Introduction to Humans in Engineered Systems

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Dedicated to Karen Remington, Stuart Davis, and Valerie Greaud Folk
for all their love and support during this project, as always.

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Preface

Courses on human factors, human-system integration, engineering psychology, human-computer interaction, or applied psychology, though varying in specific content or approach, all share a common concern with the human as part of a system built by humans. The title of this book—*Introduction to Humans in Engineered Systems*—reflects that common link. Our core idea was to develop a program for the study of human-system integration based on the combination of a concept-oriented text with a flexible, interactive website. The book is designed to introduce major concepts and principles common across the various disciplines. As an integrating factor, the material is organized around the flow of information in control theoretic diagrams. A high-level treatment of control theory is a powerful way to link the various system elements, including the human, and to guide the analysis of real-world situations. The website (http://www.wiley.com/go/remington) provides a resource for pursuing topics in more depth. The website is conceived as a collection of exercises complete with the necessary programs to demonstrate concepts, case studies that provide a foundation for discussion, links to interesting demonstrations online, and material on topics not covered in detail in the text.

One of the underlying principles of control theory is that the behavior of human operators cannot be fully understood in terms of just mental and physical capabilities. It is necessary also to understand the goals the operator attempts to attain, the system being controlled (aircraft, car, computer), and the influence of the environment in which the system is embedded (including other people). The organization of the text reflects this focus on the human in context by treating four broad thematic areas.

Historical Perspective. This section is designed to prepare the reader for the material in later chapters by providing a fundamental understanding of the human as a component of a system. The concept of human-system integration is introduced with emphasis on systems-level thinking. A brief history chronicles the key role that usability has played in technological progress throughout human history, and documents how the increasing complexity of machinery and manufacturing has given rise to the modern study of human-system integration. Related disciplines (e.g., organizational psychology, engineering psychology) are discussed in terms of how they overlap with, or are different from, human-system integration.

The Environment. This goal of this section is to build awareness of the range of challenges posed by environments that characterize home and work. The key concepts introduced are adaptability and complexity. Because people are adaptable, the demands and incentives of the environment itself are strong determinants of behavior. Reliance on adaptability is seen in management approaches that emphasize a rule-governed, procedural, or incentive-based environment. Limits on adaptability are introduced through a discussion of environmental complexity and its role in human-system performance. Comparisons of fields such as medicine, transportation, and human-computer interaction provide examples of how different environments place different demands on human performance.

This section also introduces the kinds of quantitative techniques that characterize modern human-system analysis. This introduction will familiarize students with task analysis techniques, information theory, finite-state analysis, and signal-detection theory; and provide a brief introduction to human-system modeling. The key organizing concept introduced here, and used throughout the book, is control theory. Control theory is treated at a conceptual level to provide a framework for representing the flow of information in a way that highlights the interaction of all the components of the system. We introduce noise as a real factor in performance, and emphasize the contribution of feedback and lag as issues in human usability. Thus, this section is designed to provide the concepts and knowledge necessary to recognize the potential for user-related issues.

The Human Element. In the first two sections, the human is treated as an adaptable component of the entire system. This section introduces the student to the limits on that adaptability by characterizing human capabilities and limitations in information processing. The control theory framework is again used to represent the flow from perception to situation understanding, from situation understanding to action, and from action back to perception. The key points are not just that people have limited processing capacity, but that we are limited in particular ways which have implications when humans occupy decision-making roles in complex systems. Although all of the many aspects of human behavior are potentially relevant to human-system performance, this section focuses on key characteristics that strongly shape behavior in human-system interactions. To aid students in understanding the range of behavior, we distinguish the characteristics of human behavior associated with the *structural* properties of the human information-processing system (i.e., the visual and auditory sensory systems, the role of attention in mediating perception, and limits on multitasking) from those associated with the *contents* of the information-processing system (i.e., memory storage/retrieval and decision making/action selection). Structural factors in general determine the limits on how much information can be processed, whereas content factors determine how that information is used. We emphasize that this distinction is somewhat artificial, in that behavior is ultimately the joint product of these two. Nonetheless, it can be helpful to students in making sense of the large body of literature on human behavior.

