Behavioral Safety

Human Error

A closer look at safety's next frontier

By Dan Petersen

IN THE U.S., ORGANIZED ATTEMPTS to prevent or control workplace injuries have existed for a long time, probably starting in the railroad industry in the 1800s. But the real attempts in general industry were relatively weak until the early 1900s. With the passage of workers' compensation laws in several states between 1908 and 1911, injuries became a cost to organizations. This provided the impetus to do something about it.

The financial incentive gave birth to "safety programs" and "safety engineers," and to both the National Safety Council and ASSE. What began in the 1900s is starkly different from the safety systems of today. As technology has changed, as management theories have evolved, so has safety programming. It is true that safety seems to change more slowly than technology or management concepts; it seems to lag by 20 or 30 years, and is influenced less by good research and experimentation than by the economy, government dictates and people selling new "solutions."

Consider the many safety approaches that have been used:

- physical condition approach, 1911 to present;
- industrial hygiene approach, 1931 to present;
- "unsafe act" approach, 1931 to present;
- management approach, 1950s to present;
- noise control approach, 1954 to present;
- audit approach, 1950s to present;
- system safety approach, 1960s and currently;
- OSHA physical condition approach, 1971 to present;
- OSHA industrial hygiene approach (when the OSHA chief was an industrial hygienist);
- other OSHA approaches, depending on the year and the current emphasis;
- ergonomic approach, anticipating an OSHA standard;
- "safety program" approach, anticipating an OSHA standard;
- environmental approach;
- total quality management thrust, using statistical process control;
- behavioral approach.

None of these were fads—they were real attempts to control losses. They are all still used today as part of safety technology. They are layers of things that must be done. Since safety staffs are now much smaller, management staffs have been cut and employee staffs downsized, choices must be made.

In all of these approaches, one thing that has not been tried is understanding the true cause of most injuries—human error. Chapanis begins one of his articles with the following case history:

> In March 1962, a shocked nation read that six infants died in the maternity ward of the Binghampton New York General Hospital because they had been fed formulas prepared with salt instead of sugar. The error was traced to a practical nurse who had inadvertently filled a sugar container with salt from one of two identical, shiny, 20-gallon containers standing side by side under a low shelf, in dim light, in the hospital's main kitchen. A small paper bag pasted to the lid of one container bore the word "Sugar" in plain handwriting. The tag on the other was torn, but one could make out the letters "S_lt" on the fragments that remained. As one hospital board member put it, "Maybe that girl did mistake salt for sugar, but if so, we set her up for it just as surely as if we'd set a trap." When a system fails it does not fail for any one reason. It usually fails because *the kinds of people* who are trying to operate the system, with *the amount of training* they have had, are not able to cope with *the way the system is designed*, following procedures they are supposed to follow, *in the environment* in which the system has to operate (Chapanis).

Peters provides this definition of human error:

> In theory, we would want to use a broadly ori-

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Figure 1

Error Spectrum

Work free of mistake and error.	Minor errors, mistakes and slight blemishes.	Errors causing delay, seconds, rework, rejects, waste.	Damage to property, material loss, process delay.	Errors causing injury.	Acts of negligence and deliberate destruction. Theft, arson, pollution.

Source: Nuberg.

ented definition which states that a human error consists of any *significant deviation from a previously established, required or expected standard of human performance.*

In practice, the term may have any one of several specific meanings depending upon the nature of contractual agreements, the unique requirements of a particular program, the customary error classification procedures, and the emotional connotations involved with the use of a term which might be incorrectly perceived as possibly placing the blame on individuals or their immediate supervision.

In the reality of situations where arguments of precisely what is or is not a human error are of less importance than what can be done to prevent them, the operational definition may be restricted to those errors a) which occur within a particular set of activities; b) which are of some significance or criticality to the primary operation under construction; c) [which] involve a human action of commission or omission; and d) about which there is some feasible course of action which can be taken to correct or prevent their reoccurrence (Peters).

As an industrial engineering undergraduate, the author studied work simplification, plant layout and motion study, not for the purpose of reducing error, but rather to increase productivity. Years later, I became acquainted with human factors concepts in graduate work in psychology. It seemed that this was a natural for the safety profession. That was 1971, and for some reason, the profession found OSHA and its standards to be considerably more interesting.

From a human factors standpoint, it seems that safety has lost 30 years of possible progress in reducing human error.

