1961

January 3
President Dwight Eisenhower announced that the U.S. had severed diplomatic and consular relations with Cuba.

January 16
Mickey Mantle becomes the highest paid player in Major League Baseball by signing a contract that will pay him $75,000 per season.

Best Actress: Sophia Loren, *Two Women*

January 20
John F. Kennedy becomes President of the U.S.

Best Actor: Maximilian Schell, *Judgment at Nuremberg*

January 25
In Washington, DC, John F. Kennedy delivers the first live presidential news conference.

March 1
President John F. Kennedy establishes the Peace Corps.

Harper Lee wins the Pulitzer Price for Fiction for *To Kill a Mockingbird*.

March 29
The 23rd Amendment to the U.S. Constitution is ratified, allowing residents of Washington, DC, to vote in presidential elections.

Engineering as a Foundation for Optimum Safety Success

By William E. Tarrants

Reprinted from October 1961

At the time this article was published, William E. Tarrants, P.E., CSP, was an instructor and research associate at the Center for Safety Education, New York University. He was coordinator for the military training program and an instructor in the industrial and graduate safety education programs. During his career he also worked with the Bureau of Labor Statistics and the U.S. Dept. of Transportation. He earned a B.S. and an M.S. in Industrial Engineering from Ohio State University, and a Ph.D. in Education from New York University. Tarrants would become an ASSE Fellow in 1972 and would serve as its president in 1977-78. He also compiled and edited ASSE's first Dictionary of Terms Used in the Safety Profession, *which was published in December 1971. When he was named a Society Fellow, Tarrants was described as "perhaps the most prolific writer in the Society."*

AT PRESENT there is some controversy over what precisely is required to achieve the objectives of industrial safety. Some writers believe that there has been an overemphasis of the engineering approach at the expense of an appropriate consideration of management factors. Others contend that the objective of creating an optimum safe climate can be achieved most effectively through the application of engineering techniques as a primary approach to the solution of accident problems.

Essentially it is the perspective from which the safety practitioner's training and work activities are viewed that influences one's point of view.

Answers are needed to such questions as:

•What type of training best prepares a person to function as a safety specialist?

•What activities should the safety specialist perform?

•What are the anticipated requirements of the industrial safety specialist of the future?

Answers to these questions should lead us to a clarification of the present positions and provide guidelines for future optimum safety success.

It should be recognized initially that there is no dichotomy between the engineering and management approaches to safety achievement. While the safety engineer normally operates in a staff position, he needs a detailed knowledge of line functions if he is to effectively serve line managers. The many tools of the manager such as planning, organizing, coordinating, controlling and communicating are important to the safety engineer.

At the same time, the safety engineer has no direct managing authority in the line structure. His only authority is that of knowledge and the soundness of the information he provides. His success is a function of his ability to gather well-documented facts based

April 12
Yuri Gagarin is the first human in space.

April 17
Bay of Pigs invasion of Cuba begins, ending in failure April 19.

Roger Maris hits 61 home runs during the regular season, breaking Babe Ruth's mark of 60 that had stood since 1927.

December 11
Vietnam War officially begins as the first American helicopters arrive in Saigon along with 400 U.S. personnel.

December 15
An Israeli war crimes tribunal sentences Adolph Eichmann to die for his part in the Jewish holocaust.

Percy Faith wins Record of the Year Grammy Award for "Theme from 'A Summer Place.'"

May 5
Alan B. Shepard is first American in space.

May 25
President Kennedy announces before a special joint session of Congress his goal to initiate a project to put a "man on the moon" before the end of the decade.

Best Picture: ***West Side Story***

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on valid measures of safety effectiveness. His efforts must largely be directed toward providing line management with accurate decision-making information.

Ability to See Hazards

The safety engineer is a resource person who should possess as a basic skill the ability to perceive hazards which others without his orientation may overlook. His primary justification for existence rests with his ability to perceive problems and deliver sound information so that managers can properly weigh the safety aspects of their decision-making situations.

