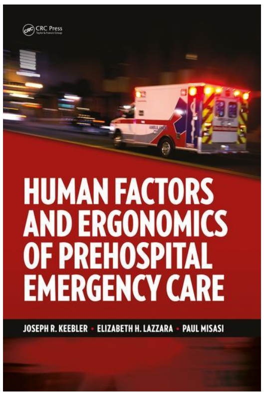

Human Factors and Ergonomics of Prehospital Emergency Care
Critical Essays in Human Geography

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Introduction to Human Factors and Ergonomics of Emergency Medical Services

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1 Introduction to Human Factors and Ergonomics of Emergency Medical Services

Paul Misasi and Joseph R. Keebler

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> Human error in medicine, and the adverse events that may follow, are problems of psychology and engineering, not of medicine.
>
> **John W. Senders**
> *Medical Devices, Medical Errors, & Medical Accidents, in Human Error in Medicine, 1994*

The delivery of emergency medical services (EMS), or what we will interchangeably refer to as *prehospital medicine* (arguably a more accurate moniker*), is a complex enterprise that exists at the confluence of medicine, public safety, public health, and transportation—both air and ground (Shrader, 2015). All but a handful of decades old, it continues to seek its place among the professional domains, especially in the United States. EMS agencies struggle for recognition as a distinct but critical element of the public's safety net and gateway into the healthcare system. Although EMS is generally well respected, it is often forgotten and receives substantially less funding and recognition than its law enforcement and fire suppression counterparts. In 2005, a New York University report investigating the preparedness of the United States' first responders revealed that EMS agencies (apart from fire departments) received less than 4% of federal monies made available in the aftermath of the devastating terrorist attacks of September 11, 2001. Unfortunately, this is a reality that many EMS providers and managers have become all too familiar with. However, EMS professionals continue to

* We recognize also that out-of-hospital medicine would probably be the best fit for the profession; but in aligning this book's vernacular, we chose the former.

forge ahead, and demonstrable progress has been made elevating the professionalism of the domain and the delivery of the service. As we write this chapter, a number of factors are beginning to converge that we believe will only increase the importance that EMS providers, managers, system designers, and leaders place on quality improvement, resilience, safety, and sustainability. Likewise, human factors, systems and industrial engineers, ergonomists, and patient safety researchers will find new and largely untapped opportunities that have been overlooked in the past.

Although certainly not an exhaustive list, we believe four interacting influences are worth mentioning as they bear on the importance of incorporating human factors in prehospital medicine and its systems of delivery. First, a significant leap in the industrialization of EMS was made in the 1980s to the 1990s through the work of Jack Stout at the University of Oklahoma's Center for Economic Management and Research, funded by the Kerr Foundation (Shrader, 2015). Since then, agencies have reconsidered the constraints and the opportunities afforded by system design with an economic lens. Stout's work identified the unique operating and market characteristics of ambulance services that influence the substantial variability in system cost compared to the quality of service, revealing critical elements of system design and operational strategies to optimize the efficiency and the effectiveness of service delivery models (Stout, 1994).

Secondly, the work of Edward Deming and others in the field of quality management has influenced general management theories and has proven the importance of systems thinking as it pertains to business processes and their design and improvement. Perla, Provost, and Parry (2013, p. 172) reviewed how the four tenets of Deming's System of Profound Knowledge are critical to healthcare's ability to make improvements:

- Appreciation for a system: A focus on how the parts of a process relate to one another to create a system with a specific aim
- Understanding variation: A distinction between variation that is an inherent part of the process and variation that is not typically part of the process or cause system
- Theory of knowledge: A concern for how people's view of what meaningful knowledge is impacts their learning and decision-making (epistemology)
- Psychology: Understanding how the interpersonal and social structures impact performance of a system or a process

As will become evident throughout this chapter and this book, there is a substantial overlap between the sciences of improvement and human factors across all four of these areas.

Thirdly, in 2012, the American Board of Medical Specialties approved EMS medicine as an official subspecialty of medicine, recognizing the unique environment, the distinct body of knowledge and skills necessary, and the constraints of care delivery, and the American Council for Graduate Medical Education subsequently began awarding fellowships in EMS.