Each reader can surely think of everyday examples of human error. Consider these types of errors:

• **Design error,** as in the Pinto gas tank, where, in an apparent attempt to save a few dollars, human lives were lost; or the DC-10 aircraft, where jet engines fell off in the air and lives were lost.

• **Communication errors,** as in the crash of two 747s on an island in the Atlantic, producing the worst loss of life in an air crash in history.

• **Management system errors,** as with Bhopal, Chernobyl, the space shuttles and others.

Sometimes, people are fascinated by—and pay more attention to—the catastrophic losses. While their causes are usually the same as those incidents that produce only minor losses, they get everyone's attention. Consider the publicity accorded the Exxon Valdez incident, which remained in the headlines for six months (although no single human was ever injured). Or the Three-Mile Island incident, in which all the fail-safe systems worked, yet it nearly destroyed the organization.

Categories of Human Error

Years ago, Nuberg provided a picture of the spectrum of error outcomes (Figure 1).

Kletz offers four different types of error:

• Errors due to slips or aberrations. Example: Opening equipment that has been under pressure.

• Errors that could be prevented by better training or instructions.

• Errors due to a lack of physical ability. Example: Someone is asked to do the physically difficult or impossible.

• Errors due to a person being asked to do the mentally difficult or impossible (Kletz).

If a person is asked to detect a rare event, s/he may fail to notice when it occurs, or may not believe that it is genuine. The danger is greatest when this person has little else to do. For example, it is very difficult for night security personnel to remain alert when nothing has been known to happen and when there is nothing to occupy their minds and keep them alert.

There is another category that is perhaps somewhat different: *Errors due to the perception of peer thought*. Jerry Harvey illustrates this category in his key essay, "The Abilene Paradox: The Management of Agreement" (from *The Abilene Paradox*). Famous examples might include what happened at the Bay of Pigs or the Watergate cover-up. This concept is more commonly referred to as "group think," as researched by Janis.

