AROUND *the* PATIENT BED

HUMAN FACTORS AND SAFETY IN HEALTH CARE

EDITED BY
YOEL DONCHIN
DANIEL GOPHER

CRC Press
Taylor & Francis Group

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Book was previously published in Hebrew by Carta Jerusalem.

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20130812

International Standard Book Number-13: 978-1-4665-7363-5 (eBook - PDF)

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http://www.taylorandfrancis.com

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Contents

Preface

There has been a growing awareness among the general public and the medical professional community of the occurrence of failures and mistakes in health care, from primary care procedures to the complexities of the operating room. Medical personnel and policy makers are desirous for both an assessment and investigation of the problem in order to unveil the root cause to pinpoint the factors and guilty parties, and to create proposals for corrective measures and improvement of the situation.

This book examines the problem and investigates the tools to improve health care quality and safety from a human engineering viewpoint—the applied scientific field engaged in the interaction between the human operator (functionary, worker), the task requirements, the governing technical systems, and the characteristics of the work environment.

The editors' major claim is that the main cause for the multiplicity of medical errors is not lack of motivation or carelessness of care providers, rather it is the hostile and unfriendly work environment confronted by doctors, nurses, and other members of the medical team. The vast majority of health care working environments are not properly planned, nor are they appropriate to the tasks facing team members. They are considerably disadvantaged by the lack of a systemic thought approach enabling the system to carry out tasks in an efficient and safe manner.

The book's chapters are based on a theoretical and practical approach developed by the editors; Yoel Donchin, representing the medical profession, and Daniel Gopher, from the human factors engineering field; the two have cooperated over a period of approximately two decades. Students from the Center for Work Safety and Human Engineering at the Technion in Haifa participated in the research and application activities, together with nurses and doctors at medical centers throughout Israel.

The first two chapters of the book comprise an introduction and discussion of the general approach to the subject matter. The following 19 chapters describe case studies of human factors and safety in medical systems, and research work carried out in hospital wards, operating rooms, emergency units, and pharmacies. These studies, compiled and presented here for the first time, reveal a wide range of problems and weaknesses in contemporary health care, which impair its safety and quality, and increase the workload. Also presented are developed and implemented solutions based upon human engineering components and cognitive psychology, as well as their driving principles and methodologies. It is argued that this approach is a productive and efficient way to significantly reduce the number of errors, leading to the creation of a safe environment and improvement of the quality of health care.

The final two chapters of the book present discussions, concluding remarks, and directions for future activities.

The Editors

Yoel Donchin is a Clinical Professor of Anesthesia and Intensive Care at the Faculty of Medicine, Hadassah Hebrew University Medical Center in Jerusalem, Israel. Since completing his medical training, specializing in anesthesia and critical care, Donchin has held clinical and academic positions in Israel and the United States, where he was a fellow in Obstetric Anesthesia at the University of Florida in Gainesville. Donchin developed the prehospital emergency system in the Israeli defense forces as well as in the civil emergency services and served as the medical director of the national EMS (Mgen David Adom) services. He is the author of three textbooks on first aid and was among the first to propose and publish papers on the use of epidural narcotics for pain relief. As a senior physician in the Intensive Care Unit (ICU) of Hadassah, he noticed the high rate of medical mishaps. This led to cooperation with Daniel Gopher; they have since established a partnership between Hadassah hospital and the Technion Research Center for Work Safety and Human Factors Engineering. Donchin spent 2 years at Technion studying and initiating health care–related human factors research and application work. He then established and became the head of the Patient Safety Unit at the Hadassah Hebrew University Hospital. Donchin's research interests focus on human factors and safety in health care. He also serves as the chair of the Israel Society for the History of Medicine.

Daniel Gopher is a professor emeritus of cognitive psychology and human factors engineering at Technion—the Israel Institute of Technology. He is a fellow of the U.S. Human Factors and Ergonomics Society and the International Ergonomics Association. In 2013, Gopher was awarded the Hal Hendrick Distinguished International Scientist Award by the U.S. Human Factors and Ergonomic Society, for recognition of his outstanding contributions to the field of human factors and ergonomics. Since 1980, he has been the director of the Research Center for Work Safety and Human Engineering, an interdisciplinary research center. In 1996, he also established, together with Asher Koriat from Haifa University, the joint Technion–Haifa University Max Wertheimer Minerva Research Center for Cognitive Processes and Human Performance. Gopher joined the Technion Faculty of Industrial Engineering and Management in 1979, after serving 12 years in the Israel Defense Forces, during which he was a senior scientist and acting head of the Research Unit in the Personnel Division (1966–1970), and senior scientist and head of Human Factors for the Air Force (1970–1979). Gopher's research focuses on the study of human attention limitations, measurement of mental workload, training of complex skills and their applications to the design of aviation systems, medical systems (assessing the nature and causes of human error in medical work, and redesign of medical work environments to improve safety and efficiency), safety at work (developing methods and models for the analysis of human factors, ergonomics, safety, and health problems at the individual, team, and plant levels), and training of complex skills (development of computer-based cognitive trainers and virtual reality multimodal training platforms).

Contributors

In addition to the book editors, most of the chapters in the book were written by faculty members and students from the Center for Work Safety and Human Factors Engineering at the Technion and the Hadassah University Hospital, Jerusalem. Some chapters are based on joint projects with nurses, physicians, and members of the Ministry of Health who participated in the studies. Our thanks to all of our contributors and collaborators.