Lastly and arguably the most influential in the United States, the Affordable Care Act of 2010 has begun to remodel payment incentives from a volume-based, fee-for-service standard to a quality of care paradigm. Although EMS has not been explicitly targeted by payers for a demonstration of value and quality as a contingency for reimbursement, leaders in the industry realize that the clock is ticking. Efforts to prepare for this eventuality are currently underway with an initiative known as *EMS Compass*, funded by the National Highway Traffic Safety Administration and administered by the National Association of State EMS Officials. One goal of EMS Compass is to develop the practical metrics by which EMS agencies can demonstrate quality and value before those metrics are developed and imposed by external agencies with less interest in their feasibility (National Association of State EMS Officials, 2015).

To summarize, as EMS rightfully aligns itself more closely with healthcare, the Affordable Care Act has communicated and codified *that* it is imperative to demonstrate quality and value of service; EMS Compass efforts that are underway will assist with the identification of *what* requires our clinical and managerial attentions, and through a grounded understanding of human factors and systems engineering, we can learn *how* to intervene in meaningful ways that do not rely on perfect knowledge, perfect skill, or perfect performance from providers at the “sharp end” to achieve improvement.

Ambulance services throughout Europe and Australia have been incorporating the analysis and the design tenets of *physical* ergonomics for some time and are leading the way in improving the physical safety of providers; meanwhile, their American counterparts are just beginning to update the decades-old standards and specifications for ambulance design to improve safety (see the study by the Commission on Accreditation of Ambulance Services, 2016). We all however, remain a long way from our goal. Maguire et al. (2014) recently published the findings of an Australian investigation, citing that the risk of serious occupational injury for paramedics was seven times higher than the national average and that the fatality rate was six times higher than the national average. Twelve years earlier, Maguire et al. (2002) published findings that the occupational fatality rate for paramedics in the United States was two and a half times higher than the national average.

The scientific investigation of the *cognitive* ergonomics of prehospital care has only begun to scratch the surface. Since the Institute of Medicine’s report *To Err Is Human* (Kohn, Corrigan, and Donaldson, 1999) was released 17 years ago, the science of human factors has increasingly focused on applications in the medical domain—covering topics such as device design and user interface, medication safety, teamwork, effects of stress and fatigue, workflow, cognitive artifacts, expertise, social and organizational cultures, judgment and decision-making—all with the aim of understanding their effects on the safety and the quality of medical care. Efforts have been made to translate the practices developed in other complex sociotechnical domains such as aviation, but prehospital medicine has not gained the same amount of attention from the research community. Thus, this book begins as an endeavor to fill a niche of applying the science of human factors and ergonomics (HF/E) to prehospital medicine, with a hope that it will not only begin an important and continuing conversation between the two disciplines but also open the eyes of everyday practitioners, managers, EMS physicians, and leaders to a science that can aid them in their daily performance of work tasks, preserve and protect their livelihood, help save the lives of their patients, facilitate optimal performance as clinicians, and optimize processes to achieve organizational goals.

Modern healthcare has been called the most complex domain of work known to humans (Gluck, 2008), a statement that was referring to healthcare delivered in controlled settings (i.e., hospitals). EMS providers face these complexities and the additional factors of delivering healthcare in a mobile, volatile, unpredictable, and unforgiving environment. As such, they arguably have one of the most cognitively and physically demanding jobs in healthcare. It is medicine on the front lines, sometimes literally in the trenches. We believe that a book such as this will enhance the current best practices and the methods by which they are achieved. It is our hope that this work leads to new efforts and relationships between HF/E and EMS. With the eventual move of EMS to the Department of Health and Human Services in the United States, this book could help lay the groundwork for a long-lasting relationship between the two fields. This chapter will provide a high-level overview of what HF/E is, what it is not, and how it can and has been applied successfully.

WHAT IS HUMAN FACTORS?