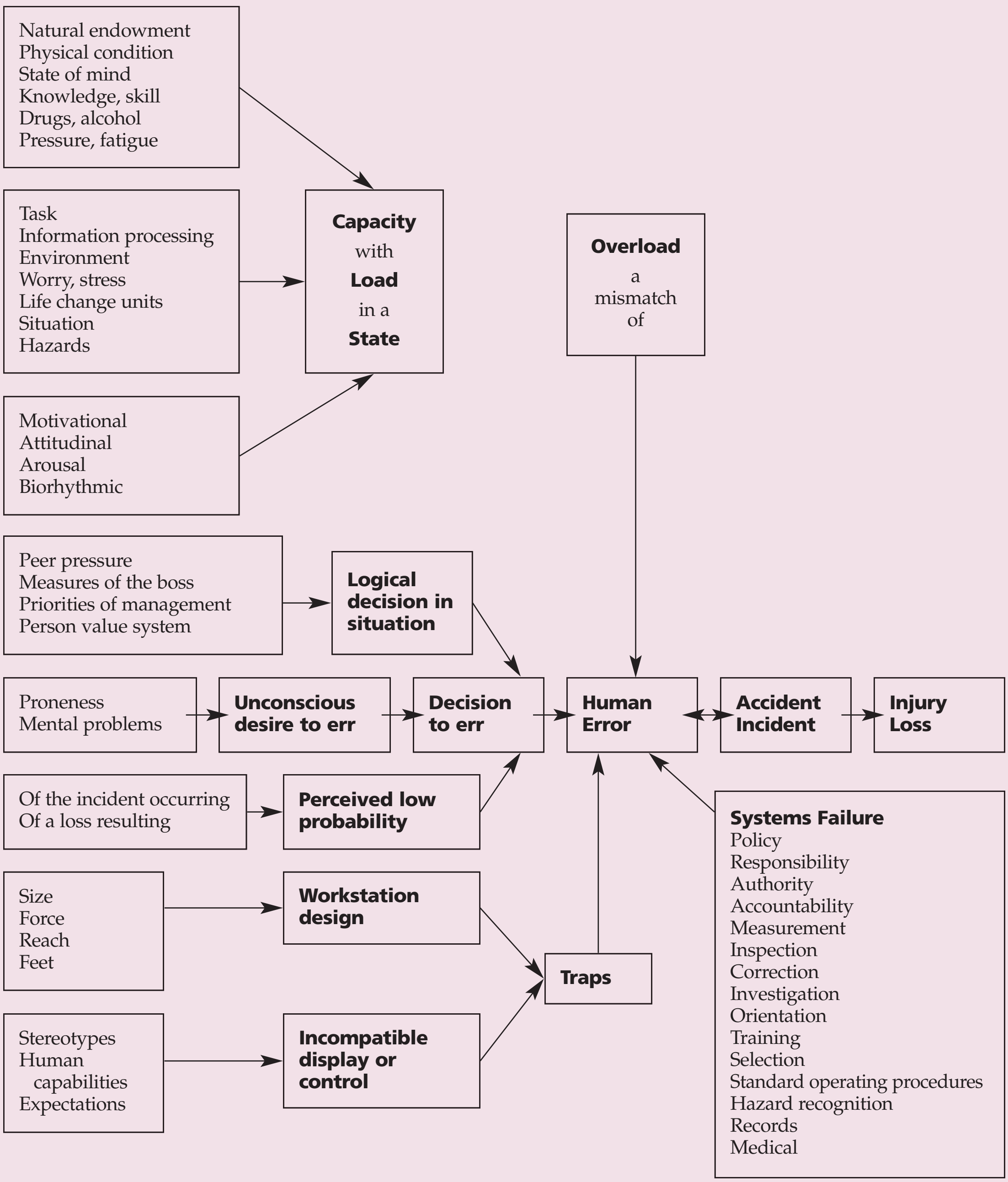
Categories of Causes

Think of human error in terms of causes that fit into three categories, as illustrated by the accident causation model in Figure 2. The model was developed as a result of inputs from many people. It was based on a human factors model of accident causation developed at the University of Arizona by Dr. Russell Ferrell, professor of human factors. From this base, a different model was developed for presentation to a conference in safety management concepts held by the National Safety Management Society in December 1977. The model was then restructured into the one shown in Figure 2 (Petersen).

The model states that an injury or other type of financial loss to the company is the result of an acci-

Figure 2

The Accident Causation Model



Source: Petersen, 30.

dent or incident. The incident is the result of 1) a system's failure and 2) a human error. Systems failure is concerned with most questions that traditional safety management might cover, such as:

- What is management's stated policy on safety?
- Who is designated as responsible and to what degree?
- Who has what authority and the authority to do what?
- Who is held accountable? How?
- How are those responsible for safety measured for performance?
- What systems are used for inspections to find out what went wrong?
- What systems are used to correct things found wrong?
- How are new people oriented?
- Is sufficient training given?

•How are people selected?
•What are the standard operating procedures? What standards are used?
•How are the hazards recognized?
•What records are kept and how are they used?
•What is the medical program?

Due to trends such as downsizing, outsourcing . . . there has never been more overload on the worker— or the manager.

The second and always-present aspect and cause of an incident or accident is human error. Human error results from one or a combination of three things: 1) overload, which is defined as a mismatch between a person's capacity and the load placed on him/her in a given state; 2) a decision to err; and 3) traps that are left for the worker in the workplace.

Overload

The human being cannot help but err if given a heavier workload than s/he has the capacity to handle. This overload can be physical, physiological or psychological. To deal with overload as an accident cause, one must look at an individual's capacity, workload and current state. To deal with overload as an organizational cause, one must identify the controls available for dealing with capacity, workload and state.

A human being's capacity refers to physical, physiological and psychological endowments (what the person is naturally capable of); current physical condition (and physiological and psychological condition); current state of mind; current level of knowledge and skill relevant to the task at hand; and temporarily reduced capacity owing to factors such as drugs or alcohol use, pressure or fatigue.

Load refers to the task and what it takes physically, physiologically and psychologically to perform it. Load also refers to the amount of information processing the person must perform; the working environment; the amount of worry, stress and other psychological pressure; and the person's home life and total life situation. Load refers to a person's work situation per se, and to work hazards s/he faces daily. State refers to a person's level of motivation, attitude, arousal and to his/her biorhythmic state.

In today's environment, due to trends such as downsizing, outsourcing, increase in span of control, employee ownership concepts, self-directed work teams and employee involvement, there has never been more overload on the worker—or the manager.

Decision to Err

In some situations it seems logical to the worker to choose the unsafe act. Reasons for this might include:

1) Because of the worker's current motivational field, it makes more sense to operate unsafely than safely. Peer pressure, pressure to produce and many other factors might make unsafe behavior seem preferable.

2) Because of the worker's mental condition, it serves him/her to have an accident.

3) The worker just does not believe s/he will have an accident (low perceived probability).

