Designing for People:

Unlocking Human Behavior to Build a Better Transportation System

Part 1 of 2: Human Factors Professionals Working Alongside Planners and Engineers

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Human behavior presents a challenge to transportation engineering professionals. Engineers and planners who work hard to create and design a transportation system that works for the needs of its users recognize that understanding human behavior is the key to designing and managing safe and efficient sidewalks, pathways, streets, and highways. Human behavior and the subsequent decisions made by drivers, pedestrians, and other road users may seem baffling at times, so an understanding of such human behavior is a critical component of the planning, design, and management of the world in which these users live. Working alongside transportation planning and engineering professionals, human factors professionals bring an understanding of human factors, the scientific discipline which offers tools and knowledge that can aid transportation professionals in understanding human behavior and refining predictions related to planning and engineering choices.

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Human factors has been defined in a variety of ways, yet all of those definitions share several common features.[1] Human factors professionals seek to use knowledge about human capabilities and limitations to understand and improve the interactions of people within the world around them. This is accomplished through scientific scrutiny of human sensation, perception, goal setting, decision-making, and response selection and execution, and it considers the way in which the environment can and cannot be acted upon (i.e., affordances and constraints).

The transportation environment includes the infrastructure provided to travelers in the form of roadways, sidewalks, pathways, and the appurtenant signs, signals, markings, and delineation. It also includes a variety of conveyances used by travelers including, among other options, passenger vehicles, trucks, buses, motorcycles, bicycles, and wheelchairs. This interaction among road users, their method of conveyance, and the built environment has the remarkable success of providing a safe and efficient transportation system in a complex environment, yet remains marked with the evidence of poor choices and the outcomes of circumstances that exceed the capability of humans to act.

The interaction of vulnerable users with motor vehicles presents perhaps one of the most vexing challenges of the 21st century, one where the outcome of "zero deaths" remains the noble goal of transportation professionals. Addressing these issues in a way that prioritizes systemic needs and improves the safety of the system often demands the development and implementation of new traffic control devices or different applications of existing devices. At no time in modern history has there been a greater need to thoughtfully apply the principles of the *Manual on Uniform Traffic Control Devices* (MUTCD) and conduct thorough experimentation of devices with attention paid to human behavioral outcomes. Further complicating this challenge are the variations in user capability which leave some populations particularly vulnerable. Today, more than ever, the transportation professional must understand the needs of the aging driver, accommodate those isolated from work sites by long transit commutes, and carefully evaluate the impact of changing demographics in a world adapting to economic pressures.

The discipline of human factors is a critical component in effective and efficient analysis and experimentation. Relative to traffic control devices alone, the MUTCD states, "A successful experiment is one where the research results show that the public understands the new device or application, the device or application generally performs as intended, and the device does not cause adverse conditions."[2] Human factors experts apply their backgrounds in the behavioral, social, cognitive, and neurosciences and develop hypotheses about how people might respond to new applications. This broad-based approach to understanding human behavior is the foundation of innovative experimental protocols and an objective evaluation that enables researchers to quantify performance.

History of Human Factors

Being closely tied to the philosophy of human-centered design, the discipline of human factors encourages engineers to "accept human behavior for what it is, not the way we wish it would be."[3] This statement refers to a traditional tension between what appear to be logical rules built into devices or systems and the apparent failure of people to follow rules or act logically. What is often perceived as human error or as a failure to follow instructions can also be seen as a failure to appreciate the innate limitations and capabilities of human beings and the expectations that they bring to tasks.

When discussing the establishment of human factors as a unique area of scientific inquiry, the work of Frederick Taylor and Frank and Lillian Gilbreth is often referenced; they conducted studies focused on increasing productivity through the elimination of unnecessary actions (e.g., bricklaying). It was during World War II that human factors shifted to focus more on the design of the environment and the well-being of the worker. At this time, human performance in human-operated systems, especially aviation, was identified as problematic. These first human factors and ergonomics studies, for what is now the U.S. Air Force and U.S. Navy, investigated issues of information presentation, detection and recognition of system states, situation assessment, use of controls and displays, workspace arrangement, and worker skills identification. After World War II, the profession of human factors saw rapid growth driven by the military-industrial complex during the Cold War and the development of a space program. Starting in the 1980s, the home computer created new opportunities for human factors professionals, and specialties related to usability and user experience were born.[4]