It is this environmental hazard perception capability that enables the engineering-trained safety specialist to seek the environment control solution as a first step toward optimum safety success.

Future applications of engineering knowledge to the control of work environments will allow the safety engineer to meet the challenge of technological advances. The engineer will be in the best position to adapt future work environments to the physiological and psychological limitations of man while keeping foremost in mind the functional requirements of production. What is needed is total industrial "climate" consideration, with the objective of reaching the optimally safe as well as efficiently productive man-machine-environment system.

Engineer the Environment

It appears that since human factors are frequent contributors to contemporary accident problems a preferred immediate approach would be to engineer the environments so that the probability of accidents involving human factors will be minimized. Of equal importance is the engineering of environments so that, when an accident does occur, the severity of the injury or result of the accident will also be minimized.

An important question for future safety effectiveness is: What type of training should the safety specialist receive in preparation for his engineering role?

In the more specialized industries where accident problems predominately arise within a relatively narrow, technical field, it would be most desirable for the safety engineer to have a rather strong background in the particular engineering specialty concerned. Thus, a company in the chemical industry might prefer a chemical engineer, while a company in the atomic energy industry might most profitably seek an engineer with a background in ionizing radiation.

For companies with diversified products and for most companies falling within less specialized industrial categories, it is suggested that courses pursued by the contemporary college-trained industrial engineer provide the best preparation for safety engineering work.

Industrial Engineering Curriculum

A glance at the major subjects included in the present undergraduate industrial engineering curriculum will serve to illustrate this point. The first two years of a modern five-year undergraduate engineering curriculum are basically identical for all major branches of engineering. The subjects of chemistry, engineering drawing, physics, mechanics and mathematics are included, as are courses in English and the humanities.

The last three years of the industrial engineering curriculum consist of courses which are well-suited to the safety specialist's activities. Included are such courses as:

- manufacturing processes;
- statistical theories and applications;
- advanced numerical analysis, including computer programming;
- physiological and industrial psychology and sociology;
- corporate organization and control;
- production engineering;
- industrial cost control;
- labor relations;
- industrial management;
- personnel management;
- industrial electronics and control;
- safety engineering;
- design of production systems;
- methods analysis and time study;
- work measurements and standards;
- plant layout and materials handling;
- electives in the humanities and social sciences.

ASSE began publishing a journal in 1956.

To celebrate 50 years of keeping SH&E professionals current in this dynamic field, each issue of Professional Safety *in 2006 will feature an article from a past issue of the journal.*

It is suggested that this educational background provides the safety specialist of today with an immediate functional capability, while serving as basic preparation for the task of optimizing future safety effectiveness.

It is recognized that limitations in environment or operational control capabilities result in the human factor playing a predominant role in many contemporary industrial accident situations. In some instances there are limitations on the degree of engineering control currently possible. In other cases engineering control may only asymptotically approach an ultimate total limit because of the desirability of retaining the human component in the system. Personal factors, therefore, will continue to require the attention of the practicing industrial safety engineer.

It should be noted that the industrial engineering curriculum suggested as foundation training for the safety specialist places strong emphasis on the human behavior or personal factor aspects of industrial operations. The engineering-trained safety specialist has many new techniques to call upon in his pursuit of industry's safety objectives. Some of these new techniques are found in the areas of human factors engineering, operations research, industrial loss control, and measurement and control theory. Human factors engineering is based on a recognition of the human as well as the engineering factors in industrial production operations. Emphasis is given to the study and solution of human problems associated with designs for mechanization, automation, and effective integration of man with his equipment and work environments.

National Safety Council *Accident Facts*, 1962 edition.

Application of the Scientific Method

Operations research involves the application of scientific methods to industrial problems. Using both theoretical and experimental models, operations research provides a scientific basis for solving complex industrial problems involving the safety aspects of scheduling, production line operations, traffic, machine breakdown and other exigencies.

The broad concept of industrial loss control through the application of engineering methods is far-reaching and should logically become an extension of the safety specialist's activities. Both accident and nonaccident industrial losses would be considered in this expanded loss prevention concept.

