Federal Railroad
Administration

Office of Railroad Safety

Confidential Close Call Reporting System (C3RS)

Peer Review Team Human Performance Handbook

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Table of Contents

Preface iii

Section 1 - Introduction to Complex Systems and Human Factors 1

Section 2 - Human Factors Analysis and Classification System 7

Section 3 - Human Error Mechanisms 17

Section 4 - Stress, Workload, Boredom, and Fatigue 23

Section 5 - Crew Resource Management and Highly Reliable Organizations 35

APPENDIX A: Glossary of Terms 39

APPENDIX B: Article, “Deep in Sleep” 47

APPENDIX C: Reference Guide for Further Reading 57

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Preface

The modern study of human error can be traced to Sigmund Freud, whose work in psychology in the late 1800's led him to conclude that human error was the product of the subconscious drives of the person. Freud considered people that made errors to be less effective, and in fact, defective. Freud's theories have had a broad influence on how our society views errors and how we respond to people that make them.

More recent research into human error and error mechanisms has dispelled many of Freud's concepts, but the impacts of his original theories have persevered. These theories have become part of the societal belief that cause our culture to seek out the defective person or persons and attempt to remove them from the system. Whenever an incident occurs, society's first instinct is to attempt to place blame on an individual or group of individuals.

In the 1930's, Herbert W. Heinrich, an industrial safety pioneer, published his book, *Industrial Accident Prevention, A Scientific Approach*. This book was the result of years of study of industrial accidents. While Heinrich's observation that 88 percent of all workplace accidents and injuries/illnesses are caused by "man-failure" is perhaps his most often cited conclusion, his book actually encouraged employers to control hazards, not merely focus on worker behaviors. Heinrich wrote, "No matter how strongly the statistical records emphasize personal faults or how imperatively the need for educational activity is shown, no safety procedure is complete or satisfactory that does not provide for the ... correction or elimination of ... physical hazards."

Unfortunately, with society already so strongly influenced by Freud's theories, most industrial safety professionals and managers read that 88 percent of all workplace accidents and injuries/illnesses are caused by "man-failure" to mean that the "man" in the system was the problem. This misinterpretation of Heinrich's conclusions served to reinforce the Freudian theory of defective people.

More recently, work by Donald Norman, Sidney Dekker, E. Scott Geller, Charles Perrow, Robert Helmrich, and James Reason, to name a few, has served to disprove many of Freud's theories. Modern researchers realize that behaviors are the result of drivers. These drivers, called antecedents, proceed and trigger behaviors and can predict consequences. In other words, humans behave in certain manners due to environmental and system drivers.

Within any system, the human is the most flexible and adaptable component, able to adjust and control the system in an ever-changing operational environment. Yet this very favorable human trait is the very characteristic that leads to human error. Every system has rules that govern how that system should function and be operated.

Without such rules the system would collapse, resulting in catastrophe and chaos. Obedience to the rules of the system is very important; yet rules cannot be written to cover every possible condition that may arise in a dynamic world. This is where humankind's ability to adapt and be flexible must intervene in order to save the system. Humans are actually the heroes that save the system from collapsing on a frequent basis.

These interventions are usually based on sensory inputs (perceiving the environment), analyzing the situation, placing the perceived situation into context with their knowledge of the system, using logic and reasoning to develop courses of action, comparing these courses of action and – through a decisionmaking process – selecting what they perceive to be the best course of action, and finally, performing an action. Often, these decisions must be made very quickly and with incomplete or misperceived information. Sometimes these decisions are incorrect, resulting in an error. Occasionally, an error will result in unintended consequences, such as an incident or accident.

With this in mind, to adequately address human error, the antecedents to the behaviors that lead to the decisionmaking process must be identified and addressed. Accidents and incidents can be analyzed to determine these antecedents, but fortunately, these events occur relatively infrequently, hence the available data is scarce.

To broaden the available data we are now analyzing close calls. When analyzing these data it is important to identify the behaviors that led to the close call, but these efforts will be ineffective if the antecedents that drove the behavior are not also identified. Once these antecedents are identified, systemic countermeasures and/or new procedures can be developed that will prevent future occurrences of the same nature.

It should be understood that these concepts do not relieve system operators from responsibility for their actions. However, it does, in many cases explain their actions. Furthermore, there are some humans that have psychomotor skills, attitudes, or characteristics that are inappropriate to function properly within a given system. In these rare cases, the person must be removed from the system. However, this type of action should be the exception, rather than the rule.

This handbook has been developed to assist you in identifying the characteristics of the behaviors that lead to a close call and the antecedents to the behaviors. With this information, we will be able to develop countermeasures and procedures that will reduce the risk to employees, railroad property, and the general public.

Section 1 - Introduction to Complex Systems and Human Factors

Complex Systems

Over the centuries, humans have developed many systems. Systems of governance, economics, religion, etc., have all been developed by humans in order to fulfill human needs. Originally, these systems were quite simple; for example, forming a team to herd wild buffalo into a canyon so they could be killed and used as a collective food source. As human needs increased, so did the complexity of the systems they designed and built. Transportation, communications, and manufacturing systems are examples of systems that continually grow in complexity.

Complex systems are characterized by many interdependent variables. The more variables that exist, and the greater the degree of interdependence is between these variables, the more complex the system becomes. Complicating the system even more is the dynamic nature of the modern world.

The great system of yesterday may be substandard today, because of the changing environment and technology within which the system exists. For example, the stagecoach system in the 19th century was the state-of the art means of traveling across America. The methods and subsystems used to operate and support this system were appropriate and adequate for the technology that was available and the environment in which the system operated.

The same methods were inappropriate when the railroad became the preferred means of crossing the country and even more so with the rise of the aviation industry. While some subsystems remained similar with way-stations becoming airport restaurants and "shotgun riders" becoming air marshals, even the nature of the subsystems became more complex.

Adding to this complexity is a feature called transparency. Much of the information that humans need to know in order to safely operate a system is invisible to the operator. For example, how many control rods are there in the nuclear reactor and what are their current positions? This is critical information for the operator, so designers build more subsystems to monitor the control rods. These subsystems add more variables to the system and more interdependence. As you can see, systems can become very complex, very quickly.

By their very nature, the more complex the system is, the larger the possibility of a system failure. So how do we control these complex systems, monitor their performance, and make adjustments to the system if necessary? We add humans to the system. The way we add the human element may be good, or it may not be so good.

For example, if we design a system and after we are convinced that it is perfect we plug in the human operator, we have a system that will, at some point, fail due to a subsystem failure. That subsystem is the human operator. At this point, convinced that our system is perfect, we can easily blame the human, label them as defective, remove them from the system and replace them with another human operator. We can repeat this process many times without questioning the system itself. After all we have already determined that the system is perfect and, at the same time, we are wondering where all these defective people came from.

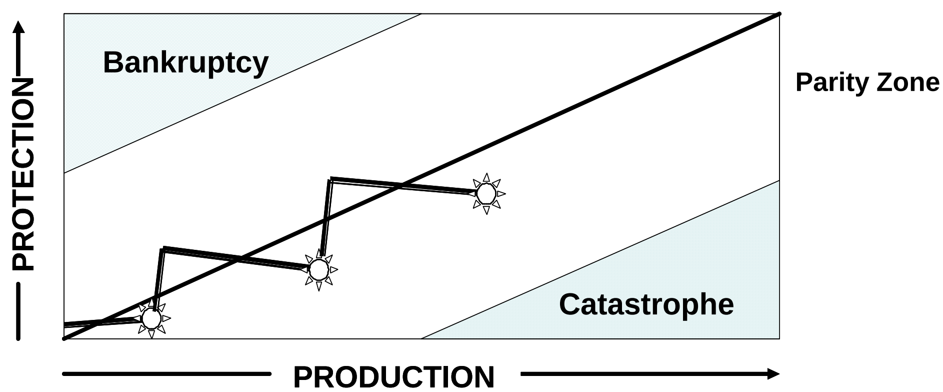
Modern railroading is an example of a very complex system. Railroad systems have many interdependent variables, many of which are transparent to the operator and the system managers.

So how do we make systems that perform their required function—knowing that human operators and managers will make errors—while maintaining the adaptability and flexibility that the human brings to the system? One method is to begin examining the systems themselves for where vulnerabilities exist for human error, then modify or redesign the system for greater reliability.

We can do this reactively by investigating accidents, determining root causes, and making the required adjustments, but this method has two distinct disadvantages. The first disadvantage is that there is already a "smoking hole in the ground" with property damage and possibly loss of life. The other disadvantage is that there are so few accidents, so by using this method, we might never discover all the system vulnerabilities. Not to say we shouldn't investigate accidents, but we should understand that the information gathered using this method is limited.

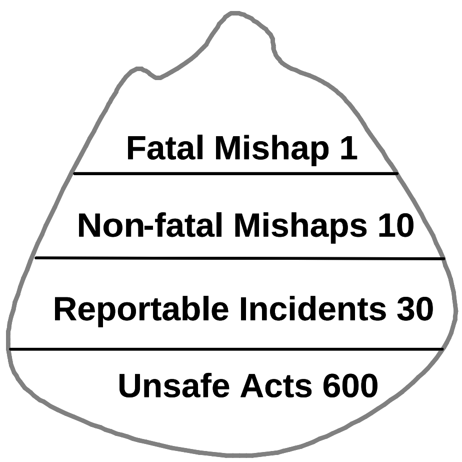
Production vs. Protection

The goal for most organizations is to remain viable (avoid bankruptcy) and at the same time avoid catastrophe. Yet at the same time, they have limited resources to spend on production to remain viable or protection to avoid catastrophe. This relationship is illustrated in the graph below:



As production increases, the system's protection becomes strained. Eventually an accident occurs that requires the system to be modified, increasing the level of protection. If a level of protection is provided that cannot be supported by production, the organization moves toward bankruptcy. Or if the system demands a level of production that cannot be provided, adequate protection the organization moves toward a catastrophic incident. This cycle is continually repeated as the organization attempts to remain in the parity zone. The model above represents the cycle of a system failure, accident, investigation, and adjustment. If we can make the system adjustments based on information from Confidential Close Call Reporting (C3RS) rather than accident investigations, we can avoid many of the accidents. In so doing, we overcome the first disadvantage of relying solely on information from accident investigations and we gain this knowledge at a much lower cost.

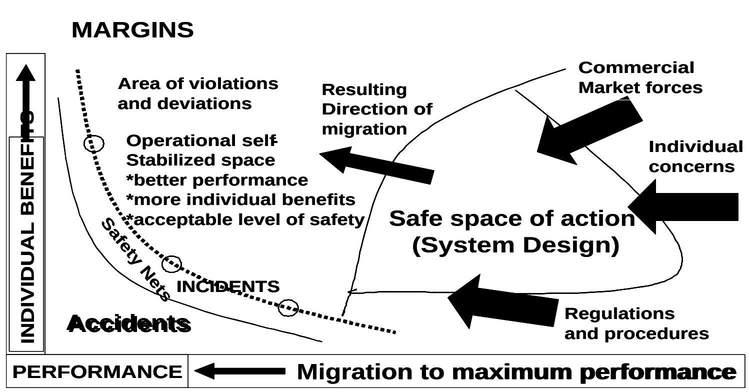
As illustrated in the Heinrich Ratio displayed below, accidents are rare compared to the number of unsafe acts or errors that occur. Discovering these errors and analyzing them for root causes gives us a larger view of the system and allows adjustments to be made before the error manifests itself in the form of an accident or incident.



Using C3RS allows us access to more information about what is going on in the real world. Furthermore, because close calls happen much more often than accidents, we can overcome the second disadvantage of too few accident investigations to be effective.

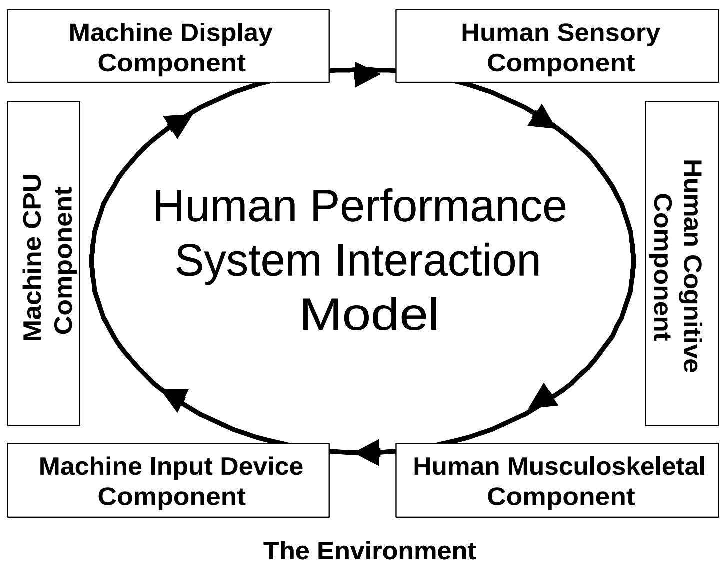
Operational Drift

Operational drift is where external forces are applied to a system. These pressures can cause the operations to drift outside their original design specification and move towards an accident or catastrophe. If no accident occurs, over time this new standard becomes the norm and the entire system is working beyond its original design.



The Science of Human Performance

The science of human performance is the study of how human beings interact with complex systems. This can be best understood with the following model:



The first step in this model is how we as human beings receive information from the environment. That is to say, how people use their senses (sight, hearing, smell, taste, and touch) in order to receive inputs from the system they are operating and from the environment. This part of the process is referred to as *perception*.

PERCEPTION	**Human Sensory Component**

These inputs are processed through the brain's **sensory memory** that discards those inputs that we are not paying attention to and passes those inputs that we are attending to into **short-term (working) memory**. This part of the process is referred to as *comprehension*.

The brain then seeks to understand these inputs by drawing upon stored knowledge and experiences in **long-term memory**. Because the brain uses stored memories of past events to comprehend the current situation, what the brain perceives may not be what is occurring in the situation. Therefore, our comprehension of the situation is termed, the *theory of the situation*. This theory of the situation is what we use as part of our decisionmaking process.

COMPREHENSION	**Human Cognitive Component**

Once we decide upon a course of action or behavior, we must again interface with the system and environment using our skeletal-muscular system. These outputs are termed *projections*, as we are projecting our desires onto the system and/or environment. We are using our theory of reality in order to manipulate the system.

PROJECTION

Human Musculoskeletal Component

These human outputs control machine inputs to the system. Human operators use their psychomotor skills to manipulate a variety of system controls in order to maintain system operations. These controls are normally in the form of sensors, switches, levers, keyboards, mouse controls, trackballs, touch screens, etc.

Machine Input Device Component

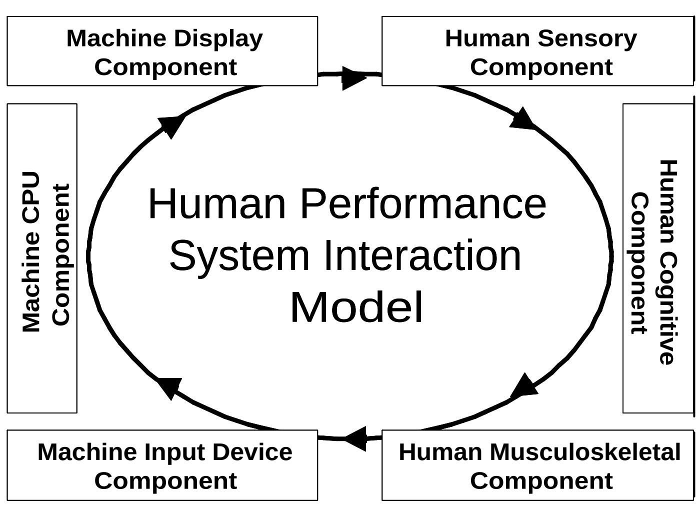
Once the operator has provided inputs to the system, it is expected that the system will react in a predictable manner as designed.

Machine CPU Component

Various sensors monitor the system status and provide feedback to the operator in the form of audible signals, visual displays, or other sensory mechanisms.

Machine Display Component

Again, the entire cycle looks like this:



The Environment

If the system does not function as intended, it is expected that the human operator will detect the malfunction by monitoring system outputs by using their senses, understanding the situation, then making adjustments to the system inputs to correct the problem and to keep the system in a state of equilibrium - safe and efficient.

The science of ergonomics focuses primarily on the human/machine interface points and works to improve the system feedback mechanisms to enhance the operator's ability to perceive the system's status. It also works to improve the relationship between the operator's psychomotor capabilities and the system's control functions; whereas, the science of human performance considers the entire human/machine relationship.

Summary

There are three points that are evident in this discussion:

(1) Systems are complex and provide many opportunities for failure.

(2) Humans are an important part of any complex system and are the heroes that often prevent the system from failing.

(3) Humans make errors.

When attempting to understand the nature of a particular human error (or series of errors) it is imperative to look beyond the error itself. We must investigate the system or process the human was interfacing with and the controls and output/displays of the system, as well as the environment in which the human and system were operating. The Multiple Cause Incident Analysis (MCIA) tool will help you in this endeavor. The MCIA is based on the Human Factors Analysis and Classification System (HFACS).

Section 2 - Human Factors Analysis and Classification System

The Human Factors Analysis and Classification System (HFACS) was originally developed at the Federal Aviation Administration's Civil Aeromedical Institute by Scott Shappell and Douglas Wiegmann. Wiegmann and Shappell further refined HFACS in their book, A Human Error Approach to Aviation Accident Analysis (2003), in order to explore the antecedents of human error. The original model has four levels of antecedent causation: unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational factors.

Unsafe Acts

Unsafe acts refer to active failures, and involve acts of omission and commission by those closest in time and physical proximity to the accident/incident. There are two primary categories of operator acts: errors and violations.

Preconditions for Unsafe Acts

These are contextual factors that foster, enable, or otherwise set up the operator or individual to err or violate a rule, policy, or procedure. Preconditions exist prior to the accident/incident. Preconditions are divided into three major categories: environmental factors, personnel factors and the condition of operators.

Unsafe Supervision

A supervisor's role is to provide operators with the opportunity to succeed. Supervisory factors consist of decisions, policies, practices, procedures, and actions by front-line supervisors (i.e., shift supervisors, trainmasters, foremen, etc.) and first- and second-level officers (i.e., superintendents, managers, directors) that contributed to the accident/incident by (1) limiting an operator's opportunity to succeed or (2) providing inadequate oversight and guidance.