Several disaster scenarios in the 1970s and 1980s also fueled the need for, and public prominence of, human factors.[5] The Three Mile Island nuclear power plant incident was originally diagnosed as human error leading to the destruction of the reactor, coming perilously close to radiation release, and halting the American nuclear industry. However, detailed inspection of the circumstances and events by human factors experts indicated that control room design itself led to errors that were inevitable.[6] These findings led to changes in operator training and staffing requirements, improved instrumentation and controls, and establishment of fitness-for-duty programs.[7]

Thus, the benefits of designing with people in mind include reducing risk and improving safety, maximizing efficiency, and improving public perception and satisfaction. Research has sought to quantify the benefits of human factors research for engineering activities. This research focuses on the consideration of the end-user and identifying system deficiencies early and often in engineering projects. Case studies of Army aviation systems found benefits of including human factors research/analyses which included rapid technology advancements and safety improvements resulting in a benefits-to-investment ratio of at least 21:1 .[8] A cost-benefit analysis of usability work has shown a 2:1 dollar savings-to-cost ratio for

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a relatively small development project and a 100:1 savings-to-cost ratio for a large development project.[9]

Human Factors in Transportation

Transportation projects often benefit from the specialized training and education obtained from integrating the work of human factors experts. Infrastructure design projects benefit from human factors research related to the development of design standards and traffic control devices. Compliance, enforcement, and educational programs are more effective when user experience is addressed in program development and deployment. Frequently, human factors professionals address the needs of road users, but often they are called upon to address the processes, procedures, and technology used by transportation professionals themselves. Applying human factors principles to transportation management center design and processes used in the management of operations can improve workflow and efficiency. Vehicle system design and development likewise benefits from insights into user experience. Human factors engineering applied to the user experience is invaluable in the deployment, acceptance, and adoption of those new technologies.

Traffic engineers have long understood the basic implications of human factors engineering in the work of geometric design and traffic control device design. The design of vertical and horizontal alignments is based in part on visibility and the ability of drivers to recognize a hazard and react to it. The ability of drivers to respond to hazards and roadway conditions with a typical perception-reaction time is an outcome of design decisions. Anything that increases these times will consequently increase the distance a vehicle travels before a maneuver is initiated and completed, and, as demonstrated in Figure 1, driver performance against increasing information deteriorates even more rapidly in unexpected situations.[10]

What can traffic engineers to do eliminate these unexpected situations? What can they do to decrease the time that it takes for a vehicle operator to perceive a hazard or process the need to take action based on a sign, for example? Many practitioners simply know this as "driver expectancy" and seek to design what they understand road users expect to see.

Decades of scientific human factors research have helped traffic engineering practitioners understand the driving task and the process by which vehicle operators and other road users reach decisions and execute the actions necessary to implement those decisions. Today, we recognize that the primacy of vehicle operating tasks, as shown in Figure 2, is correlated with operator workload and that an increase in workload in any one task will cause a degradation in performance of other tasks.