Traps

The third cause of human error is the traps that are left for the worker. This primarily involves human factors concepts. One trap is incompatibility. The worker errs because his/her work situation is incompatible with the worker's physique or with what s/he is used to. The second trap is the design of the workplace—it is conducive to human error. A third trap is the culture of the organization—what behaviors it encourages or discourages. Certain situations are "error-provocative" (a notion examined later in this article). This concept is perhaps the most important single contribution made by error-reduction theorists. It leads to the conclusion that much more progress can be made by changing the situation than by preaching or disciplining. Human errors at lower levels of the organization are symptoms of things that are wrong in the organization at higher levels.

Human error can be reduced by changing the situation. This change is accomplished by assistance from the outside (staff safety, line management, etc.), working within a corporate philosophy, through study of the situation and through participation of the individual worker.

Culture & Safety

A similar model is shown in Figure 3. Instead of a simple chain of events model (A causes B, which causes C, etc.), we have a fault-tree type configuration to be better attuned to safety technology, and a number of factors are added.

Perhaps the most important point in this model is that everything done to reduce human error—and thus losses—is dependent on the employer's perception of the organization's culture.

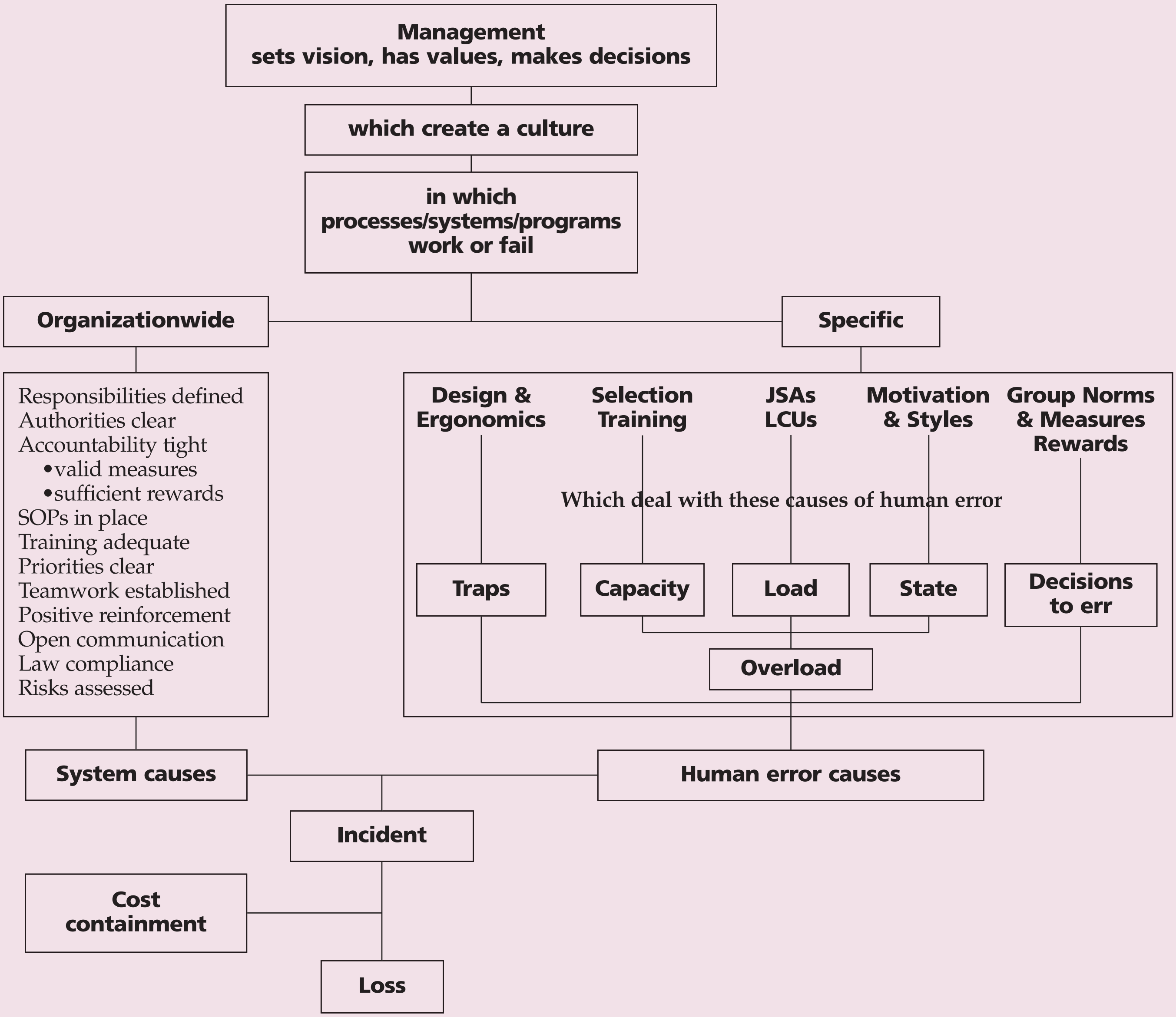
This model incorporates the overriding thought: Culture is the key. Or, said another way, perception of culture (which by definition is culture), is what makes or breaks safety—what makes any element of the process work or fail.