Human-System Integration. Up to this point, students have been presented with a broad understanding of the discipline, knowledge of techniques for inquiring into system performance, and how the information-processing and decision characteristics of humans shape performance. In this final section, we present an analysis of an illustrative case history (the *Exxon Valdez* disaster) with the goal of showing how concepts and principles in the first three sections can be applied to the analysis of real-world situations, again within the context of a control theory framework. The key idea is that common intuition can be replaced by a structured approach to thinking about systems outcomes. Thus, this section examines how the environment, the human element, and the task to be performed come together to affect system performance. Operational constructs of situation awareness, workload, human error, and usability are discussed in terms of the underlying psychological principles developed in the first three sections.

The website (http://www.wiley.com/go/remington) complements the text and is structured around modules. Each module is structured into sections, as appropriate, including the goal of the module, description of the exercise, materials needed, instructions, readings for further information, and reference to the corresponding book section. Some modules contain questions and descriptions of case studies that can be used as the basis for discussion. Others contain interactive exercises that either demonstrate phenomena (e.g., control order) or provide opportunities for students to further explore material described in the book (e.g., task analysis). Links to demonstrations available on the web that illustrate basic psychological phenomena are also provided. Finally, some modules focus on material not covered in depth in the text (e.g., anthropometry). The website is designed to grow over time to include additional modules and materials; we also intend to update the modules to keep the material fresh. For example, we anticipate that as new technologies (for example, the iPhone) are introduced, articles and examples of them will be incorporated into the site. The instructor can tailor these modules to meet various pedagogical goals. Some of the modules will be suitable for undergraduates at the junior or senior level, others more suitable for graduate courses. Instructors also can select web modules as desired to focus on topics as they see fit. Thus, engineering departments may choose modules associated with finite-state modeling of systems, whereas human factors courses may focus on the task analysis modules, and engineering psychology classes may omit both and instead add extra modules on auditory processing. We hope that instructors who adopt the book will contact us with suggestions for new topics that they would like to see covered.

As with any project, this one consumed a great deal of time and effort. We thank those who helped us along the way, including Shayne Loft, Beth Lyall, Jennifer McKneely, and Hal Pashler, who read the book and provided us with many suggestions for improvements (although they should not be faulted for any remaining inaccuracies); and Rebecca Davis, who helped us with reference checking and indexing, as well as editorial feedback. We thank David Kidd, Brian Taylor, and Nicole Werner, who developed the initial ideas and structure for the exercises included in our website. We also thank our (very) patient spouses, Karen Remington, Stuart Davis, and Valerie Folk, who gave us the space we needed to produce the program we desired. Without their support, this project would not have been possible.

Roger Remington, Deborah Boehm-Davis,
Charles Folk

Part I

Historical Perspective

On 19 April 1770, James Cook, captain of HMS *Endeavor*, made the first direct recorded observations of the indigenous peoples of Australia, commonly referred to as aboriginals. They were of the Greagl tribe, whose territory was the area around what is today Sydney in southeastern Australia. The Greagl were but one of thousands of small groups of hunter-gatherers scattered across the continent. To the European sailors, the aboriginals seemed desperately primitive. For the most part they were naked, bathed in the grease of a native marsupial (the Australian possum) to protect them from the swarming flies and mosquitoes. They built no impressive shelters, nor did they appear to have permanent settlements. The sailors had previously encountered primitive natives in Patagonia along the banks of the Straits of Magellan. Yet the aboriginals seemed to lack even the accoutrements of these primitive natives. Despite this, the aboriginals showed a high degree of social organization, had a remarkable knowledge of the flora and fauna of their territory, possessed an impressive array of hand tools for hunting and fire sticks for keeping fires lit, and were skilled at acquiring ochre and other minerals for painting. As many Europeans would discover to their dismay, their spears could strike with deadly accuracy, and they were skilled in the use of spear throwers. European explorers and settlers were also to discover new tools, as for example, the boomerang and didgeridoo. Everywhere the explorers of the great age of discovery ventured and found people, they found sophisticated tools adapted to the needs of the local people and to which the people owed their existence.