HF/E is a broad, interdisciplinary science based on psychology and engineering that deals with the interface between humans and their work systems. Born out of necessity during World War II,* it integrates knowledge and practice from multiple disciplines, including but not limited to computer science, organizational management, cognitive and social science, ergonomics, engineering, and industrial design (Wickens et al., 2004, 2013). The goal of HF/E is to make systems safe, reliable, intuitive, and supportive of the human operator by enhancing their work experience and optimizing performance (Russ et al., 2013). HF/E science takes a multilevel approach that focuses on individuals, teams, tasks, tools, systems, and organizations to best understand the complexity of the work system. The term *ergonomics* in a pure, holistic sense is defined as the study of work that is broadly inclusive of how the human mind and body interact with information and tools in the environment to achieve the goals of work (Wickens et al., 2013). While this definition is more commonly understood among our European and Australian counterparts, in colloquial American parlance, the term more commonly refers to the design of physical environments, tools, and devices (e.g., chairs, grips, and seats) in a more anthropometric† sense. There are a number of terms that have become common in order to capture the nuances of specialized HF/E practice as the built environment becomes more complex and technical, just as there are various and increasing levels of specialization in medicine (e.g., physician → surgeon → plastic surgeon; physician → orthopedist → hand surgeon; physician → internist → cardiologist). Some examples of these terms include *cognitive ergonomics*, *cognitive engineering*, *cognitive systems engineering*, *macroergonomics*, *usability*, and others that are generally encompassed by the umbrella term of *human factors* (Lee and Kirlik, 2013). However, in HF/E, there is a substantial overlap among subspecialties, and they are not as conveniently distinct as organ systems in the human body or necessarily divided in terms of skill sets as they are in medicine. HF/E is considered a science because its practitioners have usually earned a PhD that requires the study and the application of rigorous scientific

* For a review of the historical development of human factors, see the study by Meister (1999).

† Anthropometry is the science that evaluates the metrics of human sizes, forms, and functional capabilities (Centers for Disease Control and Prevention, 2016).

methods and statistical evaluation for describing a phenomenon with a high degree of reliability and validity, beyond what may be attributable to chance.

Finally, the phrase *human factors approach* is commonly used to mean and is arguably synonymous with the phrase *systems approach*, in the sense that both seek to design systems that support human performance (while accounting for human limitations) and are resilient to perturbations or unanticipated events (Dekker, 2011).

Russ et al. (2013, p. 802) describe that there are two goals for the HF/E application in medicine: "1) support the cognitive and physical work of healthcare professionals and 2) promote high quality, safe care for patients." In relation to prehospital care, HF/E can aid providers, managers, and leaders by enhancing the design of their medication preparations and packaging, tools, gear, ambulances, communication systems, teamwork (from the dyadic, two-person interaction to the much larger multiteam systems), organizational policies, and general work practices. This book is organized to focus on the aspects of the individual, the team, and the organization to holistically capture the delivery of prehospital medicine.

WHAT HUMAN FACTORS IS NOT

When someone says that they are a physician, they have communicated to you that they have a professional doctorate degree in medicine (MD for allopathic physicians; DO for osteopathic physicians), which means that they have obtained the broad knowledge base about the physiology, the pathophysiology, and the treatment regimens of the human body that all physicians receive; what the term *physician* has not communicated is their particular specialty or which branch of medicine they have chosen to focus their practice on (e.g., family medicine, orthopedics, etc.). In the same manner, when someone indicates that they have a doctorate in psychology, it would be incorrect to assume that they are a clinical psychologist who sees patients in an office or a hospital performing talk therapy. This is a leap that is analogous to assuming that all physicians are surgeons, although the converse is certainly true—all surgeons are physicians. Psychology comes in many different flavors (the American Psychological Association recognizes 54 divisions), and along the same lines, engineering has four main categories, with many branches and divisions. Thus, when someone says that they are a human factors engineer (or human factors psychologist), they have told you that they have a broad base of knowledge and training in cognitive/social science as well as in industrial/systems engineering. What they have not told you is their particular specialty or interest(s) of study, for example, psychophysics, visual perception, computer interface/display design, or usability.

Russ et al. (2013) highlight some myths about HF/E so that the uninitiated are not misguided in their expectations. To emphasize, human factors is not just about soft skills (i.e., effective communication, teamwork, leadership, etc.), although they are indeed important areas of investigation and practice. Secondly, HF/E is not about manipulating or training people how to account for their "human factors" or eliminate human error. On the contrary, human factors seeks to optimize human performance for whatever particular situation, environment, tools, constraints, pressures, and goals people have. The point of human factors is to bring to bear our knowledge of people's physical and cognitive limitations in the design of work systems such that they are robust to the vulnerabilities of the human condition. A human factors expert will be the first person to tell you that the term *human error* is meaningless, as well as any of its synonyms: *loss of situation awareness*, *failure of crew resource management*, etc. (Dekker and Hollnagel, 2004). These terms are not an explanation of anything in and of themselves; they are the starting point for investigation. Additionally, human behavior is the least responsive element of a system to remedial intervention, especially if the context that influences behavior is ignored. In fact, it is precisely our human capacity for adaptation and innovation that prevents poorly designed systems from failing (Woods et al., 2012).