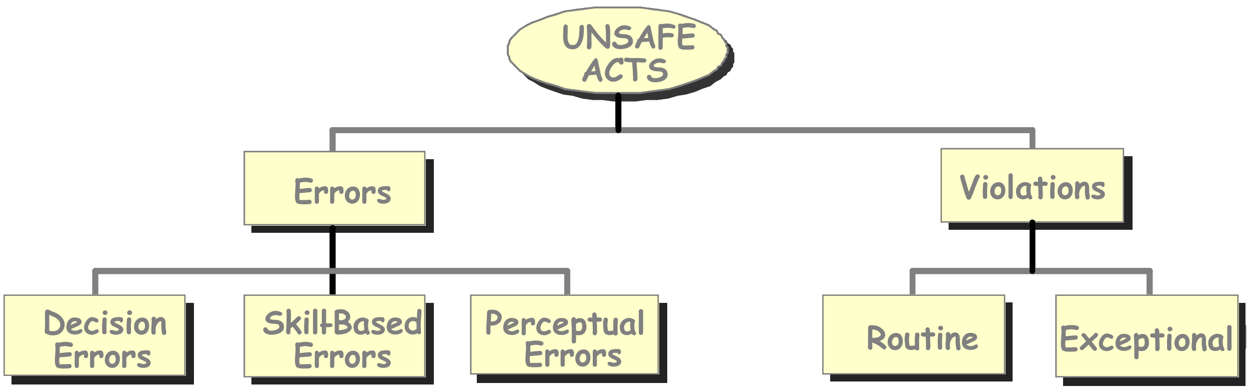
Supervisory factors are further divided into four categories: inadequate supervision, planned inappropriate actions, failure to correct known problems, and supervisory violations.

Organizational Influences

Organizational influences include senior management and executive-level decisions, practices, policies, and procedures that guide the operation and general governance of an organization and that have contributed to an accident/incident. Organizational factors are further divided into four categories: resource management, organizational climate, organizational processes, and change management.

Unsafe Acts

As displayed in the diagram below, unsafe acts can be divided in to two primary categories: errors and violations. Errors are further divided into error types: decision errors, skill-based errors, and perception errors. Furthermore, violations are divided into two types: routine and exceptional. Errors are physical or mental activities that deviate from intended behavior.



Errors

Decision errors. Decision errors are intentional behaviors that proceed as planned, yet the plan itself proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes," these unsafe acts represent the actions or inactions of individuals who meant to perform correctly, but they either did not have the appropriate knowledge, or had the appropriate knowledge and made a poor choice.

Decision errors differ from skill-based errors in that decision errors involve deliberate and conscious acts, while skill-based errors are based on highly automated behaviors. Decision errors consist of conscious decisions that are believed to be correct, but are in fact poor or erroneous. Decision errors can be divided into three types: procedural errors, poor choices, and problem-solving errors.

> **Procedural errors.** Rule-based mistakes that occur during highly ordered or structured tasks, such as "if X occurs, then do Y." A procedural error may be a misapplication of a good rule or procedure, or the application of a bad rule or procedure.
>
> **Poor choices.** Knowledge-based mistakes. Poor choices occur when there is no explicit procedure to apply to the particular situation, and the operator must choose from among several response options. These options may be explicit or implicit. This type of error is often due to insufficient knowledge or understanding of the situation, and may arise when the operator lacks sufficient training or adequate time to respond.

Problem-solving errors. Problem-solving errors occur when the nature of the problem is not well understood, and formal procedures or other options are not available. In situations like this, humans can develop and apply unique solutions that are wrong. In developing these solutions, humans use cognitive resources that can result in loss of situational awareness and a delayed response.

Skill-based errors. Skill-based errors often occur during the execution of highly practiced actions in which there is little or no conscious thought required. Skill-based errors can be further classified into attention failures (slips), memory failures (lapses), and technique errors.

Attention failures. Failures of attention typically occur when carrying out highly automated behavior. Attention failures are characterized by missed or otherwise unnoticed sensory information, and are frequently caused by distractions, stress, or fatigue. Attention failures, or slips, may be manifested as delays, reversals, mis-orderings, and mis-timings in procedures and tasks.

Memory failures. Memory failures, or lapses, involve a failure to remember critical information involved in a task or procedure. Memory failures are often manifested as omissions in a checklist, forgotten intentions, or losing one’s place.

Technique errors. Technique errors involve the execution of a sequence of actions that are technically correct but that contributed to an accident/incident. Technique errors occur when an operator can carry out a task using one of several acceptable sequences. An example is train handling that, although technically adequate, leads to a break-in-two under specific environmental or operational conditions.

Perceptual errors. Perceptual errors occur when one’s theory of reality (perception) is different from the reality of the situation. This may be the result of degraded or unusual sensory input, or poor or erroneous information displays. The error is the operator’s incorrect response to the illusion or degraded sensory information. Perceptual errors include misjudging distances and misidentifying signal aspects under certain conditions (i.e., solar glare). Perceptual errors also arise from false sensations, ambiguous information, and misperception of hazards.

Violations

Violations are intentional deviations, or a willful disregard, of a rule, procedure, or policy. Violations are further divided into two types: routine and exceptional.

Routine. Routine violations include habitual behaviors and actions that violate governing rules, procedures or policies, and that are carried out with good intent. Routine violations are the result of a perceived license to bend the rules. They are often tolerated or condoned by management and are frequently intended to save time and/or effort, and negative outcomes are not intended. Examples include delays in bad ordering defective cars or not protecting the point because it will save a few minutes of time and effort.

Exceptional. Exceptional violations include isolated actions or behaviors that are: (1) not indicative of the operator’s typical actions or behaviors and (2) not condoned by management.

Exceptional violations are often extreme in nature, but like routine violations, the negative outcome was not intended (i.e., driving 100 mph in a 55 mph zone was intentional, but the crash wasn't). Exceptional violations are considered exceptional because they are neither typical of the individual nor condoned by authority. An exceptional violation is a rare act that defies accepted and typical behavior.

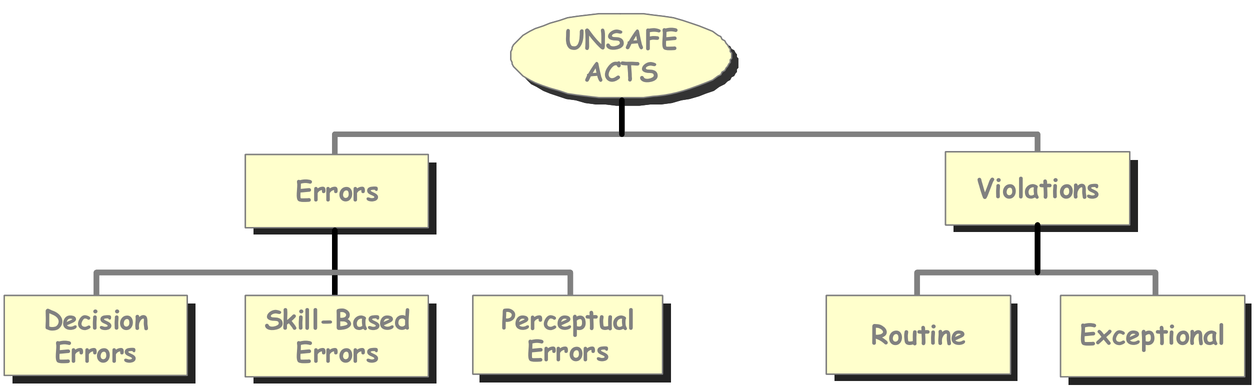
Other Considerations

Some authors include acts of sabotage in this category. Sabotage is an intentional act and will not be used for the purposes of the Peer Review Team (PRT).

Preconditions for Unsafe Acts

Preconditions for operator acts are contextual factors that fostered, enabled, or otherwise set up the operator or individual to err or violate a rule, policy, or procedure. Preconditions exist prior to the accident/incident.

Preconditions for unsafe acts, as shown in the diagram below, are subdivided between Substandard Conditions of Operators and Substandard Practices of Operators. Substandard Conditions of Operators refers to Adverse Mental States, Adverse Physiological States, and Physical/Mental Limitations. Substandard Practices of Operators refers to Crew Resource Mismanagement and Personal Fitness.



Condition of the operators

Operator conditions include an individual's mental and physiological conditions that can affect job performance, or mismatches between physical or mental abilities and job/task demands. Condition of operators is further divided into three categories: adverse mental states, adverse physiological states, and physical/mental limitations.

Adverse mental states. Adverse mental states include mental conditions, perceptions, expectations, biases, attitudes, beliefs, moods, or states that negatively affected an operator's performance. Examples include reduced situational awareness, distraction (e.g., personal problems) or preoccupation, task fixation, cognitive fatigue, poor motivation, low self-esteem, learned helplessness, boredom, job dissatisfaction, complacency, and overconfidence.

Adverse physiological states. Adverse physiological states include physiological and medical conditions that can negatively impact safe operations. These include common and serious medical illnesses or diseases (e.g., diabetes), disturbed sleep patterns, intoxication, physical fatigue, hypothermia and heat stroke, and negative physiological effects of medications.

Physical/mental limitations. Physical/mental limitations occur when operational requirements exceed the capabilities of the individual. These situations can also induce stress, further reducing the human's ability to perform. These limitations may be due to sensory limitations; lack of familiarity with task requirements; inadequate training and/or limited experience, education, or knowledge of the particular task or situation; incompatible physical capabilities for the task, or any other general physical or mental incompatibility between operator capabilities and task requirements.

Practices of the operator

These personal factors include two somewhat distinct sets of issues: deficiencies in coordinating and communicating between or among individuals (crew resource mismanagement) and a failure to adequately prepare mentally and physically for duty. Personal factors are further divided along these lines.

Crew resource mismanagement. Crew resource mismanagement factors include conflict, poor communication, and/or poor coordination among individuals involved in the accident/incident. Examples include communication breakdowns and inadequate job briefings.

Personal fitness. Personal fitness includes behavioral factors and decisions that affect physical or mental readiness for duty. These behaviors include inadequate rest, impairment due to self-medication, poor diet, overexertion, and the use of drugs and alcohol before starting work.

Other Considerations

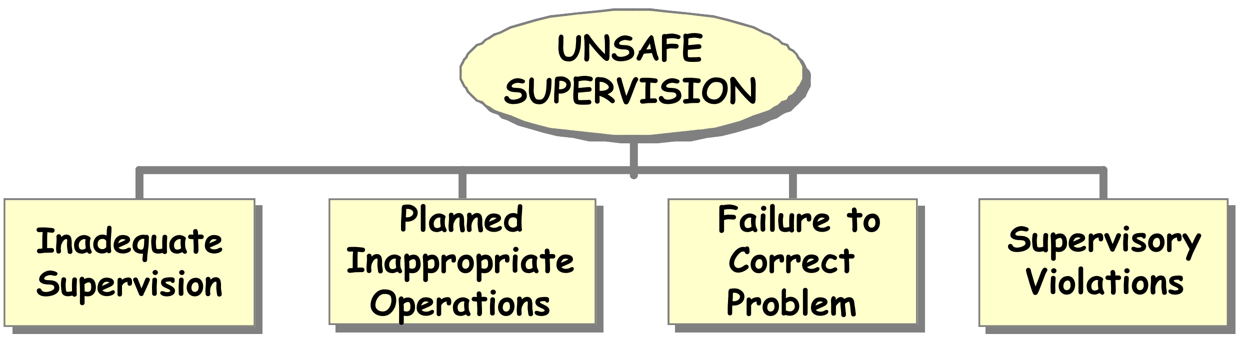
Environmental factors. Environmental factors are further divided into the physical environment (i.e., workspace, yard, main track, office) and technological environment in which the operator works and interacts to carry out job tasks.

Physical environment. Physical environment includes the tangible, visible or otherwise sensed environment in which the operator works, and includes factors in the operating environment (i.e., walking path, distance between track centers, debris and tripping hazards due to poor housekeeping, etc.) and the ambient environment (i.e., noise, vibration, temperature, lighting, etc.).

Technological environment. The technological environment includes the interaction with, or operation, maintenance, and inspection of, any tools, materials, vehicles (e.g., locomotive air brakes), plant equipment (i.e., signal and track circuitry systems, switches, grade crossing system), signage, personal protective equipment, or machines used during the accident/incident sequence. Examples include equipment or component failures, poor design of equipment (such as poor human-machine interface), or inappropriate use of equipment for the task/job.

Unsafe Supervision

Unsafe supervision has four subcategories, as displayed in the diagram below: inadequate supervision, planned inappropriate operations, failure to correct problem, and supervisory violations.



A supervisor's role is to provide operators with the opportunity to succeed. Supervisory factors consist of decisions, policies, practices, procedures, and actions by frontline supervisors (i.e., shift supervisors, trainmasters, foremen, etc.) and second-level officers (i.e., managers, superintendents, directors) that contributed to the accident/incident by (1) limiting an operator's opportunity to succeed or (2) providing inadequate oversight and guidance.

Inadequate supervision. Inadequate supervision covers factors by which a supervisor or manager does not provide sufficient support to operators to enable them to perform their jobs. This may be manifested as insufficient supervisory or managerial oversight, inadequate training, being a poor supervisory example, or otherwise not preparing an operator to perform his/her job functions safely.

Other examples of inadequate supervision include inadequate tracking of operator qualifications and/or job performance, not allowing sufficient opportunity for rest, and not providing up-to-date or current documentation and materials (i.e., bulletins, rule books, special instructions, etc.). Inadequate supervision also can include officers not knowing or understanding relevant rules and how the rules are applied, or inconsistently applying those rules.

Inadequate supervision may occur in situations where supervisors and managers are over-tasked, overworked, or undertrained/qualified, to the point where the supervisor loses awareness about what is going on in the area for which he/she is responsible. An example of how this can happen is when there is a transfer of administrative tasks from administrative personnel to supervisors. Administrative tasks are often easier to measure than supervisory tasks, and therefore receive priority in accomplishment.

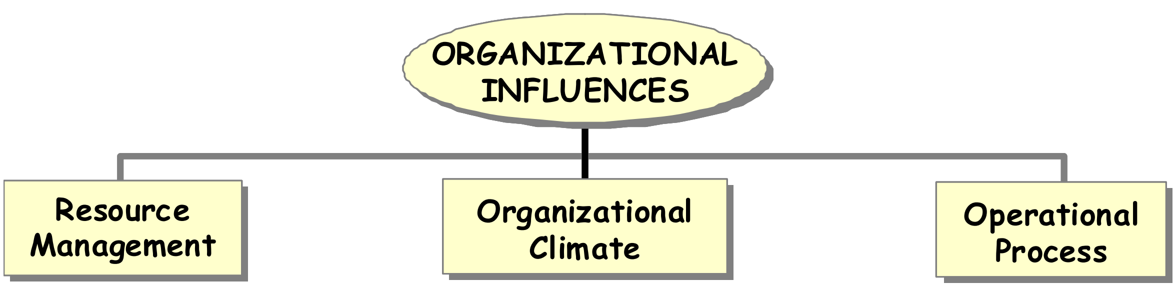
Planned inappropriate operations. Operations are those that are conducted in spite of the fact that there is more than the customary risk in either the tempo or tasks associated with the operation. Planned inappropriate operations are those that involve poor supervisory decisions that place operators at unnecessary risk. Examples include placing an excessive and/or unusual workload on an operator or expecting an operator to complete a task in less than the customary amount of time.

Failure to correct problem. Failure to correct known problems refers to instances when deficiencies among individuals, equipment, training or other related safety areas are known to the supervisor, yet are allowed to continue unabated. These include failures by a supervisor or manager to correct observed or known unsafe behaviors, conditions, and hazards.

Supervisory violations. Supervisory violations include occasions when a supervisor or manager consciously violates or disregards existing rules, regulations, and policies, or allows subordinates to do the same. Examples include encouraging operators to bend or ignore rules (cutting corners), failure to enforce the rules and regulations, and permitting unqualified operators to work. This results in a degradation of the purpose and importance of the rule and can lead to routine violations.

Organizational Influences

Organizational influences have three categories, as displayed in the following diagram: Resource Management, Organizational Climate, and Operational Process.



Organizational influences include senior management and executive-level decisions, practices, policies, and procedures that guide the operation and general governance of an organization and that contributed to an accident/incident.

Resource Management

Resource management factors include organizational decisions regarding the allocation and maintenance of organizational assets such as human resources, monetary assets, equipment, and facilities.

Human resources. This category includes organizational decisions, policies, etc., that govern, determine, or affect the adequacy, quality, and/or amount of recruitment, selection, staffing, scheduling, training, and retention of qualified employees at all levels of the organization.

Equipment/facility resources. This category includes organizational decisions that affect the acquisition, maintenance, management, and operation of adequate equipment and facilities. Examples include:

- Unavailable, missing, or a shortage of, equipment or lack of resources needed to perform work safely and within the customary time frame.
- Acquisition of unsafe, poorly designed, or inappropriate equipment; equipment and facilities that are in poor condition.
- Lack of formalized practices and procedures for the acquisition, maintenance, management, and/or operation of equipment and facilities.

Monetary/budget resources. This category includes the allocation of monetary assets. Examples include excessive cost-cutting and inadequate funding for safety, operational, and maintenance programs, staff, and equipment.

Organizational Climate

Organizational climate includes the working environment within an organization, and may consist of formal, informal, and unwritten policies and practices. Organizational climate is further divided into three categories: organizational structure, organizational policies, and organizational culture.

Organizational structure. Organizational structure is the family tree of an organization as reflected in an organization's chain-of-command, delegation of authority (and autonomy), communication channels, and formal accountability for actions, as well as access to various management levels.

Organizational policies. Organizational policies are the official guidelines that direct management's decisions about such things as hiring and firing, promotion, retention, sick leave, and a myriad of other issues important to the everyday business of the organization. Organizational policies are the institutionalized position of the organization, but not necessarily reflective of what actually occurs in the work environment. In addition to the examples above, organizational policies include health and wellness programs and fitness for duty standards/requirements.