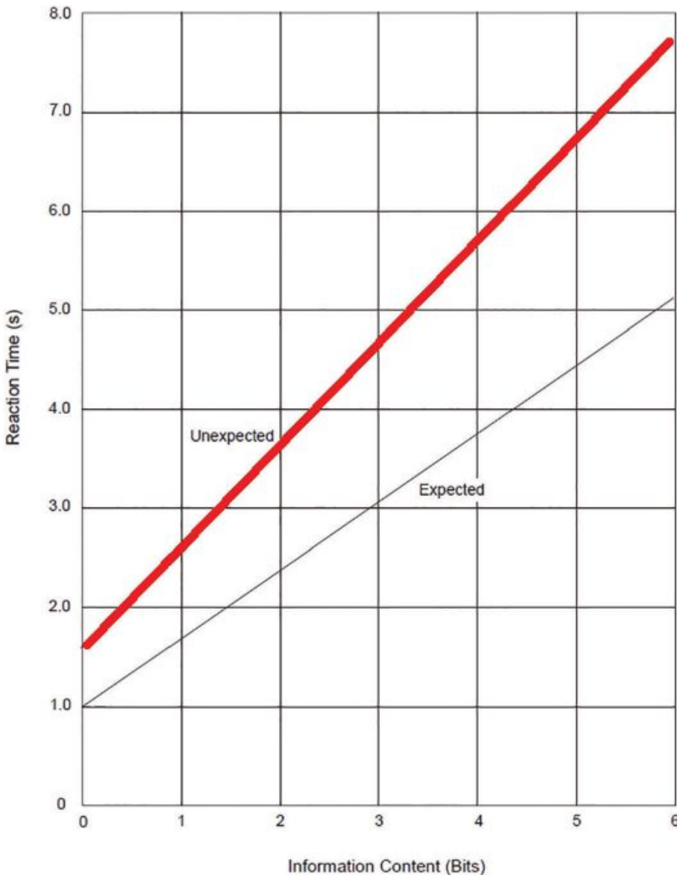

Figure 1. The American Association of State Highway and Transportation Officials (AASHTO) Policy on the Geometric Design of Highways and Streets *addresses the critical issue of information overload and its compounding effect on driver reaction in unexpected situations.*[11]

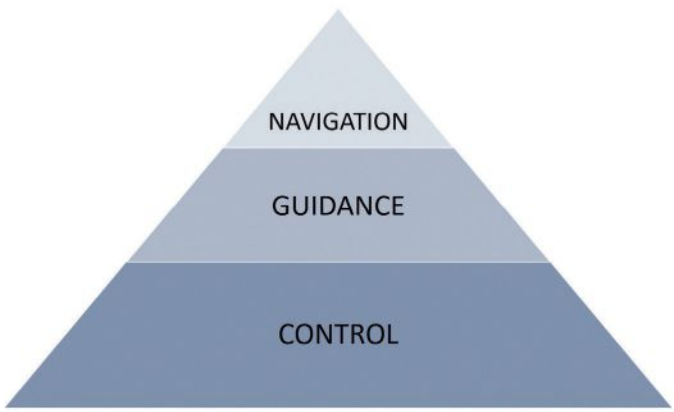

Figure 2. The vehicle operation primacy triangle displays how tasks of increasing primacy and consistent workload form the foundation for tasks of increasing complexity.

The three sub-tasks which vehicle operators undertake (control, guidance, and navigation) are tasks of increasing complexity but decreasing primacy. Although the navigation task may be more complex on its own, the vehicle operator may choose to discard or delay the processing of information related to navigation if the guidance task is consuming a large amount of attention. An example of this phenomenon would be driving in a heavy rainstorm, at night, on a roadway with poorly-maintained pavement markings. Attention devoted to navigation will be decreased and the result may be missed signs, missed turns, and route corrections that further complicate the navigation task. The priority of the guidance and control tasks is a result of the inherent primacy of those tasks, that is, the immediate conditions under which the tasks must be performed. When the workload of a task is reduced, other tasks of increasing complexity can be performed without compromising the necessary attention required by the primacy of keeping the vehicle on the road and between the lines. Easing the guidance task on that dark and stormy night may be simply a matter of installing raised retroreflective pavement markers or roadside delineation. The control task may also be similarly aided with driver assistance technologies, including dynamic stability and traction control systems.

The Federal Aviation Administration has long understood the significant implications of task primacy and workload, particularly related to aircraft instrument approaches. Single-pilot operation under Instrument Flight Rules (typically occurring in meteorological conditions that prevent a view of the ground and horizon) has been recognized as particularly conducive to task saturation.[12] While the use of automatic pilot systems, even on small general aviation airplanes, serves to greatly reduce the workload of the control and guidance tasks, such use may also result in decreased situational awareness and the loss of pilot attention to the navigation task. The implications are severe and include terrain and obstacle incursions, often following loss of orientation and control upon deactivation of the automatic pilot.[13] The lessons for automated vehicle deployment from aviation are readily apparent: tools used to facilitate workload management and the control and navigation tasks must be carefully evaluated to ensure they do not adversely impact other tasks, such as guidance.