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1 Human Factors and Safety in Health Care

Daniel Gopher

CONTENTS

HEALTH CARE IN THE AGE OF COMPUTERS, THE INFORMATION REVOLUTION, AND ARTIFICIAL INTELLIGENCE

Modern medicine, in the second decade of the 21st century, is a powerful discipline and advancing rapidly, with the ability to diagnose, treat, and cure diseases that not long ago were considered incurable. An amazing revolution has taken place, thanks to modern diagnostic methods, long-term monitoring options, and development of analytical capabilities and intervention. But these capabilities have led to an extremely complex and costly system. Each year, modern industrialized nations invest a very high percentage of their gross national product (GNP) on health expenditure.

The 2010 Statistical Abstract of Israel provides health expenditure data as a percentage of gross domestic product (GDP) for various countries: the United States leads in the percentage of GDP spent on health (16%), followed by Switzerland (10.7%), and Austria and Germany (10.5% each). Moreover, this expenditure is steadily increasing. For example, between 2000 and 2004, health care costs in the United States rose from 13.3% to 15.2% and in Switzerland from 10.4% to 11.6%. At the same time, the number of medical mishaps increased and medical treatment safety began to decline. Lucien Leape and colleagues from the Harvard University School of Public Health wrote a seminal article published by the medical flagship journal *New England Journal of Medicine* (*NEJM*) in 1991, estimating the number of deaths per annum due to medical errors at between 98,000 and 120,000. This is a massive and sobering number, larger than the number of traffic fatalities and the number of deaths from heart disease and cancer. There are those who claim a lower number and those that claim a higher number, but no one disputes that the number of mishaps and fatalities due to mistakes is too high. Thus, the medical paradox was born, so-called in American medical jargon: a system where doctors and nurses have extensive knowledge and expertise, use the most modern and advanced technology available, and have an annual medical expenditure exceeding 15% of GDP and flourishing research—but a high number of mistakes and medical mishaps occur, most of which could be prevented! The question of questions is: What causes this paradox? And, perhaps more importantly—how can the rising rate of errors be prevented?

Another fact that should be taken into consideration: the high cost of advanced medicine prevents it from being available to all, making this a significant ethical dilemma for a modern and democratic society espousing equal opportunity and provision of welfare to the needy. The efforts to find a solution to this problem have been accompanied by an increasing workload on the system to treat a great number of patients in the public health sector and "cutting corners" to reduce costs. The burgeoning workload and limited resources create a conflict that increases the probability of the occurrence of adverse events and mishaps. This is a serious problem endangering the safety of patients and caregivers.

Another major development in the medical care system is the dramatic increase in the technological complexity of the system and the medical work environment.

Moreover, at all times and for all medical treatments, a rapidly expanding information base is created, in part because of the diversity of the medical team as well as the experts from different fields, which characterizes most medical treatment processes.

These facts turn every treatment process into a relay race, in which each baton transfer (patient transfer) must be accompanied by a transfer of responsibility and a transfer of appropriate information. A solitary failure would result in the failure of the whole process.

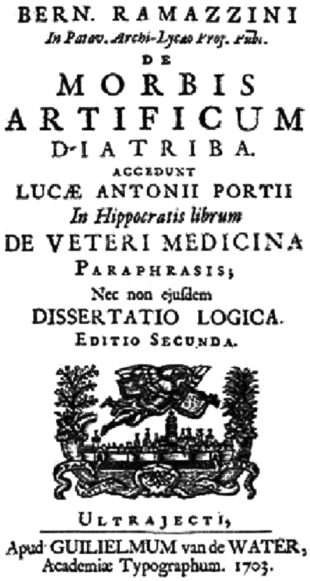
Referring again to the vast investments in medical systems, we find that the great majority of resources are directed toward investigation and ways of combating illness, toward development of new drugs, and toward development of technologies to improve the quality of life for chronic sufferers, while almost nothing is invested in creating user-friendly systems designed to assist the team in the use of developing technical capabilities, a system designed coherently and based upon human engineering factor principles and suited to the human operator's capabilities and limitations. Therefore, as mentioned above, from a human engineering viewpoint, those providing medical services are required to function in an unfriendly, poorly planned environment, which places a load on the shoulders of personnel, limits efficiency, and most importantly, is extremely susceptible to failures. In our view, these are the main causes for failures, not "medical carelessness" and not lack of motivation. Here is an opportunity for the intervention of human engineering personnel. The good news is the recent growing awareness of human engineering factors both as far as the general public is concerned and in terms of allocation of resources into the areas covered by this book.

HUMAN FACTOR ENGINEERING COMPONENTS IN WORKING ENVIRONMENTS AND MEDICAL SYSTEMS

The relationship between the worker and his tools or working environment—the essence of human engineering—did not happen in the latter part of World War I as claimed in many textbooks. Its beginnings can be found beneath the earth's surface in descriptions of the effect on miners of working in mines. In an extensive monograph from 1552, the mineralogist Georgius Agricola describes the many sufferings of mine workers in Italy. Eleven years later, the Swiss physician Paracelsus wrote a book about mine workers and described the toxic effects of inhalation of mercury vapor. In other words, there is a link between the workplace and the worker's health, well-being, and capability.

In 1700, the Italian doctor Bernardino Ramazzini (Photo 1.1) published the comprehensive "Lecture on Worker Diseases," describing almost all trades and professions existing at the time, beginning with diseases suffered by the workers, from lung diseases of silversmiths to a description of the more familiar insufferable wrist pains borne by writers using quills dipped in ink. In 1857, the Polish scientist Wojciech Jastrzębowski published a paper defining ergonomics, the science of work, detailing the advantages of applying science to improve the lot of the worker and his labors. The paper was published in Poland without any significant reaction at the time.