Organizational culture. Organizational culture includes the unofficial or unspoken rules (i.e., norms, values, attitudes, beliefs, and customs) of an organization as well as the values, beliefs and attitudes employees hold toward the company.

The degree of harmony in labor relations (i.e., whether this relationship is more harmonious or adversarial) is one indicator of an organization's culture. Another indicator of organizational culture is the extent to which the organizational culture is viewed by employees as a "blame" culture or a "just" culture.

Senior and executive-level managers that bend, shortcut, or otherwise violate (1) existing organizational structures or policies, or (2) external municipal, county, State and Federal regulations, though rare, is also an indication of an organization's culture. Organizational culture provides an indication of what is truly valued by the organization.

Organizational Process

Organizational process refers to corporate decisions and rules that govern the everyday activities within an organization, including the establishment and use of standard operating procedures and formal methods for maintaining checks and balances (oversight) between the workforce and management.

Organizational process can be further organized into one of three categories: organizational operations, organizational practices and procedures, and organizational oversight

Organizational operations. Organizational operations include work-based processes that influence the quality, quantity, pace, or style of operator performance and work. Examples include operational tempo, time pressure, competing goals (such as processes that favor presumed productivity over safety), and the use of incentives or quotas (e.g., compliance goes unrewarded).

Organizational practices and procedures. This category includes formalized activities, practices and procedures that govern or directly affect operations. Examples include a lack of, inadequate, ill-defined, poor, or inappropriate:

1. Standard operating practices, procedures, tasks, instructions, and/or rules
2. Procedures, instructions or information dissemination about these practices, procedures, tasks, and rules.
3. Supporting materials, such as rule books, instructions and instruction manuals, checklists, and other job aids.

Organizational oversight. Organizational oversight includes an organization's formal approach to policy, procedure, and rule compliance. Examples include

- Corporate safety programs.
- Risk and quality management programs.

- Hazard identification and elimination/mitigation activities, safety, or defect reporting systems.
- Accident/incident investigation procedures.
- Corrective action implementation.
- Tracking and monitoring the resources, processes, procedures, etc., that are necessary to ensure safe operations.

Other Considerations

Change management. Change management involves the formal process of managing significant changes to, or transitions within, an organization's structure, processes, and equipment/systems. Change management focuses on the impact that a change has on both the organization and its employees. This is not an original component of HFACS, but deserves consideration by the PRT if significant changes are occurring within the system or organization.

Summary

Using the MCIA tool and understanding the principles underlining the HFACS will greatly assist the PRT in properly analyzing close-call reports. Without this analysis it will be difficult to develop policies, procedures, and countermeasures that will effectively address the cause(s) of human error. It is important that the PRT explore causes that are driven from above the operator level. Without that exploration organizational and system defects will continue to be masked from detection. It is equally important for the PRT to understand the mechanics of error. These error mechanisms are both the why and how of how humans commit errors.

Section 3 - Human Error Mechanisms

An in-depth scientific exploration of human error mechanisms is well beyond the purpose and requirements of this handbook. Therefore, for the sake of brevity, human error mechanisms will be categorized into two broad and often overlapping groups: internal error mechanisms and external error mechanisms. This categorization is for the use of the PRT in analyzing close-call reports only.

Internal error mechanisms can be considered as those errors that are a result of individuals' physiological or psychological states or limitations; in other words, those functions that occur within the human cognitive system. This would include memory function, workload, stress, and fatigue, etc.

External error mechanisms would include all the influencers and drivers that led people to make errors. This would include the system within which the person is operating and the human/system interfaces.

There are four general error mechanisms that must be considered when analyzing an incident. These are:

- Poor or mistaken decisionmaking
- Cognitive errors - knowledge, logic, reasoning
- Affective thinking - attitude and mindset
- Psychomotor skills - brain, hand, and eye coordination

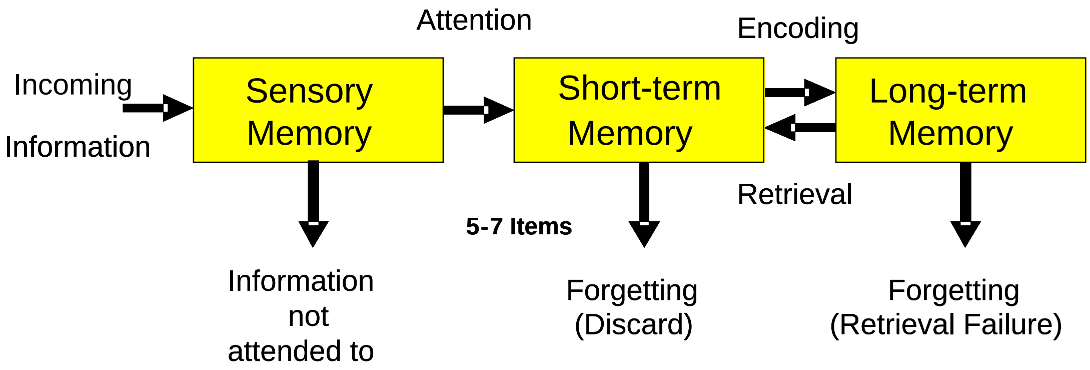
General Decisionmaking

Errors are often the result of a poor or mistaken decisionmaking process. Decisionmaking is a process that depends on cognitive thinking (knowledge, logic, and reasoning), affective thinking (attitude and mindset), and psychomotor skills.

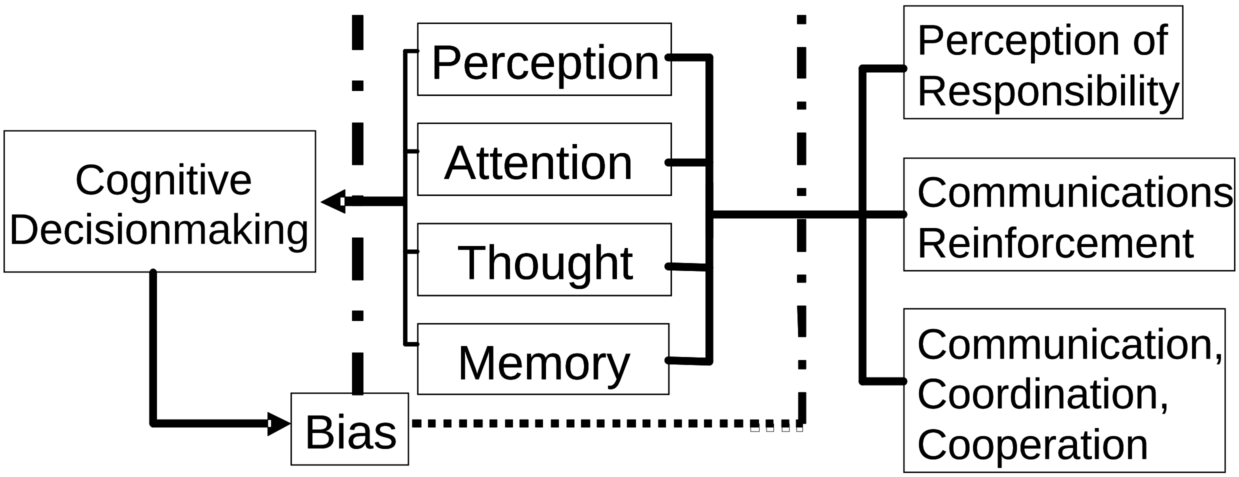
Cognitive decisionmaking is a result of several factors. How the individual perceives the environment and situation is a key factor in decisionmaking. Misperceiving the environment or situation can result in errors of commission or omission.

Every moment of every day, our senses bombard our brains with information (sensory memory). Our brain must sort through this barrage and decide what we will pay attention to in our conscious mind. This thought process takes place in the sensory memory portion of the brain.

What we decide to pay attention to is passed to the short-term or working memory of the brain. This portion of the brain is where decisionmaking takes place. Prior to making a decision our brain search through our experiences (long-term memory) to see if we have faced a similar situation or environment in the past.



While the decisionmaking process uses each of the above factors, before a decision is made these factors must pass through a filter of biases, preconceived ideas, and other prejudicial influencers. It should also be noted that information drawn from the long-term memory might be faulty. We may have remembered it wrong, or it may have been altered by other memories.



Tracking further back in the decisionmaking process to what impacts what we perceive, what we pay attention to, how we think, and our memories, we find how we perceive our responsibilities (task or job), what communications reinforcements occur, and how we relate to and work with others (communications, coordination, and cooperation). These upstream factors must also pass through the filter of our biases, preconceived ideas, and other prejudicial influencers. The diagram below illustrates this process.

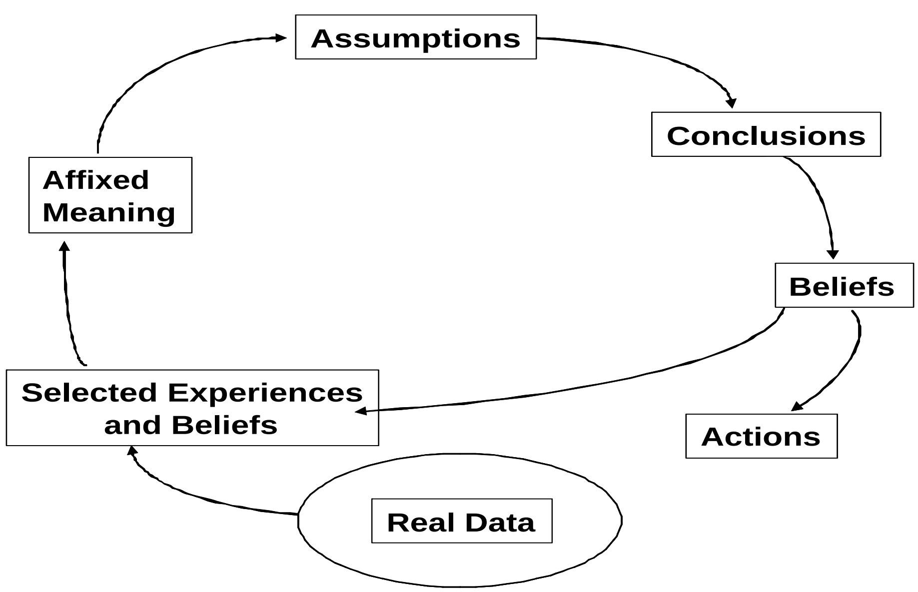
Perception of the situation is a key factor in decisionmaking. How we perceive the current situation and the future desired state determines what we pay attention to, how we think about the situation, and what long-term memories we access. How we perceive the situation is a combination of sensory memory and long-term memory coming together as a result of stimulation from the environment. Because perception is a combination of sensory memory and long-term memory elements, our perception may have no relevance to the current situation. Therefore, perception is not a true reflection of reality. We only try to make it that way. Hence, we refer to this perception as the *theory of the situation*.

It should be noted that the biases, preconceived ideas, and other prejudicial influencers mentioned above are not all bad. For example, training can influence these bias filters. If the training is appropriate and effective, it will develop biases that will filter out many bad decisions. As illustrated above, the decisions we make are fed back into our biases and either reinforce or degrade that bias. For example, standardization, such as the hot water is always on the left, facilitates learning and causes good biases that reduces errors.

Attention is another key element of decisionmaking. We sometimes think of attention as an internal choice, but external stimuli have a significant impact on what attracts and captures our attention. Attention influencers can be categorized into four domains: environmental, affective, design, and physiological.

- The environmental domain consists of noise level, temperature, weather, etc.
- The affective domain deals with our interest level and attitude towards the task.
- The design domain lies in the area of display, controls, and alarm/warning mechanisms.
- Fitness for duty and alertness levels fall into the physiological domain.

Biases can have a significant impact on our thought and memory processes. As mentioned, we are constantly bombarded with information and we must be cautious not to use this information to begin the climb up the "Ladder of Inference." The Ladder of Inference takes the incoming information and filters it through our past experiences and belief system. Any information that is contrary to those experiences or beliefs is quickly discarded. We then take what's let over and affix meaning to it. From that meaning, we draw assumptions and conclusions. The conclusions then reinforce our belief system and we take action on those beliefs rather than the original information.



This is sometimes referred to as confirmation bias. Confirmation bias is where an individual searches selectively for evidence to confirm an underlying belief, discounting contradictory evidence, and stops searching once the confirming evidence is found. This type of bias prevents the discovery of the influencers and drivers that caused the behaviors that resulted in the incident occurring.

The PRT must overcome these confirmation biases and attempt, to the largest degree possible, to place themselves in the position of the people involved in the incident and understand what they were perceiving at the time of the incident and how their decisionmaking process led them to the behavior being analyzed. *"Life is tough, but it's even tougher if you're stupid,"* is not a correct analysis.

Stress

Stress can be defined as the quality of transactions between a person and the demands of the environment. A relationship between a person and the environment that is perceived as being relaxing and requiring little mental resources results in complacency and overconfidence. This may be great for a day at the beach, but not when interacting within a complex system. At the other end of the spectrum, if the relationship between the person and the environment is perceived to be taxing or exceeds the person's mental resources, the result is stress. High, or low, stress levels can result in irrational decisionmaking, loss of situational awareness, and exhaustion.

It should be noted that stress in and of itself is not necessarily bad. An optimal level of stress keeps us focused on the task at hand without over-taxing our ability to maintain situational awareness.

Workload

Workload, like stress, can impact our decisionmaking process. Our brains have a certain capacity for mental processing and like to fill that capacity. If the workload is too light and not utilizing its full capacity for the task, the brain fills that excess capacity with other thoughts. We daydream, thinking about hobbies, other chores and tasks, or other thoughts unrelated to the task at hand. We can become bored or complacent with the task, performing the task as if our brain was on automatic.

If the workload is too high, our brain is filled to capacity, or nearly so, with the performance of the task. Again, our brains have only so much capacity. As the workload demand increases, our ability to process sensory information decreases. This results in a loss of situational awareness, fatigue, and irrational problem solving, along with other psychological and physiological problems.

Fatigue

For the purposes of this handbook, we will not discuss the aspects of physical fatigue; rather we will focus on cognitive fatigue and how fatigue impacts our situational awareness, decisionmaking, and mental attitude. As the brain becomes increasingly fatigued, the ability of the short-term memory to process information decreases.

As discussed in Section 2, there are three classes of human error: decision-based, skill-based, and perception-based. It should be noted that each of these could also be the result of a communications error. The degradation of mental capacity due to fatigue can directly impact each of these error classes.

Some of the symptoms of fatigue are as follows:

Forgetfulness	Channelized thought process - Fixation
Poor decisionmaking	Apathy
Slowed reaction time	Lethargy
Reduced vigilance	Bad mood
Reduced attention span	Nodding off
Short-term memory loss	Distraction
Poor communication	Loss of visual perception skills
Loss of situational awareness	Loss of initiative
	Poor attitude

Summary

Stress, workload, and fatigue are each an example of the overlap between internal and external error mechanisms. These internal physiological and psychological influencers impact the individual's performance, but their sources are often external of the individual and originate in the environment, situation, and/or the system.

Each of these items will be discussed in more detail in the next section.

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Section 4 - Stress, Workload, Boredom, and Fatigue

As discussed in the previous section, stress, workload, and fatigue, along with boredom, are major mechanisms leading to human error. When reviewing this section, keep in mind that these mechanisms often have their roots in the environment, the situation, supervision and/or the organization/system. For example, the lack of training or experience in performing a task may cause stress, poor job design can result in a less than optimal workload, or poor scheduling practices can lead to fatigue. These may very well be the underlying causes of many operator errors as discussed in the "Operator Error" portion of HFACS in Section 2.

Stress

Stress can be defined as the quality of transactions between a person and the demands of the environment. A relationship between the person and the environment that is appraised by the person as taxing or exceeding his or her resources and endangering his or her well-being is stressful. High stress levels can result in irrational decisionmaking, loss of situational awareness, and exhaustion.

The absence of stress on the job can also be an unsatisfactory situation. For example, if the performance of a certain task generates little or no stress, the task may become automated. That is, the individual performs the task without thinking about it and without regard for the risks involved. Such a relationship between a person and a task that is automated or is perceived as requiring little mental resources often results in complacency, overconfidence, and loss of situational awareness. When humans interact with or within a complex system this situation can greatly increase the risk for error.

There are many sources of stress, but they can be placed into two broad categories: direct and indirect.

Direct stressors are related to the particular task being performed. Lack of training or experience can be a source of direct stress while the individual attempts to cope with the task requirements. An example of such a direct stressor might be attempting your first solo flight or making your first sky dive. A less dramatic, yet perhaps equally stressful, example is performing a familiar task in an unfamiliar environment, such as, being a skillful engineer operating an unfamiliar train consist in unfamiliar territory.

Another source of direct stress is the rate of production. As the rate of production increases beyond the physical and/or cognitive abilities of the individual, stress exceeds the person's ability to cope with the situation. Placed in this situation, people will usually begin trading accuracy for speed. This often introduces errors into the production, hence increasing rework or introducing a latent unsafe condition. For example, if a track production crew is pressured to produce more completed track than they have the physical or mental capability to produce, they will begin to take shortcuts.

Shortcuts are a person's mechanism for coping with the direct stress of increased production. Such shortcuts can result in errors/defects being introduced into the track structure. These errors/defects can latently exist for years in the track structure until the right circumstances exist to cause a derailment. Another example would be a track inspector that was expected to inspect X miles of track, and then due to personnel reductions is now expected to inspect 2X miles of track. In making this reduction the organization has made a business decision and has accepted additional risk of error. This decision may be appropriate and justifiable, but it should be one that is carefully analyzed to insure that the organization is not unknowingly accepting more risk than is desirable or prudent.

Environmental and situational stressors are considered direct stressors if they are directly associated with the task. An example of such a stressor would be the inspection of railcars in Barstow, CA in August, or in Minneapolis in January. Another example would be working in a shop environment with a very high noise level, or performing a relatively simple task (changing a light bulb), but doing the task at the top of a 1,000 feet tall tower.

Some common sources of direct stress include:

- Effort - the total effort required to perform the task.
- Frustration - things don't go as planned.
- Performance demands - production and quality.
- Mental demands - the mental effort required to perform the task.
- Physical demands - the physical effort required to perform the task.
- Temporal demands - time constraints.