Humans, it seems, are natural engineers. Evolution has imbued us with the capacity and compulsion to sculpt the environment in ways that not only enhance our ability to survive, but also just make the task of living “easier.” Think about it: from the time we wake in the morning until we go to sleep at night, we are surrounded by a world of our own devising, an engineered environment. Alarm clocks wake us; refrigerators keep our food cold; stoves and microwave ovens heat our food; clothes keep us warm; automobiles or trains or busses take us to work, where we communicate and create using telephones, computers, and (the newest of creations) small handheld devices that instantly put us in contact with even the most remote places in the world. The companies and institutions in which we work are themselves engineered environments. The rigid hierarchy of one company shares with the free-flowing egalitarianism of its competitor the fact that each was created to fulfill a specific vision, to achieve a goal. On a larger scale, our society, though much more complex and difficult to manage, is itself a product of our own engineering. Laws are made with the express intent of achieving some societal outcome. Even customs are often vestiges of explicit solutions whose ancestry may or may not be traceable.

It appears that we were engineers from the very beginning. Using mitochondrial DNA (mtDNA) passed from mother to offspring, geneticists trace a common female ancestor of all living homo sapiens, “Eve,” to around 200,000 years ago (Cann, Stoneking, & Wilson, 1987; Penny, Steel, Waddell, & Hendy, 1995). Similar analyses of the male Y chromosome yield a roughly comparable date (Cavalli-Sforza & Feldman, 2003; Mitchell & Hammer, 1996). Yet, archeologists have found flaked stone tools for cutting and hewing, made with considerable skill, dating from about 2.5–2.6 million years ago (Dominguez-Rodrigo, Rayne Pickering, Semaw, & Rogers, 2005; Sileshi, 2000). Not only are we engineers, we are descended from engineers. Indeed, it is not too speculative to suggest that our prowess as engineers facilitated our success as a species. There was a shift in climate around the Pliocene-Pleistocene boundary roughly 2.5–1.8 million years ago in which grasslands took over from dense forest, exposing our ancestors to new and dangerous challenges (Bobe, Behrensmeyer, & Chapman, 2002; DeMenocal, 2004; Reed, 1997). This created something of an evolutionary bottleneck: of the many proto-humans who existed at the time, only a few thousand emerged to give rise to the *Homo sapiens* of today. It may well have been our ability to engineer our societies and our tools that made it possible to survive.

It is true that many animals also engineer tools and alter their environment. Birds build nests, beavers build dams and lodges, termites and bees build hives, and crows have been observed to use rocks dropped from above to break shells. What makes us different is not just that we do more tool-making or more environmental modification (damage if you are of one ideological persuasion). More so than any other species, we humans seem to come equipped with characteristics particularly adapted to engineering.

For example, one important skill for engineers is the ability to build on previous successes. This skill requires being able to observe and learn from the behavior of others. In turn, learning from others includes formal instruction—another engineered system, devised for a purpose—but also informal learning, which occurs by mimicking the behavior of other members of a society. Studies have shown that children will observe an adult or an older child and repeat the actions they observe. In an experiment run on Australian and African children (Nielsen & Tomaselli, 2010), the children observe an adult going through an elaborate series of steps to open a rather odd-looking box. When presented with the box to open, the vast majority of children mimic the actions they have seen. The interesting outcome is that children above the age of four tend to mimic even when they know an easier way to open the box. Children under four years of age tend to use the simpler method they know to get the box open.