It is also imperative to recognize that training as a remedial management intervention has very specific utility, just as different medical therapies have specific indications and contraindications. In other words, not every problem or issue that arises throughout the course of work can be fixed by hauling everyone into a classroom. Thirdly, HF/E is not just about dials, knobs, and checklists. As healthcare (to include EMS) slowly becomes more informed about human factors, it is tempting to take ideas off a shelf and somehow insert them into practice (e.g., a checklist as a cognitive aid). Just as it has been said of prehospital care—"a competent paramedic knows how to intubate a patient, an expert paramedic knows when not to"—HF/E requires professionals with the depth of knowledge in the field to know when a particular intervention such as a cognitive artifact (to use a more precise term) is appropriate and when it is not; otherwise, interventions may be met with failure or limited/transient success. Finally, HF/E does not promote blame-free policies or organizational cultures; rather, it promotes the recognition that human behavior is inextricably bound and produced within a rich, situated context. As such, those responsible for designing systems contingent upon human performance must appreciate the influences that those systems impose upon performance, given human limitations.

A human factors approach balances personal accountability and managerial accountability for system design, which, perhaps given the historical extent to which punishment and individual-level remediation has been used to fix problems in healthcare, it may seem a bit blame-free at first. Reason (1994), a cognitive psychologist and the author of *Human Error* and many other works, has written time and time again that blame as a managerial tool for behavior modification is popular because it is fast, easy, and emotionally satisfying. It may also seem to get the desired results, but the truth is that a blame culture only impairs a system's ability to learn. System improvement, on the other hand, requires expertise, time, effort, capital, leadership, humility, and courage to expose the decisions, the process flaws, and the fundamental goal conflicts that seed latent error into the system.

HUMAN FACTORS HAS ALREADY MADE A DIFFERENCE IN EMS

An example of what human factors is capable of achieving in EMS, not just in terms of processes but also in terms of clinical outcomes and human lives, is the rapid spread of the "pit crew approaches" to field resuscitation of cardiac arrest patients, also known as high-performance cardiopulmonary resuscitation. Given the growing body of literature extolling the importance of uninterrupted chest compressions to improve the likelihood of restoring a patient's cardiac activity and spontaneous circulation while preserving the possibility of functional neurological outcomes, innovative methods have been employed to orchestrate the process of resuscitation. Elements such as predefined roles, communication protocols, call-outs, space organization and utilization, cognitive artifacts, explicit multiteam coordination, expectancies, and others have been included in many designs. See Figures 1.1 through 1.3.

CARDIAC ARREST CHECKLIST **R – 21**
REFERENCE V1.2 (12-12-12) Effective 11-1-2012

BLS [No pauses over 10 seconds]

- ☐ Designate and Announce BLS Team Leader (first name included) to all providers on scene upon arrival

Compressions

- ☐ Metronome (Ensure 110 per minute setting)
- ☐ SWITCH every 220 compressions to new compressor, NO EXCEPTIONS
- ☐ Determine who is next for compressions immediately after each switch and move into position

Cycle	1	2	3	★ 4	5	6	7	8	9	10	11	12

Ventilations and Airway Management

- ☐ Non-Hypoxic Arrest | High flow O_2 by NonRebreather Mask/OP for first three (3) cycles of arrest (660 compressions)
- ☐ Hypoxic Arrest | High flow O_2 by BVM/OP for entire code with interposed ventilations at 6/minute (20:1)
- ☐ ★ Switch from CCR to CPR with BVM/OP after 660 compressions and interpose ventilations at 6/minute (20:1)
- ☐ Place $ETCO_2$ immediately upon availability

Defibrillation

- ☐ Attach AED and power on

Shock ☐ 1 ☐ 2 ☐ 3 ☐ 4

ALS [Do not interfere with BLS triangle]

- ☐ Designate and Announce Code Commander (first name included) to all providers on scene upon arrival

ECG

- ☐ Verify monitor is in PADDLES mode at all times unless actively pacing
- ☐ Announce ECG interpretation and protocol for rhythm found on ECG

$ETCO_2$

- ☐ Place $ETCO_2$ filter line to BVM immediately
- ☐ Verify $ETCO_2$ waveform is present and being monitored
- ☐ Print $ETCO_2$ waveform [Upon airway placement | Any patient movement | Termination of care]

Airway

- ☐ After 660 compressions, place advanced airway if needed (Do not stop compressions for airway management)