In the latter stages of World War I, it was found necessary to increase productivity. The workforce, who had been exploited to the limit, was unable to meet the tasks at hand. As a result, a committee was set up comprised of physiologists and psychologists, an initial task force named *The Committee for the Well-Being of Workers in the Arms Industry*—with the stated objectives to increase productivity without the loss of manpower. At the end of the war, the name was changed to *The Committee for Investigation of Worker Fatigue*, indicating that the root problem had already been identified (fatigue). The investigating team was complemented by experts from other fields, such as lighting experts and physicists, focusing on the working man and the interaction with the workplace. In fact, subsequent wars provided enormous momentum to the research and heightened the relationship to human engineering factors.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ARTIFICUM
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DISSERTATIO LOGICA.
EDITIO SECUNDA.
ULTRAJECTI,
Apud GUILIELMUM van de WATER,
Academiæ Typographum. 1703.

PHOTO 1.1 Bernardino Ramazzini's 1703 book on workers' diseases.

Human factors engineering is the scientific field engaged in the application of knowledge of human capabilities and limitations in the design of engineering systems, instrumentation, machinery, and working environments to meet the capabilities of the operator. The field also deals with the design and formulation of work processes, to enable efficient and safe operation of systems under controlled workloads. The key function of human engineering is the estimation of the measure of compatibility between the functional requirements and the ability of the worker charged with carrying out the function. This estimation is made by detailed analysis of the tasks, assessment, and definition of engineering design components, and the environment and work process for a given task, in terms of the requirements and effect upon the worker. The results of this analysis are compared with existing knowledge and assessment of the worker's capabilities and his level of knowledge and experience in handling the demands of the task.

Figure 1.1 illustrates this approach in a flow net that depicts the interaction between the various components: the task at hand, characteristics of the engineering system, and workplace features that together determine task requirements and the required level of implementation. The worker's capability, his skill, and his level of training will determine the measure of his ability and unsuitability to meet the demand of the task at hand. Unsuitability may be signified by a number of implications: deterioration in task implementation, delayed reactions, growing inaccuracy, and increasing workload due to failures, mistakes, and workplace accidents: the greater the mismatch, the more serious the problem.

Unsuitability can be treated in three main ways:

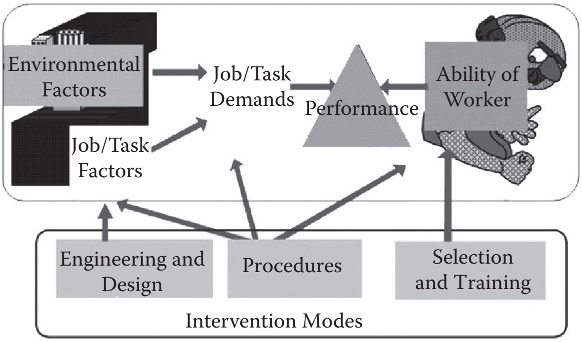

FIGURE 1.1 The interventions between system components and operator capabilities.

1. Engineering design changes or redesign in order to improve system suitability for the operator.
2. Changes to the work process and its formulation so that the worker can meet the work rate and deadlines and handle satisfactorily the task at hand.
3. Screening of workers and their training in order to match the task requirements.

Engineering design and work process and formulation planning are part and parcel of the work of human factor engineering. Screening and correct manpower selection, training, and practice come mainly under human resources development.

HUMAN FACTOR CHARACTERISTICS IN CONTEMPORARY MEDICAL SYSTEMS

From a human factor engineering viewpoint, modern medical systems are complex entities embracing engineering and human subsystems required to operate in unison with a very low level of allowable failure, where the price of a mistake, even a minor mistake, is liable to be very high. The general pattern in Figure 1.1 enables identification in the medical system, from a human factors engineering viewpoint, of a range of components that generate a complex array of worker requirements. The intervention paths shown in Figure 1.1 denote required operation directions: adoption of engineering steps and at the same time, creation of the framework and procedures applicable to functional implementation. The main components of each of the aforementioned viewpoints are detailed below.

Physical and Engineering Components of the Workstation and Its Surroundings

Design of Devices and Unit Systems

All medical staff members use a large number of health-support devices and systems to carry out their work: monitoring devices, surgical tools, various imaging devices, intravenous infusion systems, respirators, dialysis equipment, and so on. Design and planning of all these instruments impact work efficiency, operating speed, and response—level of awareness to mishaps. Correct design for easy usage and operation in the working environment at the patient's bedside reduces the workload. Poor design increases the load. For example, when the monitoring device literature or indicator is clearly visible even from a distance, discernment becomes easier and the burden on the employee is reduced.

Design and Layout of Individual Workstations

Medical systems feature many workstations where an individual member of staff provides treatment for an individual patient, while operating a large number of systems, such as the anesthesiologist's station in the operating room, the patient's bed in intensive care, as well as the dispensary and life support incubator for a premature baby. All these are personal workstations, typically encompassing a large number of custom designed instruments, not part of a complex system. In many cases, this leads to a lack of consistency and compatibility, and major workstation complications. The overall workstation system, including location of the various components, their arrangement and degree of compatibility, and the functioning of the employee in the given workstation is of vital importance. The best-known integrative and coherent workstation model is the flight cockpit, the result of considerable thought, both at a general level and from the planning perspective of human engineering factors. This begs the question, is it possible to design and install similar criteria in the planning of medical workstations?