The model can be explained this way: Management—through its vision, honest real values, systems of measurement and reward and daily decisions—creates organizational culture. In that culture, various processes and procedures attempt to operate. Their intent is to control losses. Some are overall (systemwide)—for example, whether people are held accountable for performance; some are specific—for example, how a supervisor's training is selected.

The field of safety largely ignored the concept of culture throughout the 1980s. As management attempted to improve culture through changing styles of leadership, employee participation, etc., SH&E professionals tended to change their approaches very little, keeping the same tools, using the same elements in their safety "programs" that they had always used. Safety programs typically consisted of the usual things: Meetings, inspections, accident investigations, using job safety analyses (JSAs), etc. These tools were perceived as the essential elements of a safety program. In fact, OSHA published a guideline in the 1980s suggesting that all companies follow all of these practices (OSHA).

Figure 3

Second Causation Model



Several states enacted laws requiring companies to do these things. These traditional elements were regarded as a "safety program."

While OSHA and the states were going down the "essential element" track to safety (as was much of the SH&E profession), several researchers began to suggest totally different answers to the safety problem. Most of their research results were confident in saying that "there are no essential elements"—what works in one organization may not work in another. Each organization must determine for itself what will work—there are no magic pills. The answer seems to be clear: It is the culture of the organization that determines what will work in that organization.

Certain cultures do, in fact, have safety as a key component, whereas other cultures make it clear that safety is unimportant. In the latter, almost nothing will work—meetings will be boring, JSAs perceived only as paperwork and so on.

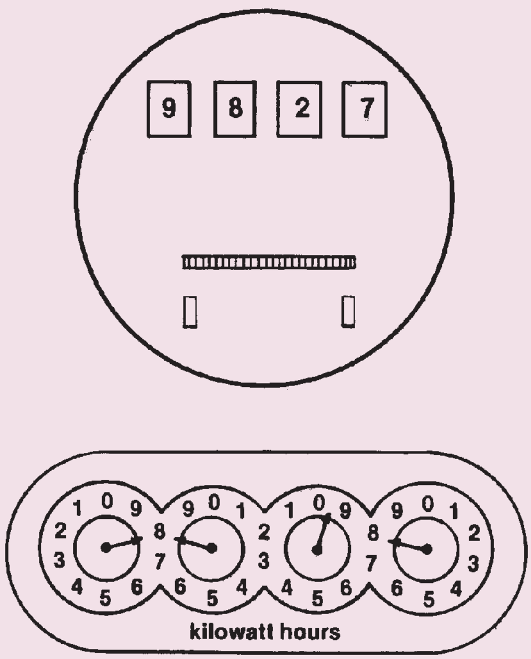
The culture of the organization sets the tone for everything in safety. In a positive safety culture, it says that everything done about safety is important. In a participative culture, the organization says to the worker, "We want and need your help." Some cultures urge creativity and innovation; others stifle it. Some cultures tap employees for ideas and help; some force employees to never use their brains at work.

Culture is a major factor in the causes of human error as well. Considerations that determine the culture include:

Figure 4

Simplicity: Electric Meters

These electric meters illustrate the principle of simplicity. Of the two electric meters shown, the top one is considerably easier to read and much less likely to cause a sensing error.



Source: F. Vilardo.

•How decisions are made: Does the organization spend its available money on people? On safety? Or are these ignored for other things?

•How people are measured: Is safety measured as tightly as production? What is measured tightly is what is important to management.

•How people are rewarded: Is there a larger reward for productivity than for safety? This indicates management's true priorities.

•Is teamwork fostered? Or is it "them vs. us"? In safety, is it "police vs. policed"?