The design of traffic signing, pavement markings and delineation, and roadway geometry can influence the complexity of driving tasks. The workload associated with the control task is generally a factor of vehicle ergonomics, driver state (e.g., fatigue, impairment), and driver distraction. Workload in the guidance and navigation tasks, on the other hand, is highly correlated with the roadway networks developed by planners and the traffic control device systems designed by engineers. Insufficient pavement markings or ambiguity in signing can dramatically increase the workload for the guidance and navigation tasks, respectively, compounding any workload increase associated with additional demands in the control task.

One of the requirements for traffic control devices, according the MUTCD, is that they present a clear and simple meaning.[14] This points to the need to directly correlate pavement marking patterns with specific use cases and to place signs in such a way that they are not likely to be improperly interpreted. This can be demonstrated by a study of the signing locations in Figure 3, in which depictions 1, 2, and 3 display the sequential views encountered by a driver in a roundabout on one side of a conventional diamond interchange.

In depiction 1, the first sign seems to indicate to the driver that the ramp just beyond the sign is the ramp for I-35 southbound. However, as the user approaches that exit from the roundabout, another sign, indicating I-35 northbound, is also in view and could be interpreted as providing conflicting information owing to its proximity to the first ramp. If the driver had missed the first sign due to its placement (reference depiction 2), they could interpret the I-35 northbound sign as referring to the entrance ramp nearest them (i.e., the I-35 southbound ramp) due to the close spacing of the ramps and the placement of the second sign.

In this example, resolving a navigation task discrepancy could cause the guidance and control tasks to suffer. The vehicle may wander from the operator's intended path or the operator may miss important cues regarding the geometry of the roundabout, resulting in lane departures. In some cases, including on high-speed roadways, users will stop at a decision point in an attempt to focus the entirety

Figure 3. A sequence of signs within a roundabout indicates how the proximity of signs to a decision point and the location of signs relative to a decision point can lead to confusion.

of their attention on the navigation task. If the control and guidance tasks are given increased primacy, a navigation error may instead occur, leading to an incorrect turning movement choice.

A road safety audit involving human factors practitioners and traffic engineers qualified in human factors applications could help resolve these issues, even prior to the opening of the roundabout or during the design phase of the project. In similar situations, additional route marking, delineators in the gore areas, and relocation of signing are all potential measures to reduce the navigation workload and restore balance to the vehicle operation tasks. Traffic engineers with human factors training and human factors specialists have the ability to understand and quantify how changes in traffic control device deployments can help reduce workload. They can make specific recommendations on the design of the devices, the sequence and placement, and the interrelationships between various traffic control devices. These professionals can also help guide traffic engineers working to revise standards by evaluating new designs for traffic control devices and new applications, particularly those in urban areas, ensuring that what is new can be evaluated with an engineering study to determine that it will not have a negative impact on road users.

Human Factors Expertise and Training

The application of human factors knowledge to the operators, vehicles, and infrastructure results in significant benefits to society. Many transportation professionals already have the desire to reap the safety and efficiency benefits of applying human factors principles in the design of new traffic control devices, traffic management centers, urban and rural roadways, and even their own workspaces. Human factors practitioners can bring these desires to life in three key ways.

First, human factors experts such as behavioral and social psychologists bring expansive knowledge about topics such as human vision and auditory systems related to sensing and perceiving information; cognitive processing mechanisms, especially as related to attention, distraction, comprehension, judgement, workload; age-related processes that affect younger or older road users; and social and organizational elements that affect user acceptance and institutional adoption. Additionally, there is rich human factors literature that addresses how these processes occur in and impact transportation-related tasks. For instance, the Federal Highway Administration (FHWA) has one of the premier human factors laboratories in the world and has produced a variety of core research efforts in many areas including traffic control devices, older drivers, pedestrian safety, and automation and advanced vehicle systems.[15]

Second, human factors experts bring specialized skills that aid in research, experimentation, and independent and objective evaluation activities. This includes a variety of widely used activities such as task analysis, experimental design and statistical analysis, knowledge elicitation, surveying and focus group facilitation, institutional analysis, collaborative design, usability evaluation, and user experience testing. In order to obtain valid and reliable findings, it is necessary to ensure that methodologies are independent of domain, organizational, or personal biases, such as those of the planner, engineer, or road user. Human factors experts are highly skilled in ensuring this objectivity and such emphasis on validity in research results ensures outcomes that can be confidently applied to policy and design guidance.