Design and Planning of Large Workspaces

In many cases, personal workstations (Photo 1.2) are part and parcel of larger care units—for example, the operating room complex in large hospitals, recovery room, the emergency medicine department, and so forth. These units have a large variety of

PHOTO 1.2 A medical workstation.

diverse equipment and staff who have to perform multiple tasks and take responsibility in different fields. For example, a hospital's ward has many beds surrounded by a given assembly of ancillary equipment, similar or different, in a particular order. The medical staff moves between these subunits to carry out their work. Major importance is attached to the planning of large units and their proper arrangement. Proper planning together with optimized and consistent internal arrangement increase work efficiency, reduce the load, and increase safety.

Recording of Information, Access to Information, and the Transfer of Information

Updated information is the most important component of today's medical work environment and its proper planning is one of the most important tasks facing human factor engineering in medical systems.

The information element holds a special status in today's medical environment—information is an integral part of diagnostic work, assessment of patient status, and the physician's decision making and that of other medical staff. Today, medical information (health informatics) is a major issue in every medical center and medical insurance system. However, although this is an ever-growing field, doctors and nurses are still struggling with the many requirements associated with making medical records and reports regarding the current patient. Staff are drowning in the proliferation of forms to be filled in, files to be organized, and computerized information systems that are not consistent with work claims in a medical department and they waste (or try to devote) precious time to delving through the various forms to extract essential information. An engineering solution, based on human engineering principles, could lead to a significant savings in time and enable the creation of a clearer situation report, enabling improvement in the quality of care and helping to prevent mishaps.

Work Procedures and Work Patterns

The importance of work procedures and work patterns in health care environments stems from two key features of these processes:

Activities Are Multistage with Many Variables and Components, Operating in a Complex Technological Environment, with a Wealth of Information

Multistage and multifunctional activities that are not well organized lead to confusion, a prevalence of stages, and many mishaps. Close supervision and constant monitoring are required and precious time is wasted in transition from stage to stage, especially in a tight and demanding schedule. This description fits the lion's share of medical activity and is similar to the functional stages of flight management. In both cases, health care and flight, the key to efficient performance lies in the possibility to split the entire function into a large number of intermediate tasks with definable objectives, definable substages, and a fixed order of measures to be implemented for each substage. The strength of this procedure is that it clarifies, defines, and organizes each of the functions unequivocally. The implementation format can be taught, learned, and assimilated until it becomes automatic, like changing gears when driving a manual transmission car—an action performed without any mental effort. Correct planning and design of processes and work patterns increase efficiency, enabling acceleration of execution of tasks, limiting the misleading options, and reducing the load. The aviation sector adopted these methods many years ago; the health care community, even if its tasks are more complex than those of a pilot, has yet to recognize this and has not yet adopted a significant number of these principles.

Effective Teamwork

Health care operations are mainly characterized by teamwork. A *team* may be on a simultaneous or serial basis in a trauma unit or a surgery department where the work of doctors, nurses, and other caregivers is coordinated simultaneously for the same patient. In many cases, one can define a team and teamwork in situations where staff do not work simultaneously, such as doctor rounds unaccompanied by nurses or shift changes. Incompatibility can occur when a patient due for an operation is hospitalized in one department, is operated on in another department, and comes into contact with other staff in the recovery room; each of these caregivers perform part of the treatment. In many cases, the same patient may be treated by many medical staff members who are not present simultaneously but are part of a single treatment process. Development of an appropriate framework is the most important challenge facing medical system designers. Key factors for such development are:

- Each team member must know the general purpose and the function's specific target or the whole procedure.
- Division of roles and areas of responsibility among team members should be clearly defined.
- Each and every staff member is committed to understanding his role and responsibilities, but must also be well aware of the activities of other members of the team and the definition of areas of responsibility.
- Each and every member of the team should be updated on the situation report of the patient: a current and correct image allowing an inclusive and extensive picture. This will enhance coordination between members of the team.
- If there are stages and no simultaneous caregivers, it is necessary to transfer information based on obtaining clear responsibility at each transition stage.

The five components of human engineering work featured in the engineering system and the physical working environment, and the two components of work procedure and pattern design are witness to the breadth of human engineering work in planning the human environment in general, and in the medical work environment, in particular, as well as the broad spectrum of issues involved. Naturally, the level and quality of design will have a crucial influence on the effective functional performance of the staff member, his safety, and the load level of the given role.

Representation of the scale of the issue and its components provides a guiding framework for data collection of the operational system and the quality of its performance. Appropriate data collection, evaluation, and lessons learned is one of the most important and at the same time, most problematic paths to the functional improvement of medical systems and the reduction of error rate in medical treatment. The following is a brief discussion highlighting the principal difficulties and their various aspects, the central theme in Chapter 18 deals with the development of complementary systems for reporting difficulties, risks, and problems in medical practice; the subject is also an important methodological constituent in many other chapters of the book.

Data Collection for the Evaluation of Functional Problems and Performance of Medical Systems—Why Is It Insufficient to Report and Investigate Incidents, Malfunctions, and Accidents?

Recognition of the existence of safety problems in health care and the existence of medical mishaps, awareness of the fact, and growing public criticism led to a growing trend in the investigation of mishaps and accidents, as well as documentation, recording, and reporting of mishaps and events deviating from the norm. A growing number of countries and large-scale medical systems have adopted mandatory reporting and reporting systems have been established, requiring medical staff to report eventful incidents, accidents, or deviations occurring in the course of care activity. Investigative and test committees were established with growing frequency whose purpose was to inspect and investigate the cause of occurrence of incidents and accidental events.