Many tasks require teamwork and communications. Stress can be induced in an individual by the ill-structured information flow or a distracting rate of information flow. Standardization of procedures and forms is designed to structure information in a format that increases understandability and decreases stress. Information that is presented too fast can cause confusion, frustration, and stress. Conversely, information presented too slowly causes frustration, boredom, and impatience.

Remember, stress is not necessarily bad. As human beings, we need a certain amount of stress in order to remain focused on the task at hand, and our longer term goals. Without stress in our lives, we would be totally complacent to the risks and dangers around us. Job/task design should seek to inject an optimal level of stress into the humans operating within the system without exceeding the individuals' capability to cope. Deviations either way from the optimum stress level should be avoided.

Indirect stressors (sometimes referred to as emotional stressors) are the issues we all have as humans during the course of our lives. They are self-referent and are truly all about the "me" in all of us. Issues such as a sick child, an argument with a spouse or friend, a broken down automobile, or a financial problem don't go away when we come to work. We may suppress them from our conscious mind, but they remain in our unconscious mind. They continue to cause us stress even when we are not focusing on them. While we may not be focused on these issues, they interfere with our mental processing. Such cognitive interference results in a performance deficit as a result of a reallocation of attentional resources - working memory.

Referring back to Section 3, you will recall that the human brain has a limited short-term, or working memory capacity. This memory capacity is allocated for a variety functions. Stress, both direct and indirect, reduces the available mental processing capability.

Workload

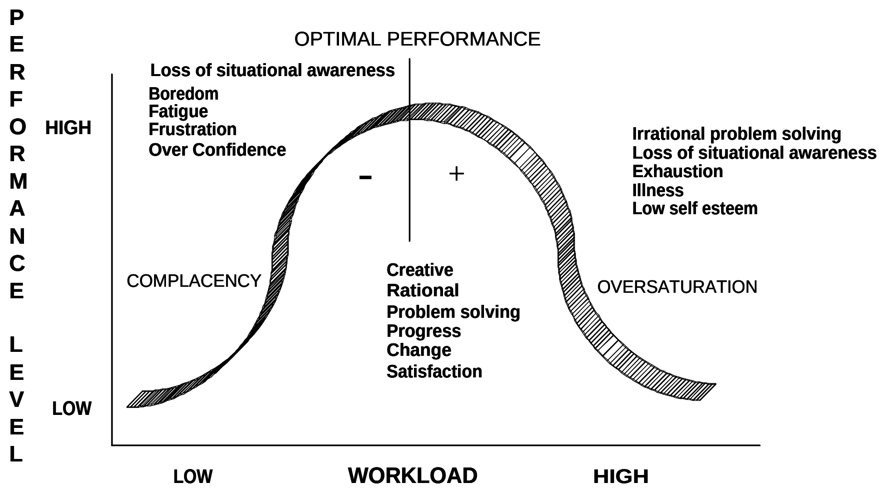
The modern study of workload and its relationship to stress and human performance began when N. H. Mackworth conducted research on why radar operators were missing critical signals on their displays (1948). Mackworth's study showed that an observer's ability to detect critical signals (changes in the display) declined over time. Numerous studies since then have also shown that the quality of vigilance performance is fragile and deteriorates quickly. This deterioration manifests itself in reduced accuracy and/or increased reaction time. The results of many recent studies on sustained vigilance have shown that not only does performance deteriorate, but people also find such tasks to be very demanding and stressful. Interestingly, the relationship between workload and stress is extremely close. The NASA Workload Index uses six individual sources to measure workload. Those are:

- Effort - the total effort required to perform the task.
- Frustration - things don't go as planned.
- Performance demands - production and quality.
- Mental demands - the mental effort required to perform the task.
- Physical demands - the physical effort required to perform the task.
- Temporal demands - time constraints.

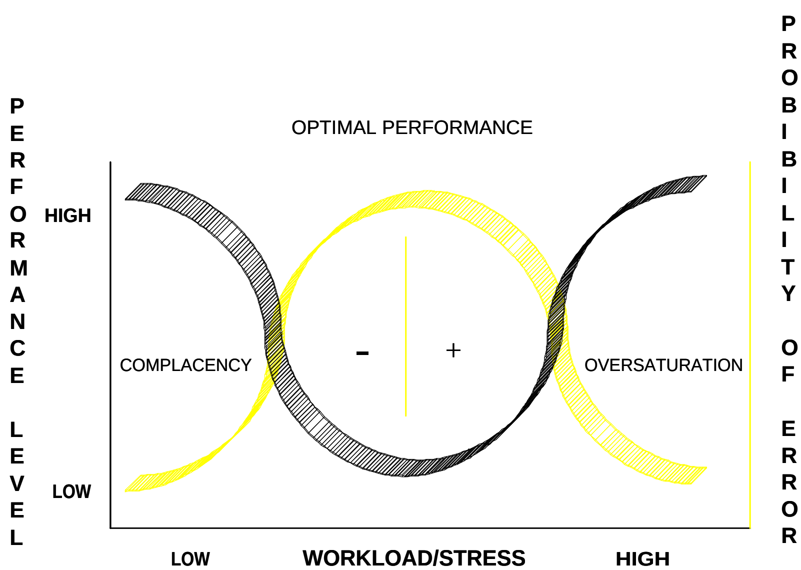
From the previous page, you will note that these are the same six areas that have been identified as common sources of stress. Another link between workload and stress, and the ability to maintain vigilance, is the structure and rate of information flow that combine to determine how much short-term memory resources will be required to maintain focus and sensitivity to a changing situation.

The issues of stress, workload, vigilance (situational awareness), decisionmaking, and performance are interrelated in such a way as to drive many human behaviors. In the analysis of close-call reports, it would serve the PRT well to ask themselves questions that explore the six areas listed above. This will greatly assist the PRT members in placing themselves in the positions of the employee involved in the event.

As such, it is important that workload, hence stress, be optimized in order to achieve higher levels of human performance. Minor deviations in task load will have little effect on resource capacity demand and subsequent performance. Greater deviations from the optimal levels, however, require the individual to expend additional resources. Initially, either increases or decreases in stress level beyond this normal zone result in discomfort with the situation. Further deviation can exceed the individual's range of adaptability. As this occurs, the individual's subjective perception of the workload increases and the individual begins to perceive the task as stressful. From this point on, if the workload is increased or decreased further the individual's range of adaptability has been compromised with a resulting rapid degradation in performance. This workload-to-performance relationship is illustrated below.



The level of workload can impact our decisionmaking process. As mentioned in Section 1, we develop our perception of the outside world through our senses. This sensory input is transferred to our short-term memory for processing. If our short-term memory is already working at or near capacity, many of these inputs will be left unattended or discarded, resulting in a loss of situational awareness. This mean the individual's internal theory of the situation is developed without updated information from the environment. This lack of comprehension of the environment results in the development of an erroneous theory of the situation. Further, this flawed theory of the situation is then used in the cognitive decisionmaking process. Once we decide upon a course of action and execute it with the best of intentions, we commit the error.



As the workload/stress level deviates from the optimal level, the individual's performance level decreases. The individual's thought processes move into the areas of complacency or over-saturation. As the individual's thought processes make this move, the probability of error increases.

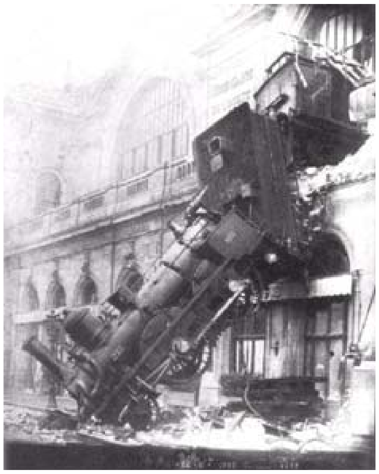
Boredom and Vigilance

Boredom is another issue that is closely related to stress and workload. Boredom can be defined as a feeling of increased constraint, repetitiveness, unpleasantness, and decreased arousal. Boredom has cognitive and affective components, and perhaps psycho-physiological components as well. Boredom, coupled with the need to remain vigilant, often causes stress.

Vigilance is stressful because of the need to remain alert and to combat boredom over extended periods of time. Vigilance tasks typically require individuals to work in highly repetitive activities, in unstimulating environments, and to remain attentive for intervals determined by someone else.

Fatigue

Fatigue is an excuse for wimping out and whining, right? Well, perhaps not. The Department of Transportation estimates that 48-50 thousand transportation fatalities, millions of injuries, and $100 billion are lost every year due to fatigue-related accidents. Furthermore, the situation has become so critical that the National Transportation Safety Board (NTSB) established a policy that, "Fatigue is a direct cause or contributing factor in every accident due to human error unless specifically ruled out." Even though fatigue has been a major factor in transportation accident for many years, our Freudian influenced society (as discussed in the introduction) is slow in recognizing the danger of having fatigued operators functioning in a complex system.



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Fatigue is perhaps the most insidious cause of human error. The reason is that as fatigue causes our cognitive abilities to degrade, we are increasingly unable to determine our own performance capability. This is a real problem because we become the worst judge of our own cognitive condition. But how bad is it in the railroad industry?

A recent study, Validation and Calibration of a Fatigue Assessment Tool for Railroad Work Schedules, of 1,400 freight rail accidents that occurred in 2003, 2004, and the first half of 2005 revealed the seriousness of this problem. This study involved about 2,800 railroad employees involved in rail accidents. It looked at the cause or causes of the accident and the 30-day work history of the employees involved. The study determined that fatigue was a factor in approximately 25 percent of the events that had a human factors cause. As significant as this is, the study also produced a number of other findings that illustrates the seriousness of the problem, and perhaps provides us with clues to finding solutions.

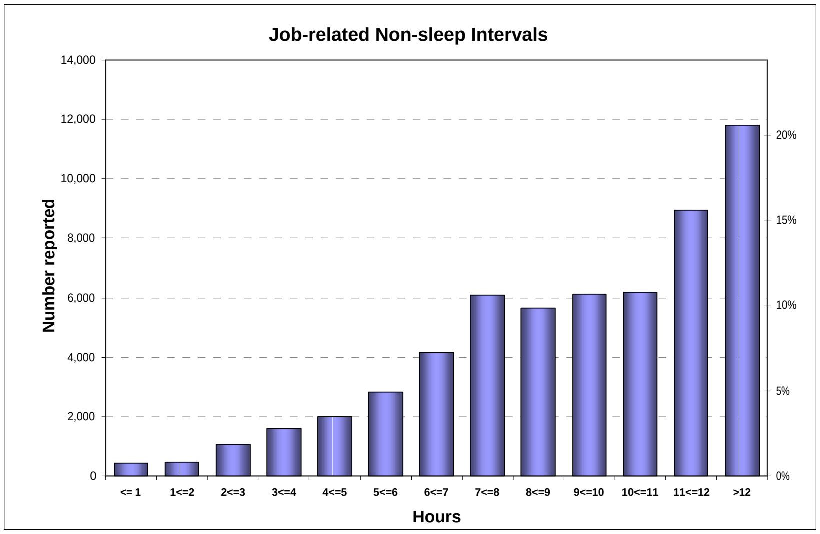
In order to understand cognitive fatigue, we must first understand the causes of fatigue and how sleep, or rather the lack of sleep, impacts cognitive performance. Sleep is a biological necessity. This biological need is driven by chemical changes in the brain. Studies have shown that the average person needs approximately 8 hours of sleep. Prior to the invention of the light bulb, the average American slept more than 10 hours per day. Today the average American sleeps 6.7 hours per day. In our 24-hour society, fatigue has risen to a serious safety and health issue.

There are two major components of fatigue: (1) The time of day and (2) The individual's sleep history and continuous hours of wakefulness. The time of day refers to the natural circadian rhythm, while the sleep history and continuous hours of wakefulness refer to an acute or cumulative sleep debt. These two components determine the individual's level of alertness and cognitive performance.

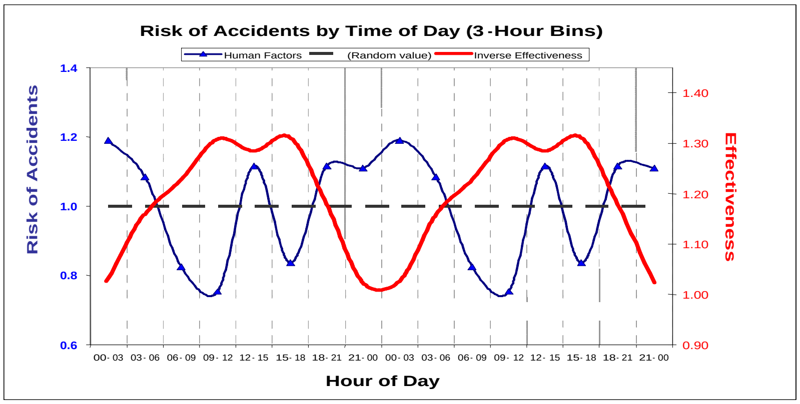
The circadian rhythm is a natural change in a person's level of alertness and cognitive performance over the course of the day. Human beings are daytime creatures with a natural drive to sleep at night. This drive to sleep is caused by a change in the chemistry of the brain over time. Normally, the circadian rhythm alertness is low during the night and is reset at dawn by light. The circadian rhythm alertness rises during the morning hours, has a small dip in the afternoon, then continues to rise in the late afternoon. This alertness level gradually declines during the evening hours and finally results in the brain signaling that it is time to sleep. The following chart represents a typical circadian rhythm pattern for an average-day worker:

The quality of sleep is as equally important as duration. Sleep is not a static condition; rather, it is dynamic and has a well defined architecture. This architecture includes four distinct levels of non-rapid eye movement (non-REM) sleep and REM sleep. The pattern of non-REM and REM sleep are repeated throughout the sleep episode.

One of the facts revealed in the Validation and Calibration of a Fatigue Assessment Tool for Railroad Work Schedules study is related to the area of acute fatigue. Acute fatigue is the result of continuous hours of wakefulness. Simply put, the longer we are awake, the more fatigued we become. Performance can drop off quickly after 16-18 hours of continuous wakefulness. The study looked at how long the individuals involved in the accident had been awake and the frequency of accidents. The result is illustrated in the following chart.

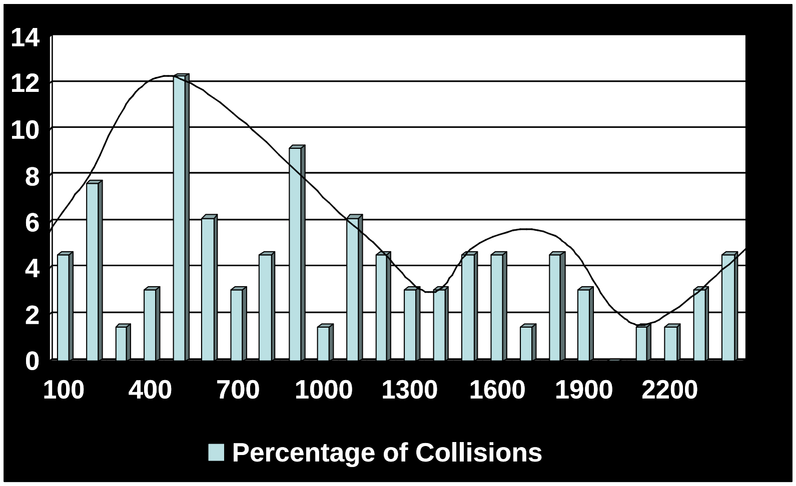


As you can see, the longer an individual is on duty, the higher the percentage of accidents. This has widespread implications for all crafts, whether it is a carman working a double shift, an engineering employee working a derailment, or a train crew. It should also be remembered that when these individuals finish their work, they must still drive home in a fatigued state. Another fact that this study confirmed is that the time of day influences the probability of an error. The following chart illustrates the frequency of accidents by time of day.



The line with data points indicates the number of accidents occurring at that time of day. The line without data points indicates the human effectiveness level at that time of day as driven by the circadian rhythm. As you can see in the chart above, there is a strong inverse correlation between the number of accidents and the effectiveness level of the individuals involved.

Another important finding that this study revealed was that there is an increase in the probability of a person being involved in an accident as their effectiveness level decreases. These findings confirm an earlier study by the Collision Analysis Working Group. This group consisted of representatives of the FRA, rail labor, and rail management. This group studied 65 main track collisions and determined that time on-duty and time of day could be correlated to the accident rate. Notice in the chart below that the accident rate per time of day follows the circadian rhythm. Note: The circadian rhythm line has been inverted for clarity.



Cumulative sleep loss is another important area to consider in determining performance levels. Cumulative sleep loss is where an individual loses a portion of the required sleep each night for several nights. For example, if a person needs 8 hours of sleep per day and they are only receiving 6 hours per day, after the course of a normal work week they will have lost the equivalent of an entire night's sleep. This cumulative sleep loss can significantly affect performance.

The seriousness of cumulative sleep loss was illustrated by a recent study by the University of Denver of the operating crews on a division of a major Class I railroad. This study developed the following facts:

- 21.3 percent of the employees were clinically sleep deprived.
- 29.2 percent of the employees were borderline sleep deprived.
- 49.5 percent of the employees were considered "Normal."

During this study a test was conducted to measure the quality of sleep these employees were receiving. This test, the Pittsburgh Sleep Quality Index, indicated the following:

- Average score (Overall) = 8.1
- Average score (Extraboard) = 8.88
- Average score (Pool) = 7.80
- Average score (Engineers) = 8.72
- Average score (Conductors) = 7.58

Note: Scores of 5 or above indicated poor sleep quality.

The lead scientist on the study stated, "Thus, the majority of the ... Engineers and Conductors would likely be considered highly fatigued in comparison to normal and even clinical populations."

As mentioned in Section 3, the following are some of the symptoms of fatigue:

Forgetfulness	Channelized thought process - Fixation
Poor decisionmaking	Apathy
Slowed reaction time	Lethargy
Reduced vigilance	Bad mood
Reduced attention span	Nodding off
Short-term memory loss	Distraction
Poor communication	Loss of visual perception skills
Loss of situational awareness	Loss of initiative
	Poor attitude

Each of these symptoms, or any combination of them, can have a significant adverse impact on operational safety and efficiency.