•What is the history? What are the traditions?

•Who are the corporate heroes and why?

•Is the safety system intended to save lives or to comply with regulations?

•Are supervisors required to perform safety tasks daily? This says that safety is a true value.

•Do big bosses wander around and talk to people?

•Is using the brain allowed on the work floor?

•Has the company downsized?

•Is the company profitable? Too much? Too little?

These are only a few of the many things that set the culture. It is more important to understand what the culture is than to understand why it is that way.

After culture considerations comes the specifics—how that culture translates itself into day-to-day operations. Beyond the elements that transfer culture into day-to-day operations, there are day-to-day issues that define culture from the design standpoint.

Design Traps

Many writers and researchers over the years have examined the worker-machine system. The human error approach concentrates on the worker component by examining four subsystems:

•sensing;
•information processing;
•responding;
•human expectations.

The Worker's Sensing Subsystem

One of the worker's functions is that of a sensor—an information seeker. Humans have more than the five senses. To use the various senses in the work environment, people build information displays—devices that gather needed information and translate that information into inputs the human brain can perceive. These displays are in two general classes: Symbolic and pictorial.

Symbolic displays represent the information in a form that bears no resemblance to what it is measuring. Examples include the speedometer, thermometer, pressure gauge and altimeter. In pictorial displays, the geometric and spatial relationships are shown as they exist. Examples include maps, pictures and television.

The two most common types of symbolic displays are visual and auditory. Much attention has been given to the design of these types of displays. Some general principles have emerged:

1) **Simplicity.** The purpose of the display will dictate its design, but as a general principle, the simplest design is best.

2) **Compatibility.** The principle of compatibility holds that the motion of the display should be compatible with (or in the same direction as) the motion of the machine and its control mechanism.

3) **Arrangement.** As the design of the display is important, so too is its location or arrangement in relation to other displays. A poor arrangement of displays can be the source of error. Sometimes dials must be arranged in groups on a large control panel. If all the dials must be read at the same time, they should be pointing in the same direction within the desired range. This will reduce check-reading time and increase accuracy.

4) **Coding.** All displays should be coded or labeled so that the operator can tell immediately what mechanism the display refers to, what units are measured and what the critical range is.

Some of these principles are illustrated fairly easily. For example, Figure 4 illustrates the principle of simplicity. Of the two electric meters shown, the top one is considerably easier to read and is much less likely to cause a sensing error (Van Cott and Kincade; Woodson and Conover). In Figure 5, the drawing on the right illustrates the principle of compatibility. To regulate heat, the user simply turns the pointer clockwise to "Hi." The principle of arrangement is shown in Figure 6; the configuration on the left is better than the one on the right and is much less likely to cause errors.

Vilardo provides several principles for auditory displays:

Situationality. The design of auditory displays should consider other relevant characteristics of the environment in which the system is to function (e.g., noise levels, types of responses controlled by the auditory signal).

Compatibility. Where feasible, signals should "explain" and exploit learned or natural relationships on the part of the user, such as high frequencies being associated with "up" or "high," and wailing signals indicating emergency.

Approximation. Two-stage signals should be considered when complete information is to be displayed and a verbal signal is not feasible. The two stages would consist of a) attention-demanding signals to attract attention and identify a general category of information; and b) designation signals that follow the attention-demanding signals to designate the precise information within the general category.

Dissociability. Auditory signals should be easily discernable from other sounds (be they meaningful or noise).

Parsimony. Input signals should not provide more information to the user than is necessary to execute the proper response.

Forced entry. When more than one kind of information is to be presented, the signal must prevent the receiver from listening to just one aspect of the total signal.

Invariance. The same signal should designate the same information at all times.

The Worker's Information Processing Subsystem

The information-processing system involves these kinds of processes:

1) Information storage: including both long- and short-term memory.

2) Information retrieval and processing, including:

- recognition or detection of signals or stimuli;
- recall, including previously learned factual information and information in short-term storage;
- information processing, categorizing, calculating, coding, computing, etc.;
- problem solving and decision making;
- controlling of physical responses.

Each of these highly complex areas is a major field of study in itself. Clearly, it would be easy to overload this subsystem in certain difficult or stressful situations.

The Worker's Responding Subsystem

The third function the worker serves in the worker-machine system is that of a controller. This function is the response that the worker must make to any given stimulus. Just as principles exist for designing displays that are less likely to cause error, similar principles exist for designing controls.

1) **Compatibility.** Control movement should be designed to be compatible with the display and matching movement.