This kind of mimicry is not characteristic of even our closest kin, the great apes. It appears that as human children develop, they reach a stage of social maturity where it becomes important to pattern their behavior after that of other members of the group. The importance of this patterning is not simply that it builds social acceptance and cultural identity, but that it provides a natural mechanism for the transmission of skills, one of which would be the design and manufacture of tools. By observation, then, without overt instruction, children learn to manipulate the world in ways like others of their group do. In this example, we see the foundation for the accumulation of skill and knowledge, and for its transmission from one generation to another.

So, it is abundantly clear that humans are uniquely equipped to engineer their environments. Indeed, we live in a world full of overlapping engineered systems of which we all are a part. But how “good” are these systems? To what extent do they achieve their intended goals? How efficiently, reliably, and safely do they do so? One could argue that systems engineering simply follows a kind of natural selection process, with better systems “surviving” in such a way that there is always movement toward better and better (i.e., more efficient and reliable) systems. The development of tools is certainly one example of this kind of process.

In the past seventy years or so, this process has been accelerated by applying the tools of science to the evaluation and development of engineered systems (see, e.g., (Fitts, 1958). Driven by wartime increases in the technological complexity of the “tools of war,” as well as their often-puzzling failures, psychologists and engineers began to systematically study the kinds of factors that influence the success and failure of human–machine systems in general. What has become clear from this study of “human engineering” is that understanding such systems requires a careful analysis of the environment, the human participant, and their interaction.

This book addresses the central conceptual issues associated with each of these three facets of human engineering. It is not meant to be an exhaustive compendium of the relevant research in these areas. Rather, it is meant to introduce students to the main concepts, assumptions, and approaches that have emerged in the study of human engineering. More detailed study of particular issues is available in the accompanying online modules. The book is organized into four sections. Part I provides historical context for the modern study of human-engineered systems, and also gives an overview of some of the real-world settings in which human engineering has been successfully applied. Most of the examples are drawn from aviation domains. In part this is because of the intense and long-standing concern over human error and safety in commercial aviation, as well as performance in military aviation. It is also because aviation environments demand much of the human operators, be they pilots, air traffic controllers, or maintenance workers. Where possible, we include examples from medicine, computer science, and driving. It must be noted, however, that the systematic study of human behavior is a much more recent development in those domains than in aviation. Part II focuses on the nature of environments, how they differ, what creates complexity, and techniques for modeling those environments. Part III focuses on the nature of humans, and their capabilities and limitations. We constrain our treatment of the vast literature on human behavior by shaping the discussion around characteristics that determine which of the many sensory events are perceived, how we construct meaning from sensory input, and how we select an action from many possible actions. Finally, Part IV addresses how the structure and content of the human information-processing system influences the capabilities and limitations of human performance, and shows how these characteristics interact with the nature of environments to affect human error and system safety.

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1

Natural and Engineered Systems

As its title suggests, this book is concerned with how humans interact with engineered systems. This immediately raises questions as to what we mean by an engineered system, what other systems might exist, and how an engineered system differs from other systems. Can the natural environment be considered an engineered system with evolution (natural selection) as the design driver? If not, what characteristics distinguish evolution through natural selection from the sort of engineered systems that are the topics of this book? Where can we draw the boundary?

In our view, the difference between natural and engineered systems is a function of three factors:

1. Design for a purpose
2. Design for a certain class of users
3. Design against failure

PURPOSEFUL DESIGN

Engineered systems have a goal, a purpose lacking in natural design. The modern scientific view of evolution (i.e., natural design) holds that there is no goal either at the level of an individual organism, a species, or an ecosystem as a whole. Rather, evolution uses mutation to generate diversity and natural selection to eliminate variants that are less competitive. According to modern theory, the world we see around us is the result of billions of such experiments having been conducted over billions of years. The natural world exists as it does because it worked, not because someone wanted it to work that way.