Address Complications

- ☐ Assess blood glucose
- ☐ Gastric distention has been considered/addressed
- ☐ If unresolved or persistent arrest situation, look for and treat if indicated:
  - ☐ Hypovolemia
  - ☐ Hypo/Hyperkalemia
  - ☐ Hydrogen ion (Acidosis)
  - ☐ Hypoxia
  - ☐ Tension pnemothorax
  - ☐ Toxins
  - ☐ Thrombosis
  - ☐

ROSC

- ☐ 12 Lead ECG following ROSC
- ☐ Initiate chilled saline bolus if not already started intra-arrest per protocol

FIGURE 1.1 Cardiac arrest checklist as a cognitive artifact developed by and incorporated into the Wichita–Sedgwick County EMS System Medical Protocols. (Reprinted with permission from Medical Society of Sedgwick County, 2012.)

Cardiac arrest pit crew roles and responsibilities

Position #1

Role	Responsibilities
To facilitate continuous compressions in cardiac arrest and assist with airway/ventilation. Positioned at patient **right**. **Assigned** to fire fighter or paramedic on first in unit.	• Assesses unresponsiveness/pulselessness and initiate compressions • Alternates compression every 220 compressions with position #2 • Counts compressions in 20's and call out 17, 18, 19, 20 each time • Ventilates with BVM in off cycle (20:1) • Assists with airway management as needed

Position #2

Role	Responsibilities
To facilitate continuous compressions in cardiac arrest and assist with airway/ventilation. Positioned at patient **left**. **Assigned** to fire fighter or paramedic on first in unit.	• Brings and operates AED or LP 12 • Initiates metronome • Applies oxygen via NRM at high flow • Alternates compressions every 220 compressions with position #1 • Counts compressions in 20s and calls out 17, 18, 19, 20 each time • Ventilates with BVM in off cycle (20:1) • Assists with airway management as needed

Position #3

Role	Responsibilities
To facilitate airway patency and ventilations. Positioned at patient **head**. **Assigned** to fire fighter or paramedic on non-transporting response unit.	• Monitors and manages airway for duration of arrest to ensure patency. Reacts to problems • Calls out compressions in increments of 20 (20, 40, 60, 80, ... 220) • Assembles and applies all airway equipment except ETT • Applies BVM/OP at 660 compression mark with two handed seal on mask • Monitors $EtCO_2$ values and communicates with team

Note: Personnel can rotate in and out of positions 1, 2, and 3 as needed so long as this does **not** interfere with care or interrupt CPR.

Code team commander (CC)—paramedic in control of monitor

Role	Responsibilities
Ownership of all clinical care. Directs all ALS care in coordination with BLS team leader oversight of all BLS care. Holds the final responsibility for patient well being. Positioned outside BLS triangle near patient's **legs**. **Assigned** to paramedic on transport vehicle.	• Communicates/coordinates with team leader • Makes all patients treatment decisions • Rhythm analysis, interpretation, and application of electrical therapy • Assures accurate on-going documentation of care (written and LP 12) • Determines when patient is moved/transported • Supervises DNR and code cessation issues • Responsible for all clinical communications • Responsible for overall conduct of resuscitation • Owns any advanced airway interventions (ETT or combitube) • Overall documentation of care for entire call

BLS team leader (TL)

Role	Responsibilities
Responsible for all BLS efforts in cooperation with code team commander. Monitors clock and communicates times. Owns BLS care. Positioned outside BLS triangle. **Assigned** to EMT or higher provider.	• Works checklist and calls out times to code commander (6, 10, 15, 20 min) • Ensures great BLS, specifically a ≥90% compression fraction • Tracks compression cycles and ensures switching compressors every 220 • Tracks and calls for ventilations at the 600 compression mark (3rd cycle) • Ensures integrity of BLS triangle • Assists with airway setup if needed • Overall documentation of care for all BLS activities and assists CC with ALS documentation

FIGURE 1.2 Roles and responsibilities of pit crew resuscitation providers from the Wichita–Sedgwick County EMS System Medical Protocols. (Reprinted with permission from Medical Society of Sedgwick County, 2012.)