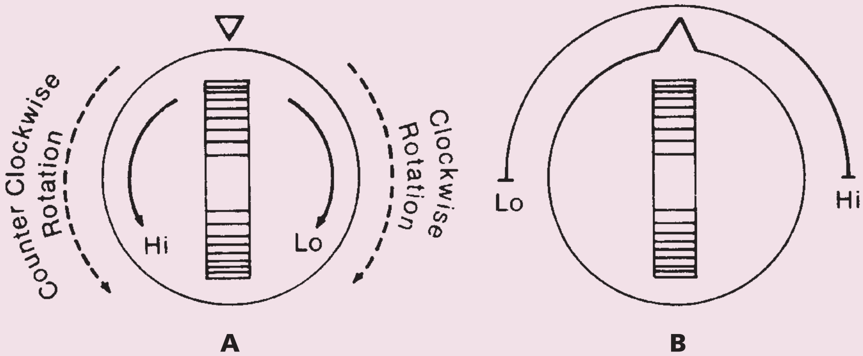
2) **Arrangement.** This principle provides for the grouping of elements or components according to their functions (those having related functions are grouped together) and for grouping in terms of how critical they are in carrying out a set of operations. It also suggests that each item be in its optimum location in terms of some criterion of usage (e.g., convenience, accuracy, speed, strength to be applied). Items used in sequence should be placed close together, and items used most frequently should be placed closer to the operator than those used less frequently.

3) **Coding.** Whenever possible, all controls should be coded in some way. A good coding system uses shape, texture, location, color and operation. Also, all controls and displays should be labeled. Labeling is crucial if the operators change often or the equipment is shared.

Figure 5

Compatibility: Heat Regulators

The drawing on the right illustrates the principle of compatibility. To regulate heat, the user simply turns the pointer clockwise to "Hi."

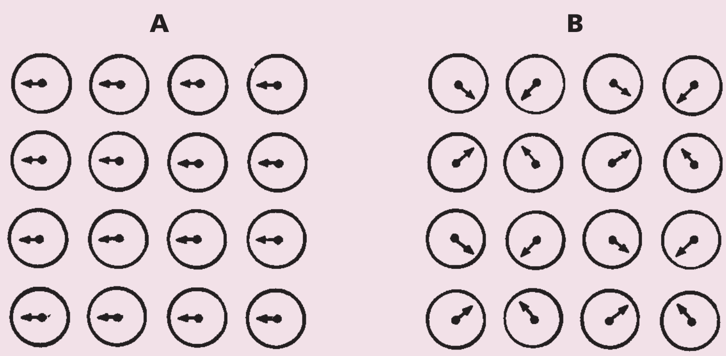


Source: F. Vilardo.

Figure 6

Arrangement: Indicators

The principle of arrangement is shown here. The configuration on the left is better than the one on the right, and is much less likely to cause errors.



Source: F. Vilardo.

Human Expectations

Any situation that calls for a movement contrary to the established stereotype is bound to produce errors. The designer is calling for errors (building traps) by asking the worker—in a given unique situation—to change a behavior pattern that can be described as a habit. People expect things to be, or work, in a certain manner. Following are some human stereotypes that should be considered in the design of both displays and controls:

- Handles used for controlling liquids are expected to turn clockwise for off and counterclockwise for on.
- Knobs on electrical equipment are expected to turn clockwise for on or to increase current and counterclockwise for off or decrease in current. (*Note*: This is opposite to the stereotype for liquids.)
- Certain colors are associated with traffic, operation of vehicles and safety.
- For vehicles in which the operator is riding, the operator expects a clockwise control motion to result in a similar motion of the vehicle, and vice versa.
- Sky-earth impressions carry over into colors and shadings: light shadows and bluish colors are related to the sky or up, whereas dark shades and

greenish or brownish colors are related to the ground or down.

•Things that are farther away are expected to look smaller.

•Coolness is associated with blue and blue-green colors, warmth with yellows and reds.

•Very loud sounds or sounds repeated in rapid succession, and visual displays that move rapidly or are very bright, imply urgency and excitement.

•Very large objects or dark objects imply heaviness. Small or light-colored objects appear light in weight. Large, heavy objects are expected to be at the bottom. Small, light objects are expected to be at the top.

•People expect normal speech sounds to be in front of them and at approximately head height.

•Seat belts are expected to be a certain level when a person sits down.