Documentation of incidents and their investigation undoubtedly makes an important contribution to public awareness of the importance of the issue and places pressure on the decision makers and professional community to change the state of affairs. As a result, considerable resources are being invested in documentation of mishaps and report collection.

An important question we wish to pose at the outset: is the investigation of errors and accidents the only source of knowledge, or even the primary source, for data collection to satisfy the needs of human factors engineering? This question was the subject of a paper by the chapter author, published in 2004 in *Biomedical Instrumentation & Technology*.[3] The paper concluded that although major public importance is attached to gathering as much information as possible on errors and accidents, as a scientific database designed to steer and guide an orderly human factors engineering work program, there was little value to be gained. This conclusion stems from a number of key characteristics of this knowledge base:

Limited representation: A major problem in relying on the investigation of errors and events deviating from the norm is limited reporting—a very small percentage of errors and events are reported, estimated between 5% and 7%, notwithstanding the large and growing investment in this area. This estimate does not differ from the estimated percentage of reported errors in civil aviation, despite the many years and the traditional care taken regarding flight safety.

Even when there is a report, in many cases the report is incomplete or biased, this being an obvious fact. Complete and accurate reporting of errors may be in the cause of "public service" but it also entails the possibility of discomforting personal results, imposition of personal liability, or the need to blame work colleagues or the reported employee's work unit or exposing them to trying procedures. Moreover, the report may be followed by an investigation or inquiry, taking up time and trouble, beyond the scope of regular reporting. Due to the low rates of reporting, sample reports are too small and biased, and therefore difficult to treat as representative scientific data to be used as the basis for a fundamental change in the system.

Quality of reported information and its completeness: Another problem also affecting the quality and validity of the reported material is that the reported errors are personal reports based on the reporter's memory. As in the case of eyewitness testimony in a trial, the quality of the reported material also depends on the quality of the reporter's memory and personal biases and preferences related to the reporter's personal perspective and involvement in the reported occurrence. A substantial and rich literature in cognitive psychology deals with biased reporting and impaired quality of eyewitness reporting and there is no reason to assume medically reported errors are not influenced by the same factors and biases.

Absence of reference base: Another obstacle to the ability to assess error and accident reports, to interpret and afford them proper weighting, is the absence of an appropriate reference base that would allow assessment of the relative frequency and severity of the reported problem. In most cases, if not all, reports of provision of incorrect medication, errors in filling out forms, incorrect medical procedure, calculation or incorrect reading of data (from a label or report) are not comparable to the frequency of similar operations performed properly and without error, as such a database simply does not exist.

For example, in a study carried out in a respiratory intensive care unit, Yoel Donchin, Daniel Gopher, and colleagues found a similar frequency of errors committed by doctors and nurses daily, even though the nurses were responsible for about 87% of the total activities in the unit. That is to say, the contribution of doctors to the number of errors was similar to the contribution of nurses, although the ratio of the scope of activity between the doctors and the nurses was about 1:7.[4]

This result clearly illustrates how the interpretation and the significance attributed to error reports in the absence of a basis of comparison capability may be flawed, and how impossible it is to achieve such a reference base for each individual case.

Wisdom in hindsight: One of the most difficult problems in investigating errors and relying on error reports as the basis for recommendations for changes and improvements is that interpretations and explanations of errors derived from their investigation result from wisdom in hindsight (*post factum*). This is one of the most serious risks inherent in drawing conclusions and their interpretation scientifically.

For example, a person who took office after working years or maintains lengthy contact with his/her spouse, if asked how he got his job or selected his spouse, will relate an orderly and logical story and recall, step by step, the sequence of events and decisions that led him to where he is today. This is wisdom looking backwards—wisdom in hindsight.

However, at each stage, if the same person was asked to predict the chances of eventually finding himself at the end of the process at the place where he is at a given moment (position, partnership), the predictive value would be reduced dramatically, if not disappear completely. For every step and point of decision the number of options is large and level of imprecision vis-à-vis all options is too high to allow a valid and reliable prediction. This is what is meant by wisdom in hindsight: the power to offer a logical and ordered explanation for the current state or occurrence but without any predictive ability, enabling prediction of the final outcome in the early stages.

This is an obstacle and a major difficulty in exploiting error investigation material as a basis for scientific work. Science aims at predicting future results from preconditions or basic characteristics. The ineffectiveness of such predictions negatively affects the ability of action and usefulness of the information collected.

Passive and reactive approach: Error and accident reports and the steps taken following their investigation characterizes a passive and reactive approach in attempting to make corrections and is not actively preventive or forward looking. Use of error and accident reports as a principal basis for system guidance in repairing a problem infers that the system changes the operation and performs fault correction after the occurrence, the "putting out fires" method, which does not take preventive action to reduce in advance the probability of accident occurrence. Relying exclusively on error reports and accident investigations as a principal source of information represents implicit adoption of this approach, minimizing active efforts to reduce errors and accidents by preventing their occurrence. For all the reasons listed above, it is absolutely clear that human factors engineering work and improving health care safety cannot rely on error reports and investigation as a central repository of information, as it is insufficient. The creation of an appropriate database, directed at the various issues discussed above, and building appropriate tools to collect, analyze, and interpret the information, are cornerstones and counted among the important challenges of human factors engineering activities in coping with improvement requirements and redesign of medical systems and methods. Various aspects of this topic will be discussed in later chapters.