Contrast this with any of the millions of tools we have engineered, each with a clear purpose. Razors are meant to cut hair, clothes to be worn, televisions to project pictures, and so on. Even a computer, a device with multiple purposes, is really a mega-tool used to run software for doing specific jobs. Compare the modern racing bicycle with a cheetah. Every feature of the racing bicycle has been carefully crafted for speed. Design teams developed specifications, prototypes were constructed, and through iterative testing and modification the final product emerged. Similarly, the features of a cheetah are also shaped by the need for speed. The difference is that whereas the bicycle was deliberately designed for the purpose of speed, ancestors of the modern cheetah who were slightly faster than other of their species were able to exploit a niche and eventually their own species. The cheetah wasn't designed with the goal of running fast; that ability evolved because it proved useful to run fast. Successive generations of selective pressure have given the cheetah the speed and body characteristics it now possesses; those cheetah ancestors that were poorer runners left fewer of their genes surviving into the next generation.

This sense of purpose doesn't end with tools or instruments. It also characterizes how we organize ourselves into working, military, and social units, as well as our financial systems and educational institutions. Our laws are intended to produce a social environment that meets the expectations of its people and government. For example, the strict hierarchies that characterize military command structures, the organization of businesses, and even some social structures are desirable when it is important to guarantee top-down control over individuals and smaller units. It is true that hierarchies are a natural way for humans to think about structures, and because of this, hierarchies could be seen as natural forms of social organization shaped by evolution. But that would be overstating the case. When the need arose for more rapid decision making in the business domain, hierarchies were abandoned and more flexible control structures adopted—most notably by high-technology start-up companies—to reduce delays in getting products to market and to take advantage of rapid advancements in technology. Similarly, in military domains where high reliability is essential (e.g., aircraft carrier operations), strict command structures are relaxed to improve the reliability of information transfer (Pfeiffer, 1989). Thus, the trend toward decentralization has been driven by a deliberate desire to reap the benefits of more egalitarian organizations. The fact that it is often difficult to achieve the desired social or institutional engineering results does not reflect a general lack of deliberate purpose. Rather, it emerges from trying to engineer a complex system, one in which there are many decision makers, each pursuing goals that may or may not be compatible with those of the lawmakers or each other.

In differentiating engineering from natural selection, we do not mean to say that every implication of an engineered system, whether a nuclear power plant, organization, or society, is completely determined at the outset. On the contrary, trial and error—largely through iteration in the design process—has been the dominant paradigm in engineering, whether in the development of the modern graphical user interface, organizational structure, or social policy. The point is that these iterations are driven specifically to achieve a clearly stated purpose (fly faster than the speed of sound, win the battle, give a competitive advantage). The process reflects this purpose-driven engineering. At each stage of design, teams of engineers evaluate all aspects of the prototype system with respect to its purpose. Only when the system meets a set of predetermined criteria, which have been derived from a statement of goals, will it be fielded.

USER-CENTERED DESIGN

The second factor, design for a certain class of users, points to another deep difference between engineered and natural systems. We build tools, engineer social systems, write music, and create art, all with the intent that our product will be used or appreciated by other people—not just as an audience but also as active users. The identification of the intended user is a critical step in engineering design. We even build special devices for animals. Some of the earliest tools include harnesses that make it possible for animals to pull carts and chariots. More recently, adaptive devices for disabled pets have become more common.

Perhaps it is counterintuitive, but nothing is more illustrative of user-centered design than the arts: music, painting, literature, theater, and the cinema. On the surface, watching a movie or viewing a painting may seem to be a passive activity, but that is only because we cannot directly see the mental state of the viewer. In truth, a movie or painting is successful only to the extent that the human user actively engages with it; that is, to the extent that it evokes some emotional or mental response in a viewer. It is perhaps easier to see how designing for human use plays a role in video games and virtual environments, where it is important to have displays and controllers that not only work well, but also allow the person to become immersed in the artificial world (see, e.g., Bystrom, Barfield, & Hendrix, 1999; Cunningham, Billock, & Tsou, 2001; Ellis, Kaiser, & Grunwald, 1993). In a broader sense, this is true for all engineered systems. Indeed, the fact that success depends on a fit with human physical and mental characteristics is central to this book. If one devises a spear that is too heavy to be thrown or a social system that is unresponsive to human needs, those systems will fail.