Included are such losses as machinery damages, increases in costs due to scrap loss, cost of reworked parts, and other losses largely the result of either acts of commission or acts of omission by personnel assigned to the multiplicity of industrial tasks. It is hypothesized that the same behavior which leads to accidents also leads to other industrial losses.

Improved Measurement Techniques

Finally, a problem area implied if not explicit in all phases of engineering and accident prevention is the need for improved measurement techniques. Measurement techniques involve an understanding of the measures by which we record, predict and control accident situations. Probably the least progress in the safety field has been made in this area.

Some questions which need answers are: How do we know when we have achieved a safe environment? How can we be certain our engineering efforts are sufficient to provide maximum safety? Are we receiving a feedback of information of sufficient quantity and quality to effectively guide us in preparing our safety programs? More sophisticated measures of safety effectiveness are needed to enable managers to determine the results they can expect from their safety expenditures.

A brief examination of two of the areas mentioned—human factors engineering, and safety measurement and control—may serve to emphasize the need for a conceptual expansion of the engineering aspects of industrial safety.

"Operator Errors"

A close examination of unsafe conditions related to an accident will often reveal ways in which engineering can be applied to reduce the possibility of "operator errors." Many so-called operator errors have been touched off by faulty design or construction, prescribed operating practices that create hazards, or lack of standardization and identification which so confuses the operator that he cannot avoid making mistakes. Often potential accidents have been built into machines, equipment and environments by a failure to properly engineer the workplace for maximum safe operation.

Human error or failure may occur in many of these situations, and environmental conditions or operating practices may predispose the worker to accidents (McFarland 1949). For example, the location of the power switch on many engine lathes requires the operator to reach across the revolving work piece in order to start and stop the machine. This practice continually exposes the operator to possible injury from contact with the rotating material and machine parts.

There have been many cases of an operator pushing the wrong button on an electrical control. One example occurred in a large bakery. Periodically, a man had to get into the dough mixers and clean them out. While the man was inside one of the mixers, he wanted to move the paddles very slightly. He reached out to press the inch button but inadvertently pressed the start button, and was killed.

Human Factors Engineering

In addition to established methods of combating accidents such as safety education programs, special protective equipment and enforcement techniques, there is a relatively new discipline, commonly called human factors engineering, which can be used to reduce both the frequency and severity of accidents by relating the design of equipment and control of environments to the biological and psychological characteristics of the operator (McFarland 1958).

Human factors engineering may be defined as the application of the principles, laws and quantitative relationships which govern man's responses to external stress to the analysis and design of machines and other engineering structures, so that the operator of such equipment will not be stressed beyond his proper limit of capabilities.

This definition implies that machines and work areas should be built around the human operator rather than placing him in a setting without regard for his requirements and capabilities (Hatch).

Dr. Ross McFarland of Harvard University has examined some of the safety aspects of this field (McFarland 1958). He has stated that machinery should be designed from the man outward, with the instruments and controls considered as extensions of his nervous system and body appendages.

More precisely stated, first, the engineer must have an understanding of the sense organs and the characteristics of human perception if satisfactory information is to be supplied in the operation of machinery and equipment. Second, the engineer must not place unreasonable demands upon the operator in regard to the physical responses involved, for example, in reaching for or operating a control or lever, or in clearly differentiating between two or more controls. Third, the engineer must consider that the operator of machinery and equipment is frequently suffering from temporary impairment of functions, such as fatigue, emotional stress and lapses of attention, with their resulting inefficiencies and operator errors. Finally, the physiological and environmental conditions such as temperature, humidity, toxic gases and other factors must be considered or physiological limits may be exceeded (McFarland 1954).

Engineering for Human Use

In one sense, human factors engineering can be thought of as engineering for human use. In a more specific sense, it can be thought of as the adaptation of human tasks and working environments to the sensory, perceptual, mental, physical, and other attributes of people (McCormick).