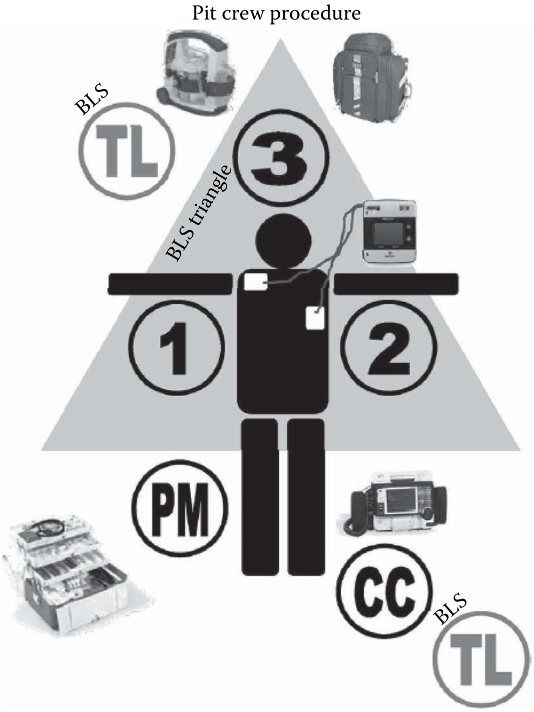

FIGURE 1.3 Pit crew spatial organization from the Wichita–Sedgwick County EMS System Medical Protocols. Locations of participants are indicated by circles. The basic life support (BLS) triangle indicates the area where the basic life support measures of continuous chest compressions are taking place and that this space is reserved for only that task, given its special importance.

The list below represents a number of observed and engineered human factors elements at work in a field resuscitation, and as you can see, none of them have their foundation in medicine; they are psychological constructs and/or engineering concepts.

The following are human factor constructs implicated and engineerable in pit crew resuscitation:

- Teamwork
- Design of clinical decision guidance
- Implicit/explicit coordination
- Cognitive artifacts
- Interpersonal communication
- Transactive memory systems
- Skills, rules, knowledge
- Alarms and technology
- Situation awareness
- Expertise

- Decision making under stress
- Dynamic fault management
- Callouts and cross-checks
- Social construction of reality
- Trust in automation
- Task switching
- Diffusion of responsibility
- Pattern recognition

Note that this list does not represent an exhaustive list.

A WORD ABOUT HUMAN ERROR

"The occasional human contribution to failure in complex systems occurs because the systems require an overwhelming human contribution for their safety" (Dekker, 2006, p. 194). Through decades of studying risk and safety in domains such as nuclear power generation and aviation, the science of HF/E has uncovered the idea that safety does not simply exist in complex systems; in essence, it is not an inherent property of the system; it is an emergent property of the interaction between humans and the system. The old view of error (Dekker, 2002) assumed that systems are inherently safe and that it is the human operators who are responsible for their demise. So when something goes wrong, all that is necessary is to find the defective part (i.e., the human) and begin the cycle of name, blame, shame, and retrain. The new view of human error acknowledges instead that complex systems are inherently intractable, dangerous, and risky and that the human serves as both a point of resilience (oftentimes striking a fine balance between irreconcilable goal and priority conflict), and the trip wire for the latent errors that they have inherited (Reason, 2000).

Furthermore, one cannot simply study the phenomenon of human error without studying normal human performance; they are inextricably linked, with only the distinction of their outcomes to tell the difference. Human error and correct/successful performance are two sides of the same coin (Reason, 1990). "Human error is not random"; it is systematic (Dekker, 2002, p. 61). To suggest that behaviors can be judged by the success or the failure of their outcomes is to say that the ends justify the means; analogously, we would consent to the countless numbers of people who drive their vehicles while intoxicated as long as they are somehow able to not destroy any people or property in the process.

Unless your agency is hiring sociopaths, your providers want to help people and do their jobs well. They do not choose to err when they could have otherwise chosen not to err. To err is not a choice (Dekker, 2006). Errors are not the result of negligent or ill intent by the provider; more often than not, they are the result of the intractable complexity of the system in which providers work—the interactions of information in the operators' situated context given their cognitive constraints and priority conflicts. Behavior always occurs in a context; it follows that understanding the context is crucial to understanding the subsequent behaviors—a concept referred to as the *local rationality principle* (Dekker, 2002), refined from the decision science concept of bounded rationality (March, 1978). People do their best given the constraints of their situation, expertise, and cognitive resources. Oftentimes, the outcome is good, but when it is bad, we tend to reframe their actions in hindsight with information that the person did not or could not have at the time. Healthcare providers, and especially EMS agents, are faced with achieving a balance between safety (theirs and their patients') and achieving the operational mission in a pressurized, unpredictable, patchwork system. Analyzing the systemic factors that contribute to errors, whether they be organizational policies, poorly designed technology, or inefficient task work, allows us to redesign the system to make it safer and more effective for our patients and our providers.

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