COGNITIVE COMPONENTS, ROLE PERCEPTION, MENTAL MODELS, AND SAFETY CLIMATE

The main thrust of human factors engineering has been in the areas of engineering design, physical work environment planning, definition of procedures, and patterns of work, although the roots of the working group, whose work is described in various chapters of this book, is also fixed on expansive cognitive psychology, decision-making processes, and organizational psychology. These areas touch on the actual functioning skills of medical teams and the general behavioral style in the hospital wards or other medical work units. Earlier in this chapter, we discussed some issues regarding effective functioning of the team and work procedures. These issues are examined more broadly when considering the overall functioning of the unit; how different functionaries perceive their role and the major impact of their responsibilities on performance of their tasks and also on subjects of communication with other team members and ways and means of communication. Moreover, not only is role function perception important; but also it is important how functionaries perceive the role and responsibilities of others with whom they collaborate.

Communication between doctors and nurses in work teams and hospital departments is a painful and familiar problem. It can be shown that the origins of this problem can be found in role perception—each and everyone to their function and that of the other person.

Similarly, one can consider the mental model where the operator has a role in the process he is involved in. If the process is complex and multistage, devoid of work procedures and defined and clear work practices, it is likely that each functional subject will initiate its own mental model process, a model that organizes its work process in general and its work in particular. For example, doctors and nurses in the emergency department often differ in their perceptions of the patient flow process and stages of treatment. Investigation of the suitability of functional concepts and mental models of functionaries is an important issue in understanding the work processes and narrowing gaps. In any discussion on safety and safety behavior, general attitudes and general perceptions of team members on the critical nature of the subject and their willingness to invest in it are of major importance.

These variables complement the complex issues and variables that were discussed in earlier sections and contribute to overall safety and effective care. The book's chapters deal with different aspects of these issues.

REFERENCES

1. Leape L.L., Brennan T.A., Laird N., Lawthers A.G., Localio A.R., Barnes B.A., Hebert L., Newhouse J.P., Weiler P.C., and Hiatt H. 1991. The nature of adverse events in hospitalized patients. Results of the Harvard Medical Practice Study II. *N Engl J Med.* February 7;324(6):377–84.
2. Agricola G. 1912. *De re metallica*, trans. Herbert C. Hoover and Lou H. Hoove. London.
3. Gopher D. 2004. Why it is not sufficient to study errors and incidents: Human factors and safety in medical systems. *Biomed Instrum Technol*. 45:387–91.
4. Donchin Y., Gopher D., Olin M., Badihi Y., Biesky M., Sprung C.L., Pizov R., and Cotev S. 1995. A look into the nature and causes of human errors in the intensive care unit. *Crit Care Med*. February 23(2):294–300.

2 A History of Medical Errors

Yoel Donchin

To err is human.

Hieronymus

Then I shall be blameless
and innocent of any great transgression.

Psalms 19,13

Large hospitals are centers of day-to-day activities involving thousands of people, health requirements, and those striving to meet those requirements. Today, it is commonplace to replace the title of *hospital* with more positive sounding names, such as *Medical Health Center*. At the entrance to such a center one can find shops, cafes, as well as bank and post office branches. Numerous companies offer inpatients and care seekers home comforts in the form of a personal TV and private phone connection. Eye-catching signs direct newcomers to the many institutes, laboratories, and clinics, with slow-moving elevators to convey the needy to all parts of the hospital.

Many of these medical centers began life as small and simple structures. Over time, wings and new buildings were interconnected as one unit by means of complicated passages, staircases, and endless aisles.

A large hospital with a capacity of about 1,000 beds may employ a staff numbering some 2,000, from maintenance personnel, providing a constant supply of electricity and medical gases, to administrative personnel, who collect payments and manage the data collection system and prompt distribution among the various users—and in-between, nurses, doctors, and other relevant professional staff.

The medical center is to all intents and purposes an industrial plant in all respects: at the start of the "production line" are patients prior to medical diagnosis and finally (hopefully), after a series of manual and sophisticated instrumental tests, the appropriate diagnosis and treatment are determined.

This plant differs significantly from its early predecessors, that is, hospitals at the onset of the 19th century or institutions that served as poorhouses and charitable institutions rather than medical or healing care centers. In fact, the concentration of patients in these institutions increased the risks of mortality, from infections, joint use of contaminated tools, and poor hygiene. Giving birth in the home was a far safer proposition than in the maternity ward. The doctors in the selfsame "hospitals" were helpless against prevailing disease and suffering. Until 1846, for example, easing of pain after surgery was not possible, as anesthesia as we know it today, was unheard of. Moreover, surgeons at the time did not keep to the rules applying to disinfection, as the causes of infectious diseases had not yet been discovered and the patient's chances of surviving surgery were very slim.

Amazingly and paradoxically, it seems that a patient hospitalized in today's sophisticated medical center is prone to risks that are no less severe than the cause of the patient's hospitalization.

Medical systems have not paid sufficient attention to those factors that can cause mishaps, as they are immersed in the implementation of medical research successes. New surgical methods have been developed—but the team itself has never been tested, nor have heart surgeons been monitored, although they stand for hours on their feet, engrossed in a narrow upheaval-prone surgery; nurses and doctors have never been tested, although they are exposed to noise in intensive care: this goes as well for ambulance drivers, laboratory workers, floor cleaners (the most common accident in a hospital is an employee or a patient slipping on a polished floor), and cafeteria staff. A long period of time elapsed before consideration was given to hospital safety issues.