Finally, human factors professionals who work in the transportation industry have played a key role in developing guidance for practitioners. This guidance is often integrated into traditional practitioner resources such as the MUTCD and AASHTO's *Policy on Geometric Design of Highways and Streets*. Human factors experts have also created stand-alone guidance and the premier example of this is the *Human Factors Guidelines (HFG) for Road Users*.[16] The HFG is another resource in the practitioner toolkit and its use will enhance initial planning and design activities, aid in diagnostic safety processes, and support the selection of safety countermeasures.

As history demonstrates, human factors professionals are working diligently in a variety of industries, and with this variety, they bring a range of educational backgrounds and hands-on work experiences. Specialized education in human factors is available at both the undergraduate and graduate level in a variety of disciplines, including psychology, engineering, and computer science. The Human Factors and Ergonomics Society (HFES) is a good resource for examining educational elements of human factors and career guidance; additionally, HFES has several special interest technical groups in relevant areas such as Surface Transportation, Aerospace, Aging, Forensics, and Computer Systems.

Part 2 of this article on *Designing for People* in the June issue of *ITE Journal* will demonstrate how human factors principles have benefited the transportation system and provide an overview of the various approaches transportation planning and engineering professionals can use to bring human factors expertise into the work of improving our transportation system and saving lives. **itej**

References

1. Human Factors and Ergonomics Society. "Educational Resources, Definition of Human Factors." HFES.org. www.hfes.org/Web/EducationalResources/HFEdefinitionsmain.html. Accessed February 18, 2016.
2. *Manual on Traffic Control Devices*. "Experimentations." mutcd.fhwa.dot.gov. http://mutcd.fhwa.dot.gov/condexper.htm. Accessed February 23, 2016.
3. Donald A. Norman. *Design of Everyday Things: Revised and Expanded*. New York: Basic Books. London: MIT Press, 2013.
4. Mark S. Sanders & Ernest J. McCormick. *Human Factors in Engineering and Design* (Seventh Edition). New York: McGraw-Hill, 1993.
5. Ibid.
6. Norman, *Design of Everyday Things: Revised and Expanded*.

7. U.S. Nuclear Regulatory Commission. "Three Mile Island Accident." nrc.gov. www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.pdf. Accessed February 24, 2016.
8. Harold R. Booher. "Human Factors Integration: Cost and Performance Benefits on Army Systems." *Army Research Laboratory Report DAAL01-95-C-0121* (1997).
9. Clare-Marie Karat. "Cost-Benefit Analysis of Usability Engineering Techniques." Proceedings of the Human Factors and Ergonomics Society Annual Meeting (October, 1990) 34: 839–843.
10. *A Policy on Geometric Design of Highways and Streets* (Sixth Edition). American Association of State Highway and Transportation Officials: 2011, pages 2–40.
11. Ibid., pages 2–41.
12. Murphy, Kevin D. *Single-Pilot IFR: Is it Safe?* Instructor Reports Series, Air Safety Institute, Aircraft Owners and Pilots Association: May 2004.
13. General Aviation Controlled Flight Into Terrain Awareness. Federal Aviation Administration, Advisory Circular 61-134: April 1, 2003, page 5.
14. *Manual on Uniform Traffic Control Devices* (2009 Edition). Federal Highway Administration, Section 1A.02.
15. Human Factors Laboratory, Federal Highway Administration Research and Technology. fhwa.dot.gov. www.fhwa.dot.gov/research/tfhrc/labs/humanfactors/. Accessed March 7, 2016.
16. John L. Campbell, Monica G. Lichty, James L. Brown, et al. "Human Factors Guidelines (HFG) for Road Users, Second Edition." Transportation Research Board, *NCHRP Report 600*: 2012.

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