A first step in applying human factors engineering techniques is an advanced analysis of the equipment, the working areas and the job requirements. If defects or stresses are present it is only a matter of time before the operator-machine-environment system breaks down and an accident occurs.

An operational job analysis should include a survey of the nature of the task, the work surroundings, the location of controls and instruments, and the way the operator performs his duties. The errors that may occur while the operator is working at a machine should be anticipated. The repetition or recurrence of near or actual accidents clearly indicates a need for redesign (McFarland 1958).

Potential Hazardous Situations

Most typically, attempts are made to analyze case reports of accidents in order to determine what unsafe acts and unsafe conditions led to the event (Ghiselli and Brown). While it is of some help to identify these unsafe acts and unsafe conditions by means of analyses of reported accidents, it would be extremely helpful to know more about potential injury-producing situations before the injuries actually occur.

In addition, lost-time injuries and other injuries included in accident reports are relatively rare events, particularly in smaller organizations. A measurement technique is needed which will allow us to detect and analyze the causal factors involved in errors and near-accidents.

A method for measuring no-injury accidents called the critical incident technique has been reported by J.C. Flanagan. In applying this technique a person is allowed to recall and talk at will about "near misses" in his experience on a particular job. A collection of these critical incidents from several persons performing similar tasks is used to define problem areas and to make inferences and predictions about the persons performing the acts. Such data can assist in the advance detection of accident repeaters and the elimination of accident-inducing situations before an actual major or minor injury occurs (Chapanis).

Aircraft Accident Study

The critical incident technique has been used successfully by Fitts in his studies of pilot errors (Fitts). He was able to identify cockpit design faults which produced errors or near-accidents in aircraft operation. In one study it was found that confusion arises when controls for operating aircraft are located too close together or are reversed from one aircraft to another. This lack of standardization often resulted in the pilot grabbing the wrong control in an emergency.

Imagine the confusion resulting when the pilot, reaching for the auxiliary fuel tank, suddenly finds he had feathered his number one engine. The critical incident technique has also been used to define problem areas and detect "near misses" in fleet motor vehicle operations (McFarland and Moseley).

The human demands of increased mechanization and automation directly concern the human factors engineering aspects of industrial safety. Currently, progress in making operations largely or completely automatic is proceeding at an exceedingly rapid pace.

Reduce Physical Efforts

For the safety specialist, the mechanizing of production processes so that the physical efforts of operating personnel are reduced is a safety improvement. The human factors engineer must closely examine the demands on the operator in an automated system if he

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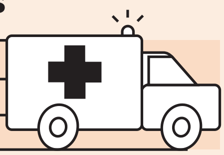
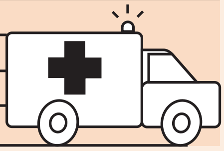
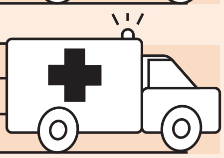
91,500 deaths and 9,300,000 disability injuries occurred in 1961.

PRINCIPAL CLASSES OF ACCIDENTS

Category	Deaths	Disability Injuries
Work	13,500	1,900,000
Nonmotor vehicle	10,800	1,800,000
Motor vehicle	2,700	100,000
Motor vehicle	38,000	1,400,000
Public nonwork	35,000	1,300,000
Work	2,700	100,000
Home	300	negligible
Home	26,500	4,000,000
Nonmotor vehicle	26,200	4,000,000
Motor vehicle	300	negligible
Public	16,500	2,100,000







**Note: Deaths and injuries shown for the four classifications total more than national figures shown because some deaths and injuries are included in more than one classification.*

National Safety Council *Accident Facts*, 1962 edition.

is to maximize safety effectiveness. Since there is an increased need for watching and listening to what the plant or machinery is doing, automation may actually increase the total informational load on the operator.

The fact that the operator of an automatic plant is often removed from direct contact with the process he is controlling emphasizes the need to consider thoroughly what information he needs to receive in order to perform his work accurately without error or accident. He must have unambiguous indications of what is happening and of the effects of his actions, as well as data which will enable him to be sure that his apparatus is working properly.