In 1940, a patient would receive one to three drugs, while today, the figure is closer to 10 to 15. Not all drugs are prescribed by the same doctor and some drugs may cancel out the actions of others. In order to be precise in the dosage of powerful drugs, use is made of supposedly precise instruments, but slight deviations in their calibration are likely to elicit unwanted or even dangerous patient reactions.

Diagnosis requires imaging of internal organs by various means—X-rays, injection of radioactive material, sound waves, magnetic fields, and so forth. Any deviation, even a small percentage, and the process could be harmful rather than beneficial. The gap between a harmful dose and a beneficial dose could be extremely narrow. The following is a recount of a medical event:

> Until 13:20 today, 57-year-old Mr. Haim Ratson has been in good health, feels good, and has never needed a doctor. Mr. Ratson is a passive sports fan (football, going to a match once a week). His parents are still alive. He is happy in his marriage and eagerly awaiting a third grandson due in a month. However, for a few hours after lunch, he felt pain in his chest. Initially, he blamed the spicy soup (this reaction of rejection of physical symptoms characterizes 60% or more of patients), then went to lie down and tried to forget the pain, but the pain stubbornly refused to disappear; on the contrary, it increased, causing undue distress. A few hours later, his wife intervened and despite his protests contacted MDA (Magen David Adom—Israel emergency medical services) and called for help.
>
> The person receiving the call addressed it with all seriousness, requesting Mr. Ratson to remain in bed, adding that help would arrive soon. Indeed, a few minutes later a doctor arrived accompanied by two men carrying bags and various instruments. They measured Haim Ratson's blood pressure, attached him to a device that recorded his heart activity and then, without further ceremony: "to the hospital!" They sat Haim on a chair, attached a greenish tube to his nose, tickling the inside of his nose with a thin stream of pure oxygen, descended the stairs that Haim had gone up and down thousands of times without any problem, carefully

lowered him into the ambulance, setting off immediately to the hospital, while honking and flashing to clear a path and not get stuck in traffic.

The hospital's emergency room staff was already waiting for Mr. Ratson, as the paramedic and MDA control center had announced their impending arrival with a "suspected heart attack." A sympathetic nurse was standing by to help Haim Ratson off the stretcher and on to the pre-prepared bed, which although very narrow was definitely more comfortable than the stretchered ride in the ambulance. The chest pain was less bothersome than before, probably thanks to the pill given to him in the ambulance ("Chew slowly," they said and placed in his mouth a small and somewhat bitter pill).

The nurse repeated blood pressure measurement, recorded the pulse rate, and took his temperature. Meanwhile, his clothes were removed and a needle injected in his arm. If that were not enough, he was asked to urinate into an odd-looking bottle from which a sample was taken and replaced in a test tube labeled with his name. The test tube was placed alongside other test tubes containing blood. A smiling and courteous male nurse attached his arms and legs to a device "for recording the heart's electrical activity" (Mr. Ratson never gave a thought to his heart's electrical activity, which until now had never disappointed him). When the test was complete, the smile disappeared from the male nurse's face, while muttering "I need to show the chart to Dr. Etgari."

When Dr. Etgari arrived, with an impressive stethoscope around his neck, he looked at the chart and proceeded to fire a volley of questions, one after the other: When did the pain start? Where did it progress? When were you last hospitalized? (Never been hospitalized.) What medications are you taking? (No medicines.) What are you sensitive to? (Not sensitive—only sensitive parts, LOL) What were the causes of your parents' death? (Both are still alive, wishing them long life.) Following the series of questions after auscultation of the heart and lungs, Dr. Etgari reaches a diagnostic assessment: myocardial infarction.

"Mr. Ratson," Dr. Etgari addresses Mr. Ratson, "All the signs indicate that you suffered a heart attack. At the moment you're in a good state of health and are receiving all the accepted treatment aimed at preventing any further damage. The arteries that supply blood and oxygen to the heart muscle are slightly clogged" (every sentence containing bad news is accompanied by soothing words, both for the patient and the doctor). "Today we can diagnose and rectify the situation in a 'single blow' (a really serious blow). To do so we will now transfer you to the Catheterization Institute for Angiography—or imaging of the coronary arteries, an uncomplicated test, lasting about an hour. Your heart will be injected with a dye (just hearing this can bring on a heart attack) to reveal the condition of the arteries. If there is a blockage, it can be unblocked and then you'll feel like a new person." Did he have a choice? Mr. Haim Ratson signed a consenting form, agreeing to the abovementioned medical procedure being carried out on his person. Before being transferred to the catheterization room he handed his wristwatch and car keys to his wife, as well as giving her precise instructions for arranging all outstanding personal matters. For whatever reasons, Mr. Ratson was calm and certain that everything would be fine (probably due to the morphine administered in the ambulance to relieve any pain). Now he's on his way to the second floor, the location of the Heart Institute and Catheterization Unit.

Mr. Ratson is admitted by a sympathetic nurse to a scene right out of a science fiction movie: huge machines and monitors everywhere. Dr. Lotem, the doctor responsible for the catheterization procedure, clad in a green robe with a mask covering most of his face, introduces himself and explains: "We shall first anesthetize the point of insertion of the catheter. You will momentarily sense a heating inside of you, but this will pass quickly. The test is not painful." Mr. Ratson was able to observe his pulsating heart on a monitor while receiving an explanation from Dr. Lotem at each stage of the procedure.