When design situations violate principles, processes or expectations, human error is designed into the systems; thus, error is bound to occur.

When design situations violate principles, processes or expectations, human error is designed into the systems; thus, error is bound to occur. Often, human error occurs not because humans are stupid or clumsy, but because management systems or designs have trapped them into error.

Chapanis provides some interesting observations:

1) Many situations are error-provocative.

2) Given a population of human beings with known characteristics, it is possible to design tools, appliances and equipment that best match their capacities, limitations and weaknesses.

3) The improvement in system performance that can be realized from the redesign of equipment is usually greater than the gains that can be realized from the selection and training of personnel.

4) For purposes of person-machine systems design, there is no essential difference between an error and an accident. The important thing is that both an error and an accident identify a troublesome situation.

5) The advantages of analyzing error-provocative situations are:

a) It is easier to collect data on errors and near-hits than on accidents.

b) Errors occur more frequently than accidents. In short, this means that more data are available.

c) Even more important than the first two points is that error-provocative situations provide clues about what one can do to prevent errors or accidents before they occur.

d) The study of errors and near-hits usually reveals those situations that may result in an accident but have not as yet. In short, by studying error-provocative situations, we can uncover dangerous or unsafe designs before an accident occurs.

e) If we accept that the essential difference between an error and an accident is largely a matter of chance, it follows that any measure based on accidents alone—such as the number of disabling injuries, injury frequency rates, injury severity rates, number of first-aid cases, etc.—is contaminated by a large proportion of pure error variability. In statistical terms, the reliability of any measure is inversely related to the amount of random—or pure error—variance that contributes to it. It is likely that the reason so many studies of accident causation turn up with such marginally low relationships is the unstable or unreliable nature of the accident measure itself.

6) Design characteristics that increase the probability of error include a job, situation or system that:

a) violates operator expectations;

b) requires a performance beyond what an operator can deliver;

c) induces fatigue;

d) provides inadequate facilities or information for the operator;

e) is unnecessarily difficult or unpleasant;

f) is unnecessarily dangerous (Chapanis).

It is obvious that the principles of human error control are synonymous with the principles of safety management—yet these two areas have avoided each other for years. At ASSE's Human Error Symposium last spring, many researchers and speakers showed that the causes of aircraft incidents were the same as the causes of medical incidents were the same as the causes of industrial incidents, etc. These fields need to learn from each other; safety in particular must learn from researchers in other fields.

It should be noted that the information and figures mentioned here are not new. Many are from the 1960s. Through research, the causes of human error have been known since then. SH&E professionals are only now beginning to think about how the field can and should use this knowledge. ■

References

Chapanis, A. Quoted in W. Johnson, *New Approaches to Safety in Industry.* London: InComTec, 1972.

Goldberg, M.H. *The Blunder Book.* New York: William Morrow & Co., 1984.

Harvey, J. *The Abilene Paradox and Other Meditations on Management.* Lexington, MA: Lexington Books, 1989.

Janis, I.L. *Victims of Group Think.* Boston: Houghton Mifflin, 1972.

Johnson, W. *The Management Oversight and Task Tree—MORT.* Washington, DC: U.S. Government Printing Office, 1973.

Kletz, T. *An Engineer's View of Human Error.* Rugby, England: Institution of Chemical Engineers, 1985.

Nuberg, A. "Reducing Damage Accidents." In *Selected Readings in Safety.* J.T. Widner, ed. Macon, GA: Academy Press, 1973.

OSHA. Safety & Health Program Management Guidelines; Issuance of Voluntary Guidelines. *Federal Register.* 54(1989): 3904-3916.

Peters G. "Human Error: Analysis and Control." *The Journal of ASSE.* Jan. 1966: 9-15.

Petersen, D. *Human Error Reduction and Safety Management, 3rd Ed.* New York: John Wiley & Sons, 1996.

Van Cott, H.P. and R.G. Kincade, eds. *Human Factors Engineering Guide to Equipment Design.* Washington, DC: U.S. Government Printing Office, 1972.

Vilardo, F. "Human Factors Engineering: What Research Found for Safety Men in Pandora's Box." *National Safety News.* Aug. 1968.

Woodson, W. and D.W. Conover. *Human Engineering Guide for Equipment Designers.* Berkeley, CA: University of California Press, 1965.

Zebroski, E. "Lessons Learned from Man-Made Catastrophes." In *Risk Management,* R.A. Knief, ed. New York: Hemisphere Publishing, 1991.

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