Other Considerations

Depression

A World Health Organization study (2004) determined that there is a link between depression and fatigue. Researchers found that while fatigue and the psychological disorder of depression are not the same, and the two have different risk factors, there is considerable overlap and inter-relationship.

The study indicates that people who are depressed are more than four times as likely to develop unexplained fatigue, and those who suffer from fatigue are nearly three times as likely to become depressed. Depression and fatigue feed off each other in a vicious cycle that makes it hard to determine where one begins and the other ends.

Although researchers have long suspected that depression and unexplained fatigue are related, the nature of the relationship between the two common conditions is unclear. But this study suggests that depression and fatigue may act as independent risk factors for each other. “One can possibly understand how a fatigued person can start feeling psychologically distressed because of his or her condition, but the opposite is more difficult to explain,” writes researcher Pertos Skapinakis, M.D., of the University of Ioannina in Greece, and colleagues.

While depression may be difficult to detect in the workplace, there are signs and symptoms that managers and coworkers can detect. Such things as excessive absenteeism, prolonged illnesses, and attitudinal and behavioral problems may be signs of depression. Also, as this study indicates, excessive and unexplained fatigue may be an indicator of depression.

As discussed in Section 3, short-term memory is critical to human performance. Anything that interferes with the memory process can significantly impact the individual's ability to successfully and safely complete tasks. Psychological disorders, such as depression and posttraumatic stress disorder, as well as significant stress, can interfere with memory.

Depression can make it difficult to concentrate, focus on details, and absorb new information. Some people who experience severe psychological trauma develop post-traumatic stress disorder and experience recurrent, intrusive, vivid memories of the traumatic event. These flashback memories are often terrifying and induce repeated acute stress responses. An acute stress response triggers the brain to release certain chemicals—otherwise known as the fight-or-flight response. If this occurs repeatedly, the chemicals can actually damage parts of the brain that are important for memory.

Being under constant lower levels of stress also can cause this type of harm. So it is important to obtain treatment and find ways to push back against stress; for example, through developing effective psychological coping mechanisms, engaging in vigorous physical activity, meditation, and learning relaxation techniques.

Sleep Disorders

There are more than 70 recognized sleep disorders. Of these, the most common are bruxism (teeth grinding), delayed sleep phase syndrome, narcolepsy, night terrors, parasomnia, periodic limb movement disorder, REM behavior disorder, restless leg syndrome, circadian rhythm disorder, sleep paralysis, sleep walking, insomnia, and obstructed sleep apnea (OSA). Of these, OSA has the largest prevalence. But remember, there over 70 others out there to reduce the safety and efficiencies of the operation.

According to Dr. William C. Dement (considered by some to be the father of sleep research), 40 percent of the population has some sort of sleep apnea, with half of them considered as needing medical treatment. Studies of over-the-road truck drivers have shown that as many as 70 percent of them had some form of apnea. Not only does sleep apnea add risk to operations on the job, it is linked to other health problems and diseases, such as heart disease, stroke, diabetes, high blood pressure, and more.

Sleep disorders are very dangerous, relatively easy to diagnose, and for the most part easily treatable. Yet most people never take the first step – diagnosis. There are three basic reasons for this phenomenon:

- They know they're always tired, but they think that's normal – ignorance of the problem.
- They don't want other people to know that there is something wrong with them – stigma of seeming defective.
- They don't want their employer to find out – fear of losing their job.

Summary

It is important to understand how stress, workload, boredom, and fatigue impact human performance. It should also be noted that the effects of stress, workload, and fatigue are interrelated and cumulative.

In the early years of accident investigation, many times the cause was determined to be “operator error.” While this may have answered “what” happened, it did not answer the question ‘why” it happened. As time moved on and we became more sophisticated in our investigation methods, the term “loss of situational awareness” was coined. While this was a positive step forward, it still didn’t answer the question “why.”

In order to answer the “why” question, we must look at the overall system/organization to find the drivers that contributed to the error. These drivers are often difficult to find, and require patience and diligence to identify, but that is where the “gold” is located. Identifying and correcting these drivers can have a significant impact on the reduction of risk and the development of a culture of safety within the organization.

Each of these issues should be considered by the PRT in analyzing close-call reports and in the development of potential countermeasures.

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Section 5 - Crew Resource Management and Highly Reliable Organizations

This section has been added as a possible countermeasure for many of the systemic causes for human errors that occur within organizations. Many of the concepts of crew resource management can be used at all levels of an organization to improve performance.

Many individual and collective errors are the result of a person's or crew's theory of the situation not matching the reality of the situation. Many incidents can be traced back to the crews' inability to manage all available resources, resulting in errors; for example, failed communications, poor task delegation, inability to adapt to changing situations, etc.

Crew Resource Management

Crew Resource Management (CRM) employs a number of techniques to improve the management of time, knowledge, and attention. Many systems reach the level of complexity that it requires more than one person to operate it properly. Whenever this occurs, it is imperative that there is an adequate level of communications and coordination between each individual in order to operate the system safely and efficiently. The final report from the Collision Analysis Working Group identified poor inter-crew communications as a possible contributing factor in 15 percent of the collisions they analyzed. If you included those events where one crewmember made an error and the other crewmember failed to detect and correct the error, the percentage would be much higher. There is also always the possibility that people other than the crew may commit a communications or coordination error that affects the crew.

This problem is not unique to the railroad industry. Many other industries suffer from communications/coordination issues. This problem was first recognized in the commercial aviation industry and was the focus of a 1979 workshop on aviation safety, hosted by NASA. The NASA research presented at this meeting found that the primary cause of the majority of aviation accidents was human error, and that the main problems were failures of interpersonal communication, leadership, and decisionmaking in the cockpit.

The output of this workshop was the development of the concept of CRM. A variety of CRM models have been successfully adapted to different types of industries and organizations, all based on the same basic concepts and principles. Examples of some of the industries that have adopted the principles and concepts of CRM are hospitals and surgical teams, nuclear power plant operators, the military, marine operations, aircraft maintenance personnel, offshore oil drilling operations, and fire fighting.

CRM Concepts, Principles, and Skills

What is CRM? First, we must explain what it isn't. It is not a crew-calling program, a quick fix training program, or a short-term accident reduction program. It is a safety-based human factors training program, a process that addresses the entire crew and other related staff, heightens awareness of attitudes and behaviors and their impact on safety, and a process to improve crew communications and coordination. CRM can be defined as a management system that makes optimum use of all available resources—equipment, procedures and people—to promote safety and enhance the efficiency of operations. In other words, it's a tool that can be used to move an organization towards achieving a culture of safety and efficiencies.

CRM is concerned not so much with the technical knowledge and skills required in operations, but rather with the cognitive and interpersonal skills needed to manage the operations within an organized, complex system. In this context, cognitive skills are defined as the mental processes used for gaining and maintaining situational awareness, for solving problems, and for making decisions. Interpersonal skills are regarded as communications and a range of behavioral activities associated with teamwork. In railroading, as in other walks of life, these skill areas often overlap with each other, and they also overlap with the required technical skills.

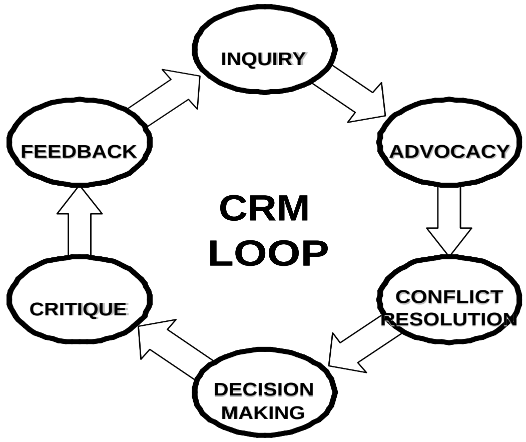
CRM fosters a climate or culture where the freedom to respectfully question authority and the free exchange of information is encouraged. However, the primary goal of CRM is not enhanced communication, but rather enhanced situational awareness. It recognizes that a discrepancy between what is happening and what should be happening is often the first indicator that an error is occurring. This is a delicate subject for many organizations, especially ones with traditional hierarchies, so appropriate communication techniques must be taught to supervisors and their subordinates, so that supervisors understand that the questioning of authority need not be threatening, and so that subordinates understand the correct way to question orders.

The intent of this dialogue is not to question or threaten authority, rather it is a process where individuals within a complex system that have a disagreement in their theories of the reality can use to achieve a shared theory of the reality. This shared theory of reality, while sharing elements of both original theories, will be closer to the actual reality of the situation than either of the originals.

CRM training encompasses a wide range of knowledge, skills and attitudes, including the following:

- Decisionmaking - A structured, mental decisionmaking process based on logic and reason.
- Assertiveness - Communicating your theory of the situation without being aggressive.
- Mission/Task Analysis - Gain a shared understanding of the mission or task.
- Communications - Sharing information to gain a shared theory of reality.
- Leadership - Understanding the leadership role of all crewmembers.
- Adaptability/Flexibility - Detect changing situations and adapt to those changes.
- Situational Awareness - Acquiring and maintain situational awareness; detect when situational awareness is being compromised and reacquire it.
- Teamwork - Work together with all the attendant sub-disciplines that each of these areas entails.

These skills are then applied in a process designed to result in a shared theory of the situation. This process includes inquiry, advocacy, conflict resolution, decisionmaking, critique and feedback.



Each of the skills and the associated CRM process must be institutionalized into the organization through extended training, education, coaching, mentoring, and behavior modeling. Once these skills have been institutionalized, the full benefits of CRM can be achieved in the form of a safer and more efficient organization. This is an investment in safety and efficiency that has demonstrated success in a wide variety of industries. The Texas Transportation Institute at Texas A&M University has recently completed three reports regarding CRM in the railroad industry. They are as follows:

Evaluation of Existing CRM Training and Railroad Team Classification
http://tti.tamu.edu/projects/project_details.htm?id=2910

Pilot course and training materials
http://tti.tamu.edu/projects/project_details.htm?id=2911

Business Case for CRM
http://tti.tamu.edu/projects/project_details.htm?id=2912

The Highly Reliable Organization

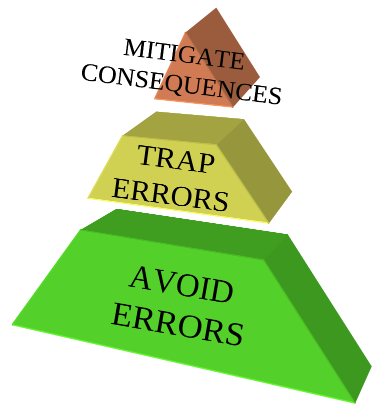
CRM is an important component in an organization's attempt to achieve high reliability, as is confidential close-call reporting (C3RS). Other programs that are characteristic of highly reliable organizations are:

- Stress, depression, and wellness programs
- Workload management programs
- Confidential Observation of Railway Safety (CORS)
- Alertness management programs
- Threat and Error Management Model (TEMM)

Each of these programs addresses a specific human performance issue, but it should be readily apparent that there is significant overlap and synergy between them. For example, information gathered by the CORS programs feed into the CRM training program and the TEMM. Likewise, this information can lead to modifications and improvements in the stress, depression, and wellness program.

High-reliability organizations use this portfolio of programs to maintain continual improve of system designs, procedure, and policies. The goal of this continuous improvement process is to prevent errors, trap errors, and mitigate the consequences of errors at all levels of the organization.

Prevent errors: Redesign systems, procedures, and operating methods in order to make it difficult, if not impossible for an error to occur.



Trap error: Those errors that cannot be prevented are detected and isolated or corrected.

Consequence mitigation: If an error cannot be prevented or trapped, procedures are in place that will mitigate the consequences of the error.

These processes not only increase the level of operational safety, but also improve operational efficiency. This portfolio of programs can lead to a significant change in organizational culture and move the organization toward operational excellence.

Summary

CRM is a proven process for improving operational efficiency, reducing human error, and is effective in countering fatigue. While it requires extensive training and associated costs, studies show that it is cost effective with organizations that invest in the process of reducing property damage costs due to accidents.

CRM, C3RS, and other human performance programs can significantly improve safety and efficiency while moving an organization toward a position of high reliability.

APPENDIX A: Glossary of Terms

<u>Terms and Definitions</u>

Active Conditions (Errors) – Generally associated with front-line operators of complex systems (engineers, conductors, dispatchers, machine operators, etc.). The effects of active errors are felt almost immediately and are often easily identified.

Acute Sleep Loss – Occurs when an individual receives less than 6-7 hours sleep in a 24-hour period. Sleep loss of 1 hour per night results in a cumulative sleep debt equal to an entire night's sleep per week.

Aggressiveness – Doing what an individual thinks will achieve their goals without regard for the opinions, feelings, or rights of others.

Antecedent – Factors that precede, trigger, or influence behavior.

Assertiveness – A willingness to clearly express your opinion while respecting the opinions, feelings, and rights of others.

Behavior – Observable actions that are measurable and based on attitude and culture.

Causal Chain (Error Chain) – A sequence of events that, if not arrested, resolved, or monitored, could relate to, involve, or cause a specific outcome.

Circadian Rhythm – The brain's sleep software. *Circa*, meaning "about," and *dia* meaning "day." A biological clock that controls over 350 bodily functions (sleep/wake, performance, temperature, digestion, excretion, hormones, immune system, etc.). Operates on an approximate 25 hours cycle and is reset by light.

Cognitive Fatigue – A degradation of mental capacities in regard to decisionmaking, reason and judgment, and the ability to remember and process contextual information. This degradation can be caused by either acute or cumulative loss of <u>meaningful</u> sleep.

Communication – The flow of information among all team (crew) members. It includes the ability to interpret body language, tonality, and verbal cues. Also, it addresses the effective use of assertiveness in decisionmaking and problem solving.

Complacency – Complacency occurs when a person is in a comfort zone or has become indifferent to a situation, usually as a result of familiarity. Complacency can cause an individual to miss important situational cues.

Conflict – Conflict occurs when people who depend on each other (interdependency) express disagreement over an issue, or have a different *Theory of the Situation*.

Confusion – Confusion or ambiguity occurs when information is unclear, or when two or more pieces of information conflict.

Consequence – The outcome of a behavior or set of behaviors.

CRM - Crew Resource Management – A methodology that addresses the human element of people working together in safety sensitive conditions and interfacing with technology. In the railroad industry, it can be considered as the effective use of all resources to achieve safe and efficient transportation-related operations.

Cues – Hints or suggestions on which to act. Cues are consciously or unconsciously perceived, and they prompt a type of behavior.

Culture – The totality of socially transmitted behavior patterns, arts, beliefs, institutions, and all other products of human works and thought typical of a population or community at a given time. (See Safety Culture.)

Cumulative Sleep Debt – Sleep need minus actual sleep equals sleep debt.

Decision Errors – Generally related to an error in selection of an appropriate solution to a problem. For example, applying the wrong rule to a given situation (rule-based) or deciding on a wrong course of action based on past experience (knowledge-based).

Effort-Performance Expectancy – Each behavior also has associated with it in the individual's mind a certain expectancy or probability of success. This expectancy represents the individual's perception of how hard it will be to achieve such behavior and the probability of his or her successful achievement of that behavior.

Epworth Sleepiness Scale – The Epworth Sleepiness Scale is a self-diagnosed, survey format test that allows for the measurement of sleepiness.

Error – A deviation from accuracy or correctness; an expected variation from the organizational or group norm. An act, assertion, or belief that unintentionally deviates from what is correct, right or true.

Error Management – The process of correcting an error (or errors) before it becomes consequential.

Equity Theory – The essence of the equity theory is that employees compare their efforts and rewards with those of others in similar work situations. This theory of motivation is based on the assumption that individuals are motivated by a desire to be equitably treated at work. The individual works in exchange for rewards from the organization.

Exchange Theory – A conceptual framework that provides a useful perspective for viewing the topic of motivation is the exchange theory. In a very general sense, exchange theory suggests that members of an organization engage in reasonably predictable give-and-take relationships (exchange) with each other.

Fatigue – Fatigue is often used as a catchall term for a variety of different experiences such as physical discomfort from overworking a group of muscles, difficulty in concentrating and problems staying awake.

Human Factors – A term used to describe a multi-disciplinary field devoted to optimizing human performance and reducing human error. Human factors are the applied science that studies people working together and working with machines and systems. It embraces both individual performance and the resulting influence on the team or crew performance.

Knowledge-Based Behavior – Occurs when there is no pre-learned skill or rule to apply to the situation. This type of behavior is the result of the individual using whatever information and experience is available to solve the problem or respond to the situation. Take, for example, a power-operated switch that is frozen in the reverse position in traffic control territory. While there are no rules governing this situation, the dispatcher solves the problem by reversing the switch at the other end of the siding and operating all trains through the siding.

Lapses – An unintentional memory (storage) error; an action that results from either forgetting or from remembering incorrectly. These errors occur during skill-based behaviors. For example, forgetting a step in a sequence or procedure.

Latent Conditions (Errors) – Most likely spawned by those whose activities are removed from the direct control interface by both time and space (designers, high-level decisionmakers, construction workers, managers and maintenance personnel).

Mistakes – Occurs when there is an intentional (though incorrect) action. An unintentional planning error; these errors occur during rule-based or knowledge-based behaviors. For example, applying the wrong rule to a situation. The planned execution is correct, but the plan is incorrect.

National Culture – A Nation's culture is the overarching framework within which all people behave. It is the shared values and attitudes of a national group that direct behavior.

Non-assertiveness (Passive) – When an individual is unwilling to express their true opinion or question another person's opinions/actions, that can result in sacrificing one individual's opinions, feelings, or rights.

Organizational Culture – This level of culture is evidenced in such things as the openness of communication between management and employees, the commitment of resources to training and maintenance, and the attitudes and behaviors of critical role models. The level of teamwork among groups (i.e. dispatchers, conductors, locomotive engineers, maintenance personnel, and road crews, etc.) is also a part of this culture.

Organizational Factors – Factors with the upper levels of an organization that affect the culture and behavior throughout the entire firm. Take, for example, factors that are promulgated by "bad parents" which result in "problem children" downstream from the actual cause. In an environment where organizational factors have a negative impact on safety at the lower echelons, corrections of unsafe behavior at the individual level will have minimal impact on overall safety.