At the end of the test (not painful? not exactly), Dr. Lotem informed him in all solemnity: "Mr. Ratson, we have succeeded in opening up the blockage. You are healthy man and in a few days you will be able to return home. In fact you have not suffered myocardial infarction, but the start of myocardial infarction, and heart muscle was not damaged."

Haim Ratson was transferred from the Catheterization Room to the Recovery Room, where his wife was waiting for him. The next morning he was transferred to the Internal Medicine ward, where Dr. Lotem, gently and without any pain, removed the catheter that had been left overnight in his groin artery.

A week later, Haim Ratson underwent a checkup in the cardiology clinic. His file recorded that he follows a lifestyle appropriate to his condition, that is, to do everything necessary to prevent infarction: frequent checking of blood pressure, consumption of permissible foodstuffs only, otherwise, the rest—as usual.

A story with a perfect ending—a prompt rescue operation, efficient medical services, a well-oiled system, with all the links in the recovery chain operating in maximum harmony.

However, events can take a different course. The selfsame Haim Ratson, who was never ill or needed a doctor, is struck by a sudden chest pain and calls up Magen David Adom. The duty officer, loaded with work and dealing with cries for help, listens to the complaint. His reading of the situation is that this is not a serious condition, having participated in a brief 40-hour course, and dispatches an ambulance with a paramedic and driver to Haim Ratson's home. As the address given was not clear enough, the ambulance was delayed and 20 minutes elapsed before its arrival at the home of the patient. The paramedic realizes immediately that the situation requires summoning the intensive care unit ambulance and informs the MDA call center accordingly. Ten minutes later a doctor and intensive care team arrives. The ambulance's electrocardiogram (ECG) machine is not working due to a technical problem, however, based on clinical indications, the doctor concludes that Mr. Ratson is suffering from a heart attack and gives directions to transfer him to the duty hospital. After several attempts to contact the emergency room charge nurse failed, the doctor decides not to waste any more time and sends the ambulance on its way to the hospital. Mr. Ratson is taken to the overloaded emergency room. Fortunately, he is given a comfortable bed, where he must wait a long time for a doctor. About an hour later a nurse comes to him, holding a syringe, containing a yellowish liquid: "Mr. Bialik! Your shot is ready!"

"But I'm not Bialik."

"Oops…" She smiles apologetically and goes in search of the appropriate patient.

The chest pain intensifies. Mrs. Ratson went to arrange hospitalization; Haim Ratson lies alone in bed, unable to ask for help. Luckily for him, the replacement duty team arrived and a team of doctors, on arrival at his bed, were amazed to discover that an ECG test had not yet been carried out, that Mr. Ratson was experiencing chest pain, that he was covered in a cold sweat and recording a rapid pulse rate. The team decides to act quickly. (At this point, time is of the essence!) Mr. Ratson is given an aspirin and intravenous pain relief ("What dedicated treatment and how good to be hospitalized here…") muses Mr. Ratson before his consciousness becomes hazy and a morphine-induced tranquility takes over his body.

Mr. Ratson's ECG chart shows clear signs of myocardial infarction and the team decides to transfer him immediately to the catheterization unit, but the room is currently undergoing maintenance operations and two patients are still waiting their turn. The catheterization procedure is set for later. Later that night the doctor informs Mr. Ratson that his blood vessels have opened up and there is no further risk to the heart muscle, however, due to the damage already caused, he will have to be hospitalized for several more days in the internal medicine department. Meanwhile, he can remain in the recovery room of the catheterization unit. Later, he is transferred to Internal Medicine. Several drugs are piped intravenously into his body via the groin artery. The catheter, when inserted, provides a system. At two in the morning, Mr. Ratson felt unwell and the bed was wet. After pressing the alarm bell and intervention of roommates, aroused from their sleep by his moaning and confused state, a nurse arrives and discovers that the catheter has removed itself from the groin and Mr. Ratson has lost two units of blood. Activity now moves into a higher gear, and so on and so forth. All events described are based on actual occurrences.

* * *

What is the probability that a patient undergoing hospital treatment will suffer harm due to error or medical negligence, due to mistaken medication, due to a respiratory device, or automatic syringe malfunction? Is it possible to check these questions? Is it possible to reach a quantitative calculation?

Dr. Lucian Leape, an epidemiologist from Harvard University, calculated the number of casualties from the mishaps and failures in U.S. hospitals.[1] His research examined thousands of cases of hospitalized patients in the State of New York. For every case in the records suggesting a failure or mishap, a thorough investigation was carried out of hospitalization procedures and of the incident itself.

In 15% of the cases, investigators found serious failures, including failures that led to fatalities. When Leape calculated the ratio of the number of hospitalized patients in the United States and the number of fatal mistakes, he found that each year 98,000 inpatients were likely to die in the United States. This number left a strong impression on the general public, especially as Leape calculated and discovered that this figure is equivalent to the number of victims of two large passenger plane disasters, including all the passengers!

With the publication of Leape's research, medical groups and associations awoke to the need to investigate and seek an explanation for why leading professionals—doctors, nurses, laboratory workers, and others—make mistakes.

An initial conference on this subject was held in 1996 at the Annenberg Center in Rancho Mirage, California. All those who had spoken openly about the occurrence of mistakes and investigated the phenomenon were invited to speak, about 160 researchers in total, most of them well informed. During a break in the proceedings, following the initial reviews and presentation of papers, a long table covered by a