the engineer and automatically brings the train to a stop in the absence of required responses.

More recently, Dr. Burki-Cohen, along with Dr. Jordan Multer, a human factors engineering psychologist at the Volpe Center, has taken this initial research further by evaluating in the laboratory the responsiveness of locomotive engineers to automation. Using a high-speed rail simulator developed several years ago in conjunction with the Massachusetts Institute of Technology, Multer and Burki-Cohen are able to evaluate how different levels of involvement affect the engineer's situational awareness and ability to control the train.

The simulator consists of a virtual locomotive cab, which features speed and braking controls as well as a screen that displays engine performance indicators and an out-the-window view down a pair of simulated "tracks." The simulator also includes a dispatcher station, which displays a layout of an entire hypothetical rail system, continuously updated with information on the positions of the virtual trains. Researchers can modify the extent to which the engineer controls the train or allows automated systems to control it, allowing them to assess the ideal balance between automation and manual control.

### Ergonomics and the Locomotive Cab

Apart from his work with automation in high-speed rail systems, Multer also has been involved in the development of human factors guidelines for locomotive cabs. As new locomotive engines are manufactured for use on freight and long-distance passenger routes, greater attention will need to be paid to the on-board conditions in which locomotive engineers work, including noise levels, air quality, and appropriate seating within the cab. Information technology systems also will find their way into this workplace, requiring systems designers to face the same human factors issues that designers of high-speed trains are already dealing with.

Work at the Human Factors Laboratory will continue on operator–system issues found in aviation and high-speed rail systems. This work helps to ensure that equipment and procedures are compatible with human capabilities and limitations. Such compatibility is critical to minimizing human error and maintaining a high level of safety.

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## Resources


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