Although it is easy to understand the examples of how a spear that is too heavy, or a computer mouse that is too sensitive, represent a poor fit to human capabilities, it may be a bit counterintuitive, or even controversial, to maintain that successful social systems are "designed" around human characteristics. After all, societies seem somehow organic, more an accumulation of customs and laws than a planned enterprise. They seem more like the twisted, crowded alleyways of old, medieval towns than the stately promenades and grid layouts of planned cities. Yet, some insight into the role of human nature can be gleaned from examining the "utopian" societies that have been established from time to time.

According to some sources, some 3,000 experimental utopian societies have been documented in human history, the vast majority of which have been in the United States, predominately in two periods: the early 19th and middle 20th centuries (Oved, 1993; Sosis, 2000; Sosis & Bressler, 2003). Many of these attempts at ideal societies were based on religious principles. Indeed, the Puritan settlement of New England and the Quaker settlement of Pennsylvania were in the main attempts to establish communities that embodied their religious beliefs about what constituted a perfect society. In the early 19th century, several communal societies were established based on religious principles, including the Shaker community in New York; the Amana Colonies, the Zoar Colonies, and the Bishop Hill Colonies; and Harmony, to name just a few (Oved, 1993). Shortly thereafter, secular communal colonies began to spring up, many of them based on the theories of social philosophers such as Charles Fourier (brought to the United States by Albert Brisbane) and Robert Owen. A basic tenet of these utopian societies, whether religious or secular, was the abandonment, or sublimation, of the twin concepts of ownership and competition in favor of communal property and cooperation. Virtually all of these utopian attempts were abandoned within twenty or thirty years of their initial establishment (Oved, 1993; Sosis, 2000; Sosis & Bressler, 2003). The principal reasons had to do with internal discord arising from conflicts in the distribution of goods and disparities in the degree of perceived cooperative effort (see, e.g., Sosis & Bressler, 2003). As a species, we appear to be possessed of a complex mix of traits, some of which encourage us to adopt group identities and cooperation, while others foster individual gain and competition. These perfect societies failed, in part at least, because they explicitly and knowingly rejected the individual orientation basic to our nature.

Nevertheless, a few of these societies flourished for far longer than others, and some are still with us today. The Hutterites, originally a 16th-century German religious group that later settled in the United States, still live in small communal settlements (Peter, 1987; Wikipedia, 2009), as do the Amish and Mennonites (Smith, 1981). An analysis of 250 such ideal communities of the early 19th century attributes success to strong religious and cultural pressures both to participate in cooperative endeavors and to support others in the community through the distribution of goods and labor (Sosis & Bressler, 2003). It is interesting to contemplate these successful societies as experiments that provide insight into the characteristics of the human social constitution.

Which characteristics of the user community are important considerations depend, of course, on the purpose for which the device or system is constructed. The social tendencies of humans may matter in the founding of a society, or the development of interactive websites, but will be less critical to the design of a new mouse or pointing device, the success of which will depend more critically on characteristics of the human motor system. Regardless, all human-engineered systems, in the sense we mean here, share the property that they are intended for use by an external agent. Very few systems in the natural world have use by an external agent or organism as the principal design feature. Indeed, antelope are not designed to be food for lions. Quite the contrary: Evolution has equipped them with mechanisms to thwart predators. A few anatomical structures, such as sexual organs (genitalia) and the mammalian nipple, do seem to have evolved to be used by other members of the same species. Still, even in these cases, it could be argued that these are adaptations designed to increase the chance of passing on an individual's genes. Nonetheless, the fact that engineered systems are designed for specific users has an important implication: It means that the designer must understand the physical, mental, and emotional makeup of the user community. For example, it will not do to create a social structure that many will feel is unfair, just as people will not adopt computer software that is too difficult to use. Designing for others requires an understanding of how people perceive fairness. Likewise, it will not do to devise a tool that people find too effortful to use or too complicated to learn.