Organizational Level – Corporate scheduling or policy-making level; includes division, regional, and corporate decisionmakers (may not all be supervisory or management personnel).

Overload – Overload occurs when the amount of information being processed is either too much at once or the information being processed is significantly above the individual's ability to comprehend.

Pattern of Entrapment – A term used to describe the cause and effect in lapses, in following procedures, decisionmaking errors, lack of situational awareness and in mistaking predictive cues through a chain of events heading to an undesirable situation.

Perceptual Errors – A perception of reality (*Theory of the Situation*) that is different than the *Reality of the Situation*. This can result in a mistake, slip, or lapse that in turn begins the causal chain.

Performance-Outcome Expectancy – Every behavior has associated with it, in an individual's mind, certain outcomes: either punishment or reward. In other words, the individual believes or expects that if they behave in a certain way, they will get certain things.

Pittsburgh Sleep Quality Index (PSQI) – The PSQI is an instrument used to measure the quality and patterns of sleep in older adults. It differentiates "poor" from "good" sleep by measuring seven areas: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction over the last month.

Pre-Conditions for Unsafe Acts – Conditions that, if not corrected, establish an environment that enables and perhaps encourages unsafe acts. Common examples include poor communication, poor ergonomics, poor housekeeping, etc.

Professional Level – Individual operator, team, or work group level. The "pointy end of the stick."

Professional Culture – This level of culture reflects the attitudes and values associated with an occupation. These include pride in the profession and liking the job.

Reality of the Situation – The actual or accurate reality that is not influenced by human perceptions.

Rule-Based Behavior – Depends on a system of rules that have been learned. These rules are then applied to new information as it is encountered. For example, when a train crew reduces train speed in response to a restricting signal, they are applying a previously learned rule to newly encountered information.

Safety Culture – The overall attitude towards safety as demonstrated by the compliance to safety policies and procedures. It is often influenced by the perception held by an organization.

Situational Awareness – Understanding the components in the environment at a particular moment in time and space, the comprehension of their meaning, and the projection of their status in the near future. Situational awareness is the resolution between the theory of the situation, the reality of the situation, and the theory of practice. It is the ability of each team (crew) member to maintain his/her awareness of their working environment, and their anticipation of circumstances that may require action.

Skill-Based Behavior – Uses skills that have been learned and developed. For example, the action performed to apply brakes of a train is a skill-based behavior.

Skill-Based Errors – An action that exceeds the skill of the operator or is the result of an inadvertent act. For example, failure to see and avoid, or the inadvertent operation of controls.

Sleep, Stage 1 – The transition from wake to sleep characterized by a slowing of brain activity lasting approximately 5 to 10 minutes. When aroused from this stage, many people believe they were never asleep.

Sleep, Stage 2 – Slower brain activity than Stage 1; considered to be the true onset of sleep; first period lasting 10 to 15 minutes.

Sleep, Stage 3 & 4 – Deep sleep; it may be difficult to arouse a person from this stage and once aroused the person may feel sluggish for several minutes.

Sleep, REM – Dream sleep characterized by quick eye movements, little to no muscle tone, and very active brain patterns. Mammals cannot regulate body temperature during REM sleep.

Slips – An unintentional execution error; an action that occurs through lack of attention or over attention. These errors occur during skill-based behaviors. For example, failing to respond to a hand signal because of preoccupation with another task, or due to complacency.

Stress – A physical, chemical, or emotional reaction that causes tension in your mind and/or body.

System Level – Environment in which professional and organizational levels must operate.

Teamwork – Teamwork is the ability to productively work together toward a common goal. It involves directing individual accomplishment toward a group accomplishment.

Technical Proficiency – Technical proficiency is knowledge of the system, as well as procedural knowledge and the execution of both. System knowledge is the familiarity with functions and types of equipment. Procedural knowledge is the adherence to the procedures that govern the work process (e.g. the movement of trains).

Threat and Error Management Model (TEMM) – Systematic methodology for analyzing the ability and capacity of an organization to mitigate the consequences of threats and errors.

Theory of Practice – A person's knowledge and skills (experiences) that are developed over time and are used to respond to *Theory of the Situation*.

Theory of the Situation – A set of beliefs about what is happening and what action(s) should be taken. It is based on the individual's interpretation of the available information. If a discrepancy (conflict) exists between an individual's *Theory of the Situation* and the *Reality of the Situation*, a loss of situational awareness occurs and an error chain begins.

Unsafe Acts – Acts that occur closest to the operation and are either errors or violations. Errors that result in unsafe acts are improper information processing and are rooted in decision errors, skill errors, or perception errors, or a combination of these.

Unsafe Supervision – The actions or inactions of supervisors and managers. Inadequate or inappropriate supervision, planned inappropriate operations, failure to correct known problem(s), and supervisory violations.

Valance – Each outcome has a "valance" (value, worth, attractiveness) to a specific individual. Outcomes have different valances for different individuals. This comes about because valances result from individual needs and perceptions, that differ because they in turn reflect other factors in the individual's life.

Violation – Deviation in behavior that within a social context is considered inappropriate. Deliberate deviations from those practices deemed necessary (by designers, managers, and regulatory agencies) to maintain the safe operation of a potentially hazardous system.

Violation, exceptional (non-routine) – A deliberate act that is a breach or infringement, as of a law, promise, or social norm. An unexpected variation from the norm. Unlike routine violations, exceptional violations appear as isolated departures from authority. They are neither necessarily indicative of an individual's typical behavior pattern nor condoned by management. For example, an isolated instance of driving 105 mph in a 55 mph zone is considered an exceptional violation. It is important to note that while most exceptional violations are heinous, they are not considered "exceptional" because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority.

Violation, routine – Habitual deviations from the norm, forming or representing part of an individual's behavioral character. Routine violations are often condoned by management or the work group. There are two generally recognized factors of routine violations: (1) The natural human tendency to take the path of least resistance, and (2) A relatively indifferent environment. For example, if the quickest and most convenient path to task completion is to violate a seemingly trivial and rarely sanctioned safety procedure, then the procedure will be routinely violated.

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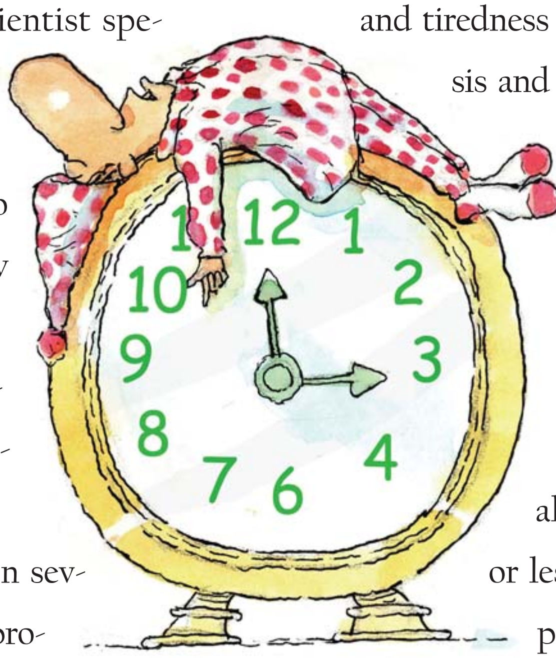
Deep into Sleep

While researchers probe sleep's functions, sleep itself is becoming a lost art.

by Craig Lambert

Not long ago, a psychiatrist in private practice telephoned associate professor of psychiatry Robert Stickgold, a cognitive neuroscientist specializing in sleep research. He asked whether Stickgold knew of any reason not to prescribe modafinil, a new wakefulness-promoting drug, to a Harvard undergraduate facing a lot of academic work in exam period.



The question resonated on several levels. Used as an aid to prolonged study, modafinil is tantamount to a "performance-enhancing" drug—one of those controversial, and often illegal, boosters used by some athletes. In contrast to wakefulness-producing stimulants like amphetamines, modafinil (medically indicated for narcolepsy and tiredness secondary to multiple sclerosis and depression) does not seem to impair judgment or produce jitters. "There's no buzz, no crash, and it's not clear that the body tries to make up the lost sleep," reports Stickgold. "That said, all sleeping medications more or less derange your normal sleep patterns. They do not produce normal sleep." Even so, the U.S. military is sinking millions of dollars into research on modafinil, trying to see if they can keep soldiers awake and on duty—in Iraq, for example—for 80 out of 88 hours: two 40-hour shifts separated by eight hours of sleep.

"No—no reason at all not to," Stickgold told the psychiatrist. "Not unless you think sleep *does* something."

When people make the unlikely claim that they get by on four hours of sleep per night, Stickgold often asks if they worry about what they are losing. "You get a blank look," he says. "They think that sleep is wasted time." But sleep is not merely "down time" between episodes of being alive. Within an evolutionary framework, the simple fact that we spend about a third of our lives asleep suggests that sleep is more than a necessary evil. Much transpires while we are asleep, and the question is no longer *whether* sleep does something, but exactly *what* it does. Lack of sleep may be related to obesity, diabetes, immune-system dysfunction, and many illnesses, as well as to safety issues such as car accidents and medical errors, plus impaired job performance and productivity in many other activities.

Although the modern era of sleep research started in the 1950s with the discovery of REM (Rapid Eye Movement) sleep, the field remained, well, somnolent until recently. Even 20 years ago, "The dominant paradigm in sleep research was that 'Sleep cures sleepiness,'" says Stickgold. Since then, researchers have developed a far more complex picture of what happens while we snooze. The annual meetings in

Illustrations by Tom Mosser

sleep medicine, which only this year became a recognized medical specialty, now draw 5,000 participants. Harvard has long been a leader in the area. The Medical School's Division of Sleep Medicine, founded in 1997 and chaired by Baldino professor of sleep medicine Charles Czeisler, has 61 faculty affiliates. The division aims to foster collaborative research into sleep, sleep disorders, and circadian biology, to educate physicians and the lay public, to influence public policy, and to set new standards of clinical practice, aiming, as its website (www.hms.harvard.edu/sleep) declares, to create "a model program in sleep and circadian biology."

A Culture of "Sleep Bulimia"

IMAGINE GOING ON A CAMPING TRIP without flashlights or lanterns. As the sun sets at the end of the day, daylight gradually gives way to darkness, and once the campfire burns down, you will probably go to sleep. At sunrise, there's a similar gradient in reverse; from the beginning of time, human beings have been entrained to these cycles of light and dark.

Homo sapiens is not a nocturnal animal; we don't have good night vision and are not especially effective in darkness. Yet in an instant on the evolutionary time scale, Edison's invention of the light bulb, and his opening of the first round-the-clock power plant on Pearl Street in Manhattan in 1882, shifted our time-and-light environment in the nocturnal direction. At the snap of a switch, a whole range of nighttime activity opened up, and today we live in a 24-hour world that is always available for work or play. Television and telephones never shut down; the Internet allows you to shop, gamble, work, or flirt at 3 A.M.; businesses stay open ever-longer hours; tens of millions of travelers cross multiple time zones each year, worldwide; and with the growth of global commerce and communication, Wall Street traders may need to rise early or stay up late to keep abreast of developments on Japan's Nikkei exchange or at the Deutsche Bundesbank.

Number of Hours Slept per Night on Weekdays (past two weeks)

	1998	2001	2002	2005
Less than 6 hours	12%	13%	15%	16%
6 to 7.9 hours	51	49	53	55
8 or more hours	35	38	30	26
Mean (# of hours)	NA	7.0	6.9	6.8

Source: National Sleep Foundation

Consequently most of us now sleep less than people did a century ago, or even 50 years ago. The National Sleep Foundation's 2005 poll showed adult Americans averaging 6.8 hours of sleep on weeknights—more than an hour less than they need, Czeisler says. Not only how *much* sleep, but *when* people sleep has changed. In the United States, six to eight million shift workers toil regularly at night, disrupting sleep patterns in ways that are not necessarily amenable to adaptation. Many people get only five hours per night during the week and then try to catch up by logging nine hours nightly on weekends. "You can make up for *acute* sleep deprivation," says David P. White, McGinness professor of sleep medicine and director of the sleep disorders program at Brigham and Women's Hospital. "But we don't know what happens when people are chronically sleep-deprived over years."

"We are living in the middle of history's greatest experiment in sleep deprivation and we are all a part of that experiment," says Stickgold. "It's not inconceivable to me that we will discover that there are major social, economic, and health consequences to that experiment. Sleep deprivation doesn't have any good side effects."

All animals sleep. Fish that need to keep swimming to breathe sleep with half their brains while the other half keeps them moving. It is uncertain whether fruit flies actually sleep ("We can't put electrodes in their brains," says White), but they seem at least to rest, because for extended periods they do not move. When researchers stopped fruit flies from resting by swatting at them, the flies took even longer rest periods. When lab technicians added caffeine to the water that the flies drank, they stayed active longer—and also rested longer after the drug wore off, evidence that the caffeine had disrupted their resting patterns.

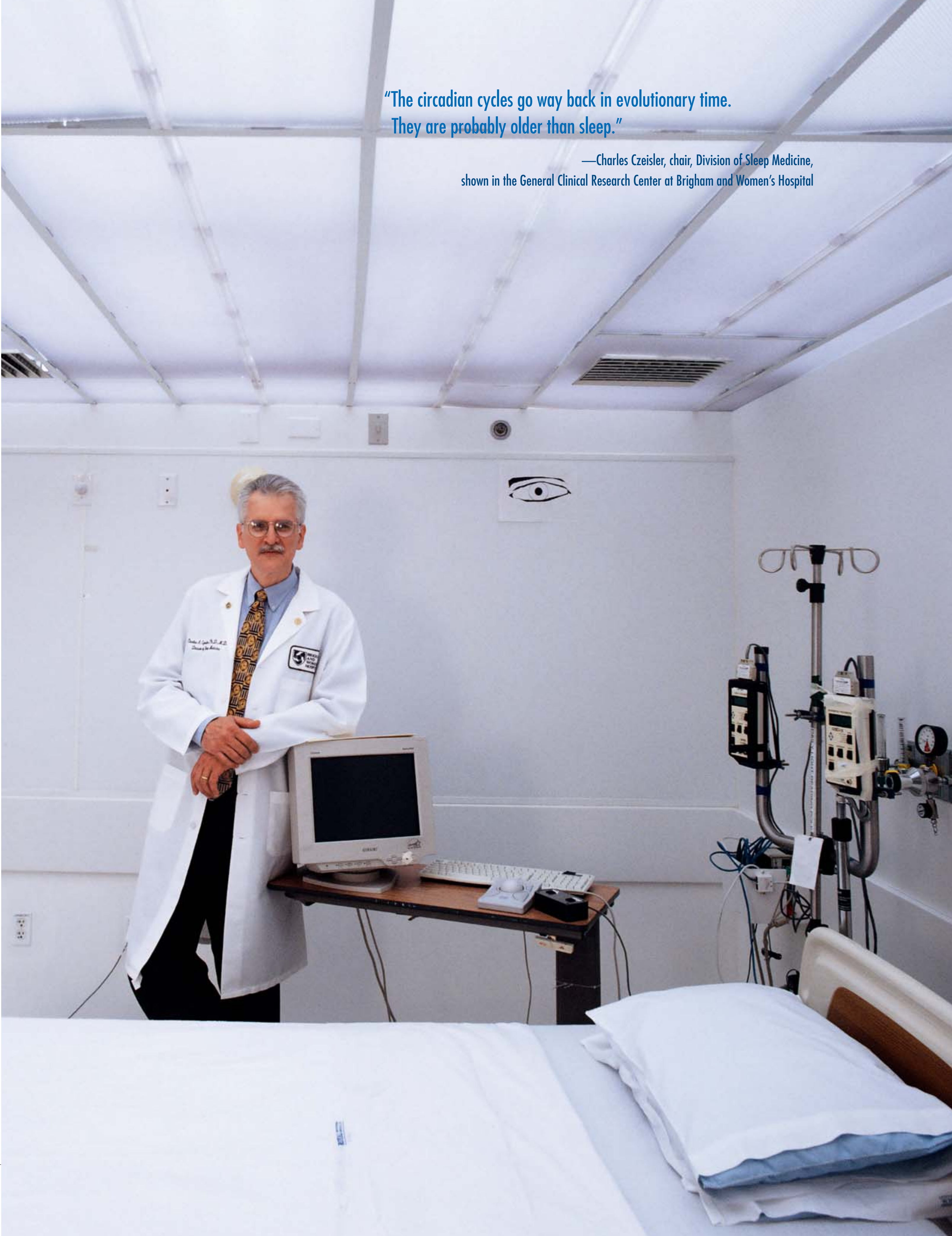
Sleeping well helps keep you alive longer. Among humans, death from all causes is lowest among adults who get seven to eight hours of sleep nightly, and significantly higher among those who sleep less than seven or more than nine hours. ("Those who sleep more than nine hours have something wrong with them that may be causing the heavy sleep, and leads to their demise," White notes. "It is not the sleep itself that is harmful.")

Sleep is essential to normal biological function. "The immune system doesn't work well if we don't sleep," says White. "Most think sleep serves some neurological process to maintain homeostasis in the brain." Rats totally deprived of sleep die in 17 to 20 days: their hair starts falling out, and they become hypermetabolic, burning lots of calories while just standing still.

There once was a fair amount of research on total sleep deprivation, like that which killed the rats. Doctors would keep humans awake for 48, 72, or even 96 hours, and watch their performance deteriorate while their mental states devolved into psychosis. For several reasons, such studies rarely happen any more ("Why study something that doesn't exist?" asks White) and researchers now concentrate on sleep *restriction* studies.

In this context, it is important to distinguish between acute and chronic sleep deprivation. Someone who misses an entire night of sleep but then gets adequate sleep on the following three days "will recover most of his or her normal ability to function, " Czeisler says. "But someone restricted to only five hours of nightly sleep for weeks builds up a cumulative sleep deficit. In the first place, their performance will be as impaired as if they had been up all night. Secondly, it will take two to three weeks of extra nightly sleep before they return to baseline performance. Chronic

Portraits by John Soares



"The circadian cycles go way back in evolutionary time. They are probably older than sleep."

—Charles Czeisler, chair, Division of Sleep Medicine, shown in the General Clinical Research Center at Brigham and Women's Hospital

"When you live on four hours a night, you forget what it's like to really be awake."

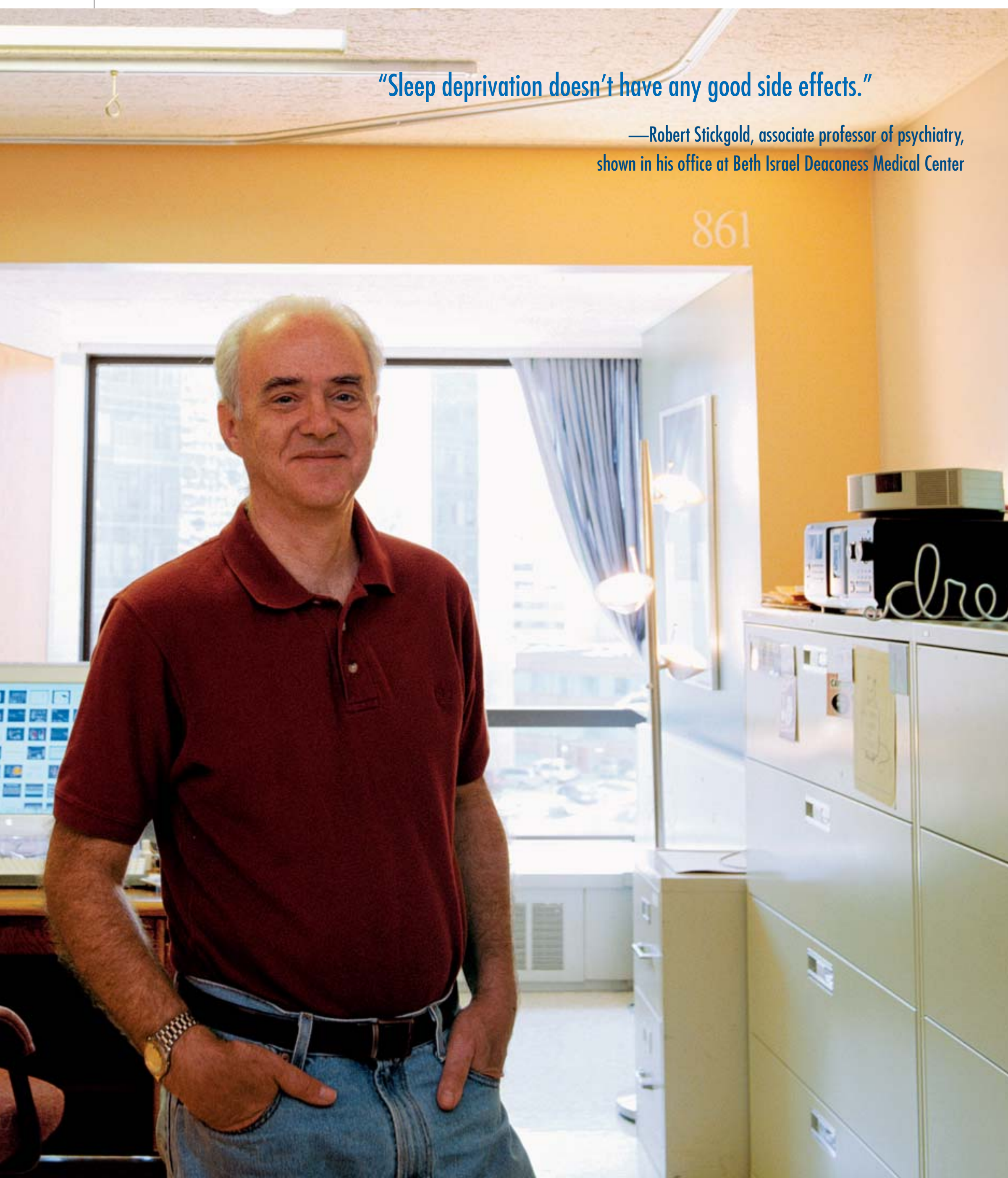
sleep deprivation's impact takes much longer to build up, and it also takes much longer to recover." The body is eager to restore the balance; Harvard undergraduates, a high-achieving, sleep-deprived population, frequently go home for Christmas vacation and pretty much sleep for the first week. Stickgold notes that "When you live on four hours a night, you forget what it's like to really be awake."

Sleep researcher Eve van Cauter at the University of Chicago exposed sleep-deprived students (allowed only four hours per night for six nights) to flu vaccine; their immune systems produced only half the normal number of antibodies in response to the viral challenge. Levels of cortisol (a hormone associated with stress) rose, and the sympathetic nervous system became active, raising heart rates and blood pressure. The subjects also showed insulin resistance, a pre-diabetic condition that affects glucose tolerance and produces weight gain. "[When] restricted to four hours [of sleep] a night, within a couple of weeks, you could make an 18-year-old look like a 60-year-old in terms of their ability to metabolize glucose," Czeisler notes. "The sleep-deprived metabolic syndrome might increase carbohydrate cravings and the craving for junk food."

Van Cauter also showed that sleep-deprived subjects had reduced levels of leptin, a molecule secreted by fat cells that acts in the brain to inhibit appetite. "During nights of sleep deprivation, you feel that your eating goes wacky," says Stickgold. "Up at 2 A.M., working on a paper, a steak or pasta is not very attractive. You'll grab the candy bar instead. It probably has to do with the glucose regulation going off. It could be that a good chunk of our epidemic of obesity is actually an epidemic of sleep deprivation."

Furthermore, "Many children in our society don't get adequate amounts of sleep," Czeisler says. "Contrary to what one might expect, it's common to see irritability and hyperactivity in sleep-deprived children. Is it really surprising that we treat them with wake-promoting drugs like Ritalin?" Schools and athletic programs press children to stay awake longer, and some children may be chronically sleep-deprived. Czeisler once took his daughter to a swim-team practice that ran from eight to nine o'clock at night, and told the coaches that this was too late an hour for children. "They looked at me like I was from another planet," he recalls. "They said, 'This is when we can get the pool.'"

Stickgold compares sleep deprivation to eating disorders. "Twenty years ago, bulimics probably thought they had the best of all worlds," he says. "They could eat all they wanted and never gain weight. Now we know that they were and are doing major damage to their bodies and suffering major psychological damage. We live in a world of sleep bulimia, where we binge on weekends and purge during the week."



"Sleep deprivation doesn't have any good side effects."

—Robert Stickgold, associate professor of psychiatry, shown in his office at Beth Israel Deaconess Medical Center

The Fatigue Tax

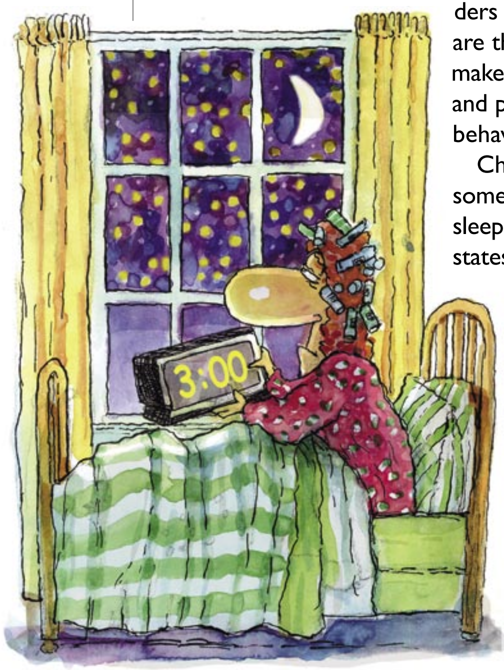
Lack of sleep impairs performance on a wide variety of tasks. A single all-nighter can triple reaction time and vastly increase lapses of attention. Sleep researcher David Dinges at the University of Pennsylvania studied such lapses using a "psychomotor vigilance task" on pools of subjects who had slept four, six, or eight hours nightly for two weeks. The researchers measured subjects' speed of reaction to a computer screen where, at random intervals within a defined 10-minute period, the display would begin counting up in milliseconds from 000 to one second. The task was first, to notice that the count had started, and second, to stop it as quickly as possible by hitting a key. It wasn't so much that the sleep-deprived subjects were *slower*, but that they had far more total *lapses*, letting the entire second go by without responding. Those on four hours a night had more lapses than those sleeping six, who in turn had more lapses than subjects sleeping eight hours per night. "The number of lapses went up and up for the whole two weeks," says David White, "and they hadn't plateaued at the end of the two-week study!"

There's fairly large individual variation in susceptibility to the cognitive effects of sleep deprivation: in one of Charles Czeisler's studies, somewhere between a quarter and a third of the subjects who stayed awake all night contributed two-thirds of the lapses of attention. "Some are more resistant to the impact of a single night of sleep loss," he says. "But they all fall apart after two nights without sleep." In a sleep-deprived state, says White, "Most of us can perform at a fairly low level. And a lot can run around sleep-deprived without it being obvious. But truck drivers, neurosurgeons, nuclear-plant workers—after six or eight hours, they have to put a second crew on and give them a break." Very few people are really immune to sleep deprivation: in Dinges's study, only one of 48 subjects had the same performance after two weeks of four hours' nightly sleep as on day one.

Students often wonder whether to pull an all-nighter before an

Unsound Sleep

The National Sleep Foundation's 2005 survey found that 75 percent of American adults experience symptoms of a sleep problem at least a few nights per week. Sleep clinics like Sleep Health Centers, a for-profit enterprise whose medical director, David P. White, supervises six sites with 32 beds in the Boston area, investigate many of the 84 types of sleep disorder that clinicians have identified. White, McGinness professor of sleep medicine, who directs the sleep disorders program at Brigham and Women's Hospital, explains that there are three main categories of sleep disorder: insomnias; disorders that make patients sleepy during the day, like narcolepsy or sleep apnea; and parasomnias, which include sleepwalking, sleep-talking, and REM behavior disorder.



Chronic insomnia may affect 10 percent of the population, but some Gallup polls indicate that as many as 40 percent have trouble sleeping on two or three nights per week. "Depression and anxiety states are the biggest cause of insomnia," White says. Besides treating the underlying problems and practicing good "sleep hygiene" (e.g., going to bed at a regular time, having no clock in the bedroom), one intervention is, paradoxically, sleep restriction. "A lot of insomniacs spend more and more time in bed—up to 14 hours a day. That's counterproductive," White says. "So you restrict them to the amount of time they can sleep: perhaps from 11 P.M. until 3 A.M. Get them to sleep well during that time and then build up from there."

In narcolepsy, which affects one in 2,000 people, components of REM sleep—being asleep, having muscular paralysis or weakness, and dreaming—affect people during waking hours. Research on narcoleptic Doberman dogs and genetically altered mice showed that animals unable to produce a protein called hypocretin were narcoleptic. The spinal fluid of humans who suffer from narcolepsy contains little or no hypocretin; hence treatment of narcolepsy may involve ways to enhance its production or replace it.

The most common problem that sleep clinics see is obstructive sleep apnea. "We're seeing an epidemic of sleep apnea," says Charles Czeisler, Baldino professor of sleep medicine. "It's related to overweight, and is especially prevalent in certain regions." Older, obese men are at higher risk. Sleep apnea affects individuals who may have a narrower passage of the upper throat; during sleep, muscles around this passage relax and close the passage partially or completely, stopping the flow of air into the lungs. This results in loud snoring, labored breathing, and even the cessation of breathing (apnea) for periods of more than 10 seconds. "It's important to breathe in the right amounts of oxygen and breathe out carbon dioxide, to keep the levels right," explains White, who trained in pulmonary medicine. "The mechanisms that control this don't work as well during sleep." Losing weight can help; in severe cases, sufferers may sleep wearing a special "continuous positive airway pressure" mask that keeps the passage open.

Parasomnias are a less common form of sleep disorder. In sleepwalking, something rouses the sleeper from deep (stage 3 or 4) sleep, and in a state somewhere between deep sleep and wakefulness, he or she can walk about or even drive a car for a period of 10 to 15 minutes. REM behavior disorder, which can be associated with degenerative brain disease, may last only seconds, but can be dangerous. "In REM sleep, all skeletal muscles are paralyzed, so that you can't act out your dreams," White explains. "But with REM behavior disorder, people can move."

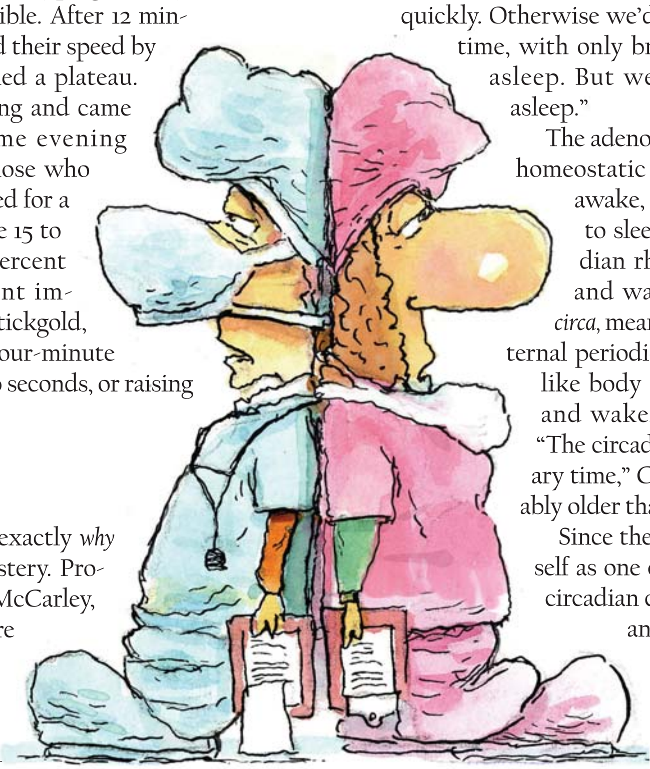
“Your ability to do critical thinking takes a massive hit—you’re knocking out the frontal-cortex functions.”

exam. Will the extra studying time outweigh the exhaustion? Robert Stickgold, who has studied sleep’s role in cognition for the past 10 years, reports that it depends on the exam. “If you are just trying to remember simple facts—listing all the kings of England, say—cramming all night works, ” he explains. “That’s because it’s a different memory system, the declarative memory system. But if you expect to be hit with a question like ‘Relate the French Revolution to the Industrial Revolution,’ where you have to synthesize connections between facts, then missing that night of sleep can be disastrous. Your ability to do critical thinking takes a massive hit—just as with alcohol, you’re knocking out the frontal-cortex functions.

“It’s a version of ‘sleeping on a problem,’” Stickgold continues. “If you can’t recall a phone number, you don’t say, ‘Let me sleep on it.’ But if you can’t decide whether to take a better-paying job located halfway across the country—where you have all the information and just have to weigh it—you say, ‘Let me sleep on it.’ You don’t say, ‘Give me 24 hours.’ We realize that it’s not just time; we understand at a gut level that the brain is doing this integration of information as we sleep, all by itself.”

Not only mental and emotional clarification, but the improvement of motor skills can occur while asleep. “Suppose you are trying to learn a passage in a Chopin piano étude, and you just can’t get it,” says Stickgold. “You walk away and the next day, the first try, you’ve got it perfectly. We see this with musicians, and with gymnasts. There’s something about learning motor-activity patterns, complex movements: they seem to get better by themselves, overnight.”

Stickgold’s colleague Matthew Walker, an instructor in psychiatry, studied a simple motor task: typing the sequence “41324” as rapidly and accurately as possible. After 12 minutes of training, subjects improved their speed by 50 to 60 percent, but then reached a plateau. Those who trained in the morning and came back for another trial the same evening showed no improvement. But those who trained in the evening and returned for a retest the following morning were 15 to 20 percent faster and 30 to 50 percent more accurate. “Twenty percent improvement—what’s that?” asks Stickgold, rhetorically. “Well, it’s taking a four-minute mile down to three minutes and 10 seconds, or raising a five-foot high jump to six feet.”



Bodily Rituals

So sleep is essential, but exactly *why* we go to sleep remains a mystery. Professor of psychiatry Robert McCarley, based at the VA Boston Healthcare System, has linked sleep to the brain neurochemical adenosine. Adenosine binds with phosphorus to create adenosine triphosphate (ATP), a substance that cells break down to generate energy. McCarley and colleagues inserted microcatheters into cat brains while keeping the cats awake for up to six hours—a long time for a cat. They found that rising adenosine levels in the basal forebrain put the cat to sleep; then, in the sleeping cat, adenosine levels fall again. In both cats and humans, the basal forebrain includes cells important for wakefulness, and adenosine turns these cells off, triggering sleep.

Like cats, when we are awake and active, we burn ATP, which breaks down to adenosine. Over time, adenosine levels build up, causing pressure for sleep. During sleep, many of the body’s cells are less active and hence burn less ATP, so adenosine levels fall again, setting the stage for wakefulness.