DESIGN AGAINST FAILURE

Natural selection succeeds by failure. That is, better fit individuals outperform less fit individuals. We do not mean to restrict this to the overly simplistic notion of 19th-century social Darwinism. There are many strategies to succeed in nature, and often-popular conceptions of conflict and competition omit the more important qualities of cooperation, friendship, intelligence, talent, and sociability. Nonetheless, the process of natural selection means that some organisms will fail. Mutation, the key to variability, is itself most often deleterious, leading to failure more often than to success. The difficult quest for food and mates also takes its toll.

In contrast, success by failure is not a particularly desirable approach to design for human-engineered devices, social systems, and entertainment. We do learn from failure, more perhaps than we learn from success. But, unlike natural selection, engineering design is often geared toward preventing failures, as they can incur substantial cost. Indeed, we have engineered laws that more often than not allow us compensation in the case of failure. Among other things, this makes failure very expensive for the designers. Then too, as our systems become more complex, with the lives of many people depending on their success, failure can become a tragedy. Thus, we cannot have aircraft design eventually succeed by having the poorer designs crash (though this occurred frequently in the very early history of powered flight). The same is true of cars, trains, medicine, and many other endeavors. As a result, aircraft designers spend years developing and testing all the systems that go into a new aircraft before that craft is actually produced. This is true of many industries. Failure is, we hope, confined to the design process.

Nonetheless, it is expensive to produce a complex device that is as free of defects as needed. The capital investment in research and development is a major expense for many companies. Not only is it expensive, but adequate testing also can add years to the development cycle. For example, in 2011 Boeing announced further delays in the development of its 787 Dreamliner, which has direct financial implications for the many airlines that have placed orders for these aircraft.

The process of designing and testing to eliminate failure is a rigorous engineering discipline. Not only does it include the physical and software systems, but it has also increasingly come to include the human response to the new system. The reason for this concern with the human operator is that as engineered systems have become increasingly complex, human behavior has remained much the same—and it will continue to be the same, at least for the near future. The role of the human in engineered systems has evolved with the access to vast amounts of data, linked communication systems, joint activity by several team members, and the requirement to make rapid analyses and decisions in increasingly complex environments, often with the lives of many at stake. Yet, evidence suggests that our brains are not that different from those of our ancestors in antiquity. The burden is on designers of modern information systems to understand the abilities and limitations of the human operator and to ensure that information presentation and control authority are predicated on these abilities and limitations.

The complicated logic of modern computerized devices can baffle even the most experienced users. When advanced automation was introduced into modern aircraft, there were numerous incidents in which the pilots made poor, sometimes disastrous, decisions based on a flawed or incomplete understanding of how the system worked. Add to this the fact that we now carry around with us cell phones, portable video players, and mp3 players that distract us rather than helping us fully attend to the world around us. The potential for cell-phone use to distract drivers has become a real issue, as evidenced by major rail accidents attributed to the train driver being distracted by texting or talking on a cell phone (Associated Press, 2008, 2009; National Transportation Safety Board, 2003, 2009, 2010, 2011).

How have we now reached a point where the devices that are supposed to make our lives better and easier actually make it more difficult? If we have been designing for ourselves for so long, you might think we had solved the problem. In part, this is because designers are only now beginning to come to a formal understanding of how people work. It has often been assumed that with practice people could adapt to whatever was required of them to use a device. We have reached a point where this is no longer true. To see how that has happened, it is useful to consider the historical roots of the practice of engineering for human use.

SUMMARY

This chapter described the differences between natural and engineered systems as a function of three factors. First of all, engineered systems have a goal or a purpose that is lacking in natural design. Second, designs are focused on users. We build tools, engineer social systems, write music, and create art all with the intent that our product will be used or appreciated by other people—not just as an audience but also as active users. Finally, unlike natural selection, engineering design is often geared toward preventing failures, not towards allowing systems to fail through natural selection.

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