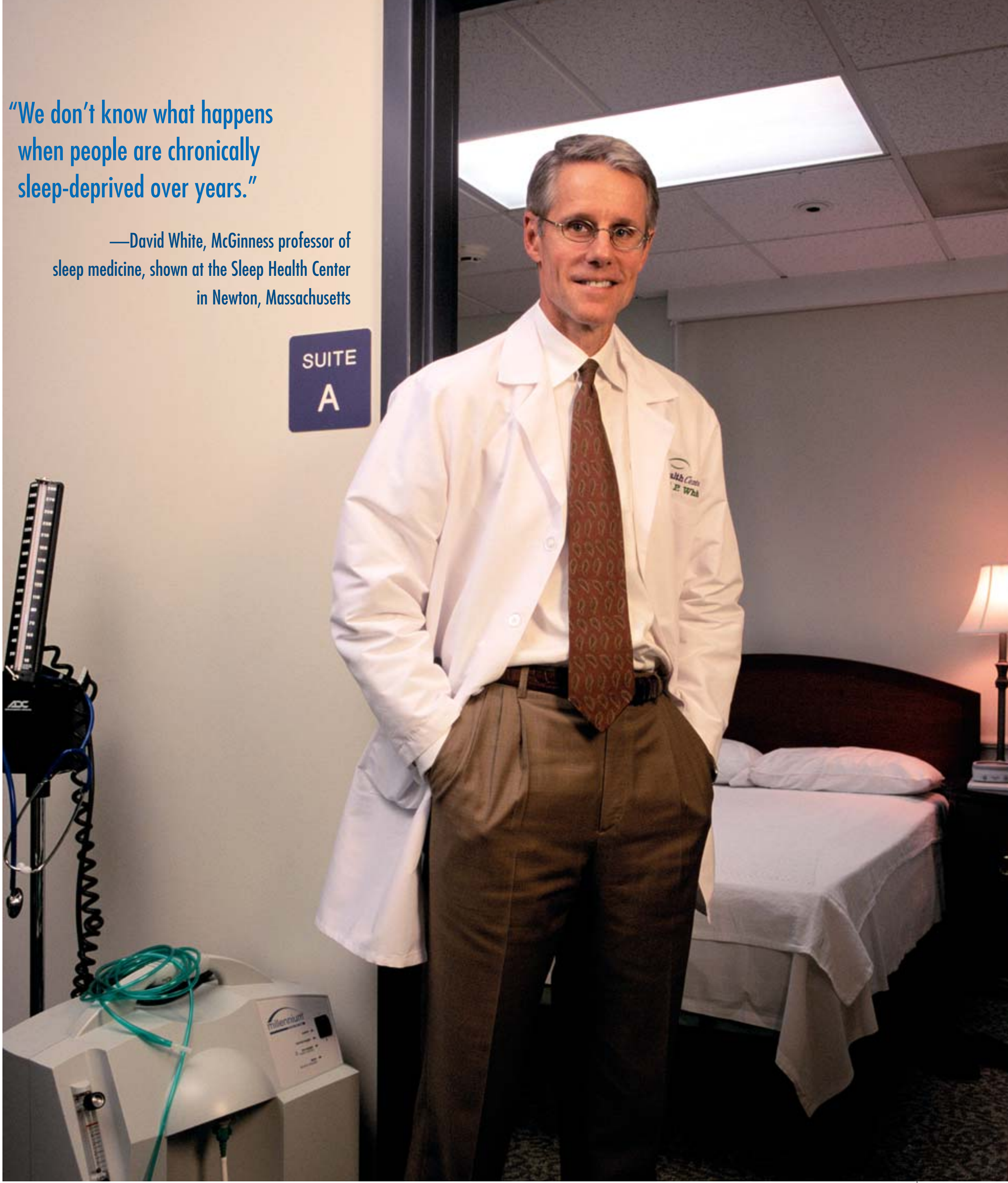
A drug like caffeine, however, partially blocks adenosine receptors, so the brain doesn’t perceive the actual adenosine level, and we don’t get tired. In a world that values wakefulness and productivity over rest and recovery, caffeine has become, in dollar amounts, the second-largest commodity (after oil) traded in the world. Some consumers require ever-greater jolts—one 24-ounce Starbucks beverage packs a walloping 1,000-plus milligrams of caffeine. (A commonly used figure for one cup of coffee is 100 milligrams.)

The lab run by Putnam professor of neurology Clifford Saper has done related research, refining the location and functions of the “sleep switch,” a group of nerve cells in the hypothalamus that turns off the brain’s waking systems; conversely, the waking systems can turn off the sleep switch. “When you have a switch where either side can turn off the other, it’s what electrical engineers call a ‘flip-flop,’” Saper explains. “It likes to be in one state or the other. So we fall asleep, or wake up, quite quickly. Otherwise we’d be half asleep or half awake all the time, with only brief periods of being fully awake or asleep. But we’re not—we are either awake or asleep.”

The adenosine cycle at least partly explains the homeostatic drive for sleep—the longer we are awake, the greater our fatigue, and pressure to sleep builds up progressively. But circadian rhythms also profoundly affect sleep and wakefulness. Circadian cycles (from *circa*, meaning “about,” and *dies*, a “day”) are internal periodic rhythms that control many things like body temperature, hormone levels, sleep and wakefulness, digestion, and excretion. “The circadian cycles go way back in evolutionary time,” Charles Czeisler says. “They are probably older than sleep.”

Since the 1970s, Czeisler has established himself as one of the world’s leading authorities on circadian cycles and the chronobiology of sleep and wakefulness. He has done groundbreaking work in the sleep laboratory at Brigham and Women’s Hospital, where a special wing on one floor is shielded not only from sunlight, but from all external time cues. There, researchers can do exotic things like simulate the 708-hour lunar day or conditions on the International Space Station, where the sun rises and sets every 90 minutes. (Czeisler leads a sleep and chronobiology team that, under the auspices of NASA, researches human factors involved in space travel.)

Exotic light environments like space challenge human biology, partly because people differ from other mammals, which take short catnaps and rat naps throughout the day and night. In contrast, we have one bout of consolidated (unbroken) sleep, and one of consolidated waking, per day (or, in siesta cultures, two of each). In addition, "There is a very narrow window [in the daily cycle] in which we are able to maintain consolidated sleep," Czeisler says, "and the window gets narrower and narrower as we get older."



"We don't know what happens when people are chronically sleep-deprived over years."

—David White, McGinness professor of sleep medicine, shown at the Sleep Health Center in Newton, Massachusetts

The origins of humans' consolidated sleep take us to the beginnings of terrestrial life, since even prokaryotes—one-celled organisms like bacteria, lacking a nucleus—have built-in 24-hour rhythms. It is not surprising that these biological clocks are so universal, as they reflect the entrainment of all living things to the primeval 24-hour cycles of light and darkness created by the rotation of Earth.

"The light and dark cycle is the most powerful synchronizer of the internal circadian clock that keeps us in sync with the 24-hour day," Czeisler says. As late as 1978, when he published a paper demonstrating this effect, many still believed that "social interaction was the most important factor in synchronizing physiological cycles—that we had evolved beyond light," he says. "But much of our subsequent research shows that our daily cycles are more like those of cockroaches than we want to believe. We are very sensitive to light."

Light strongly affects the suprachiasmatic nucleus (SCN), a biological clock in the anterior region of the hypothalamus that directs circadian cycles. All cells have internal clocks—even cells in a tissue culture run on 24-hour cycles. "They all oscillate like violins and cellos, but the SCN is the conductor that synchronizes them all together, " Czeisler explains.

While the homeostatic pressure to sleep starts growing the moment we awaken, the SCN calls a different tune. Late in the afternoon, its circadian signal for wakefulness kicks in. "The circadian system is set up in a beautiful way to override the homeostatic drive for sleep," Czeisler says. The circadian pacemaker's signal continues to increase into the night, offsetting the build-up of homeostatic pressure and allowing us to stay awake well into the evening and so achieve our human pattern of consolidated sleep and wakefulness. (There is often a dip in the late afternoon, when the homeostatic drive has been building for hours but the circadian signal hasn't yet kicked in; Czeisler calls this "a great time for a nap.") The evolutionary benefit of consolidated sleep and wakefulness is a subject of speculation; Czeisler says that long bouts of wakefulness may enable us to "take advantage of our greater intellectual capacity by focusing our energy and concentration. Frequent catnaps would interrupt that."

The circadian pacemaker's push for wakefulness peaks between about 8 and 10 P.M., which makes it very difficult for someone on a typical schedule to fall asleep then. "The period from two to three hours before one's regular bedtime, we call a 'wake maintenance zone,' " Czeisler says. But about an hour before bedtime, the pineal gland steps up its secretion of the hormone melatonin, which quiets the output from the SCN and hence paves the way for sleep.

Some years ago, melatonin supplements became popular as a natural sleeping pill, but as Czeisler's research has proven, light is a more powerful influence on the biological clock than melatonin. Mangelsdorf professor of natural sciences J. Woodland Hastings has shown that even a split-second of light exposure can shift the circadian cycle of a single-celled organism by a full hour. Light interferes with sleep, at least partly because it inhibits melatonin secretion and thus resets the biological clock. For this reason, those seeking a sound sleep should probably keep their bedroom as dark as possible and by all means avoid midnight trips to brightly lit bathrooms or kitchens; blue light, with its shorter wavelength—and its resemblance to the sunlit sky—has the most powerful resetting effect.

Light resets the pacemaker even in the case of some completely blind people, who generally lose circadian entrainment and suffer recurrent insomnia. "The eye has two functions, just as the ear does, with hearing and balance," says Czeisler. "The eye has vision, and also circadian photoreception." A subset of about 1,000 photosensitive retinal ganglion cells connects by a direct neural pathway to the SCN; these cells are sometimes active even in those who are blind to light. Exposure to bright light will decrease melatonin levels in some blind persons, and this subset, unlike other blind people, generally do not suffer from insomnia and are biologically entrained to the 24-hour day.

Disastrous Exhaustion

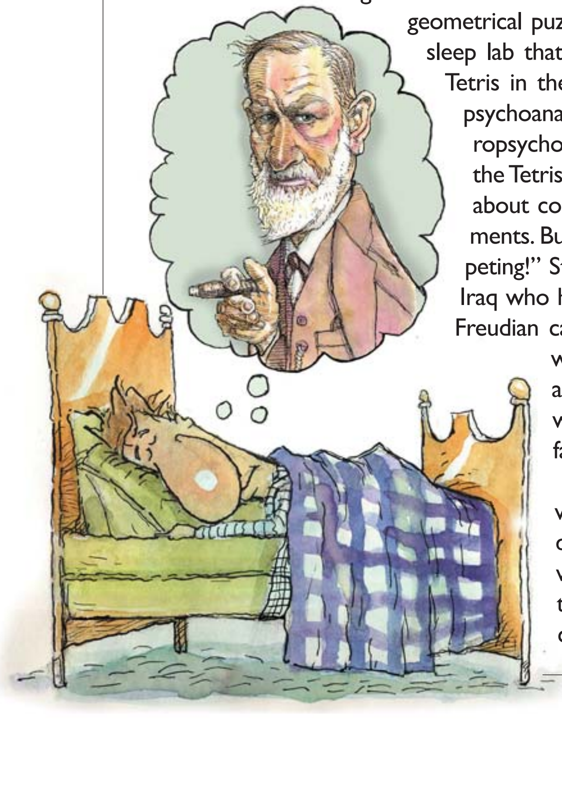
THE HUMAN SPECIES, or much of it, anyway, apparently is trying to become simultaneously nocturnal and diurnal. Society has been squeezing the window for restful sleep ever narrower. (Czeisler likes to quote

Freud's Guesswork on Dreams

One of Sigmund Freud's great complaints about his mistreatment in life was that although he won a literary award for his famous book *The Interpretation of Dreams* (1900), it never received a scientific award. A century later, his peers' judgment has been vindicated. Freud's unscientific theory of dreams—based on self-analysis and a cherry-picked group of clinical anecdotes—has been demolished by the discoveries of sleep medicine. "I came into the field so far post-Freudian that Freud felt like someone with a goofy theory two centuries back," says Robert Stickgold, associate professor of psychiatry, who has studied dreams in sleep studies for years, often in collaboration with professor of psychiatry J. Allan Hobson. "The Greeks tried to explain thunder and lightning by creating gods; Freud tried to explain dreams by creating demons like the id and repressed desires," says Stickgold. "In general, Freud's dream theories have been remarkably resistant to scientific confirmation. He made a lot of observations that are quite prescient, but his attempt to build a model to explain them is completely wrong and there is no piece of it that holds up."

For example, Freud thought we dream to keep ourselves from being awakened. "That's absolutely false," says Stickgold. "Freud thought that as we sleep, with constraints on the id reduced, all these nasty Victorian desires well up, and if they were allowed to come into the conscious mind, they would be so distressing that the sleeper would wake up. So dreaming is all about disguising and transforming these desires to make them more acceptable to the conscious mind. Freud probably was assuming that people dream one or two times a night, for a few minutes—most people think that, since that's what we remember on waking. But since the 1960s, it's been clear that we dream most of the night—six hours out of eight hours of sleep. During the Rapid Eye Movement (REM) phases of sleep, which make up 15 to 20 percent of sleep time, we do have our most intense dreaming activity, but we dream in other sleep phases, too. If dreaming is all about repressed childhood desires, does everybody have the same amount of them?"

Another core tenet of Freud's dream theory is that a dream is the fulfillment of a wish. Stickgold reflects on this by describing a study using the game Tetris, a kind of geometrical puzzle. Subjects were taught to play the game, and in a sleep lab that night, 60 to 75 percent of them saw images from Tetris in their dreams. "Someone asked Mark Solms, a brilliant psychoanalyst who is trying to create a new field called neuropsychoanalysis—an oxymoron if I ever heard one—about the Tetris dream imagery. He said, 'Those are probably dreams about competition and winning'—in other words, wish fulfillments. But nobody dreamed about winning the game or competing!" Stickgold also wonders about a mother with a son in Iraq who has nightmares about her child being killed. "Maybe a Freudian can interpret that as wish-fulfillment," he says. "But I would take that as perverse, and blind adherence to an outdated model. Any dream can be interpreted as wish fulfillment, but there's no evidence that it is. In fact, there's tons of evidence against it."



Entering into the interpretation of dreams "gets very messy," Stickgold says. "If I could give the same dream to 10 analysts and they all said, 'This is about a wish for immortality,' then I could say, 'OK, at least they all agree on the same interpretation.' But they can't even do that."

colleague Thomas Roth of the Henry Ford Sleep Disorders Center in Detroit, on the minimal-sleep end of the spectrum. "The percentage of the population who need less than five hours of sleep per night, rounded to a whole number," says Roth, "is zero.")

Czeisler has conducted several studies of medical interns, an institutionally sleep-deprived population who provide a hugely disproportionate fraction of the nation's healthcare services. Interns work famously long 80- and even 100-hour weeks; every other shift is typically 30 hours in duration. "On this kind of schedule, virtually everyone is impaired," he says. "Being awake more than 24 hours impairs performance as much as having a blood-alcohol level of 0.1 percent—which is legally drunk."

In addition to both acute and chronic sleep deprivation, interns sleep and wake in patterns that misalign with circadian cycles—being asked, for example, to perform with full alertness at 4 A.M. A fourth factor is that the human brain is "cold" and essentially impaired during the first half-hour after awakening—even more impaired, says Czeisler, than after 70 hours of sleeplessness. "It's a colossally bad idea to have an intern woken up by a nurse saying, 'The patient is doing badly—what shall we do?' " he says. "They might order 10 times the appropriate dose of the wrong med."

The intensity and growing technological advance of medical care only enhance the probability of errors under such conditions. Christopher Landrigan, assistant professor of pediatrics, led a study that compared interns working traditional schedules with those on an alternate schedule of fewer weekly hours and no extended (e.g., 30-hour) shifts in intensive-care units. The doctors on the tiring traditional schedule made 36 percent more serious medical errors, including 57 percent more nonintercepted serious errors, and made 5.6 times as many serious diagnostic errors.

Some Harvard-affiliated teaching hospitals, like Brigham and Women's, where Czeisler works, are taking the lead in substantially reducing work hours for physicians and surgeons in training. Yet no rules limit the work hours of medical students (including those at Harvard Medical School), and at the national level, little has changed for interns and residents. Not long ago, the Accreditation Council of Graduate Medical Education, faced with the threat of federal regulation, enacted new rules limiting extended shifts to 30 hours (before the new rules, they averaged 32 hours), and capped work weeks at 80 hours (beforehand, the average was 72 hours)—with exceptions allowable up to 90 hours. "The new, self-imposed rules largely serve to reinforce the status quo," Czeisler says. "They haven't brought about fundamental change, and haven't changed the length of a typical extended shift, which is still four times as long as a normal workday. And those marathon shifts occur every other shift, all year, several years in a row during residency training."

The risks don't end when the doctors leave work. Research fellow in medicine Laura Barger led another group in a nationwide survey of interns that showed them having more than double the risk of a motor-vehicle crash when driving home after an extended shift. (They aren't alone: 60 percent of American adults drove while drowsy in the past year.)

The moral of much sleep research is startlingly simple. Your mother was right: You'll get sick, become fat, and won't work as well if you don't get a good night's sleep. So make time for rest and recovery. Stickgold likes to compare two hypothetical people, one sleeping eight hours, the other four. The latter person is awake 20 hours a day, compared to 16 hours for the first. "But if the person on four hours is just 20 percent less efficient while awake, then in 20 hours of waking he or she will get only 16 hours of work done, so it's a wash," he says. "Except that they are living on four hours of sleep a night. They're not gaining anything, but are losing a huge amount: you'll see it in their health, their social interactions, their ability to learn and think clearly. And I cannot believe they are not losing at least 20 percent in their efficiency."

Yet instead of encouraging restorative rest, many of our institutions are heading in the opposite direction. This fall, for example, Harvard will begin keeping Lamont Library open 24 hours a day, in response to student demand, and Harvard Dining Services has for several years offered midnight snacks. "These are the wrong solutions," says Stickgold. "This is like the Boston Police Department getting tired of drunk drivers killing people and setting up coffee urns outside of bars. At Harvard there is no limit on the amount of work students are assigned; you can take four courses and have three professors say, 'This is your most important course and it should take the bulk of your time.' Students are dropping to four hours of sleep a night, and the University sees it has to do something about it. But the way you deal with students overloaded with work is not by having dorms serve snacks at midnight and keeping the library open all night. Instead, you can cut back by one-third the amount of work you assign, and do that in every course without serious detriment."

Such are the prescriptions of sleep researchers, which differ radically from those of the society and the economy. The findings of the sleep labs filter only slowly into the mainstream, especially in areas like medical internships, where enormous financial pressures favor the status quo. Even at Harvard Medical School, in a four-year curriculum, only one semester hour is devoted to sleep medicine. For a sleep disorder like narcolepsy, the average time between symptom onset and diagnosis is seven years; for sleep apnea, four years. "Physicians aren't being trained to recognize sleep disorders," Czeisler says.

When all else fails, there is always the option of common sense. Sleep is quite possibly the most important factor in health, and neither caffeine nor sleeping pills nor adrenaline can substitute for it. "As it looks more and more like some of these processes occur exclusively during sleep and can't be reproduced while we are awake, the consequences of losing them look more and more terrifying," says Stickgold. "And that's the experiment we are all in the middle of, right now."

"Being awake more than 24 hours impairs performance as much as having a blood-alcohol level of 0.1 percent—which is legally drunk."

Craig A. Lambert '69, Ph.D. '78, is deputy editor of this magazine.

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