For example, the absence of significant events in the process should not be signaled merely by the absence of any indication but, rather, by a positive stimulus which will elicit a desired accident-free or error-free response (Welford). These, then, represent a few of the human factors engineering problems which should be considered in any long-range program for maximizing industrial safety effectiveness.

Safety Measurement Problem

The field of measurement and control is within the special competence of the safety engineer who has completed a contemporary industrial engineering curriculum. The safety measurement problem is probably the greatest single contemporary obstacle to immediate progress in industrial safety. We might define three basic problems which currently exist:

1) Measurement of accidents or the measurement of safety performance.

2) Prediction of accidents.

3) Control of accidents.

In order to predict and control accidents, we first need some way to measure them. Better, more objective answers are needed to such questions as:

- How good is our accident record?
- Where do our accident problems lie?
- How can we most effectively predetermine our safety budget requirements?
- How can we best use our available resources to achieve maximum safety effectiveness?

An initial step toward the development of improved measuring instruments might consist of a critical examination of the objectives of safety measurement. The adequacy of any instrument of evaluation must be appraised in terms of the purpose for which it is constructed.

Regardless of purpose, however, it is possible to postulate a number of characteristics of measuring instruments which will apply to most measurement situations. Such characteristics then may be used as standards or criteria in judging the effectiveness of a presently used or proposed measurement instrument (Wert, et al).

Desirable Measuring Technique

The following are postulated characteristics of a desirable measuring technique:

1) The technique should be administratively feasible to construct and use.

2) It should be adapted to the range of characteristics to be evaluated.

3) The units of measure on a scale should be equidistant throughout the range to be evaluated. This means that the difference between successive points on the lower end of the scale should be the same as

the difference between successive points on the upper end. For example, the difference between 12 inches and 13 inches is the same as the difference between one mile, one inch and one mile, two inches on a linear scale.

4) The technique should yield absolute rather than relative readings or scores. This means that the location of the zero point of the characteristic being evaluated and the zero point on the scale should coincide. For example, 10 pounds is just pounds heavier than an object having theoretically no weight at all. Contrast this with scores obtained from measurements of intelligence. If student A scores 50 and student B scores 100, we are not necessarily justified in concluding that B knows twice as much as A.

5) The fifth characteristic of a good measuring technique is sensitivity. It must be sensitive enough to detect differences and to serve as a criterion for evaluation. We would not weigh a diamond on a cattle scale, just as we wouldn't judge the effectiveness of a safety program by looking at a death rate alone.

6) The technique should be capable of duplication with the same results from the same items measured. In other words, it should be reliable or consistent over time.

7) The technique should be valid; that is, it should measure what it is supposed to measure.

8) Finally, the technique should yield readings, or scores, free from error.

Need Immediate Information

What are the major difficulties with present measures of safety performance? The presently used frequency and severity rates are not sensitive enough to serve as accurate measures of safety effectiveness. We need a more immediate report on the results of prevention efforts. The frequency rate, for example, does not immediately reflect improvements in safety program activities or modifications in work environments. The smaller the sample, the less reliable the frequency rate as a measure of accident prevention performance, particularly when less than the base number of 1 million man-hours are worked during the period.

Lost-time accidents, deaths and other reportable injuries are relatively rare events. Small units may go for a long period without a chargeable accident under the present reporting system.

There are problems related to the lumping of exposures from nonparallel hazard categories into the computation of a single rate. Consideration should be given to the problem of variation in exposure to different environmental hazards.

A single severe injury or death will drastically alter the severity rate in smaller organizations and thus it may not reflect overall accident prevention efforts and accomplishments.

Many accidents, particularly the less severe ones, are never reported. Information valuable for analysis and control purposes is thus frequently not included in the presently used measurement system.

More Sophisticated Methods

Better measures of engineering quality are needed. How do we know what degree of safety is actually present in a given environment? What are the criteria for a safe plant? How can we be sure our engineering efforts are sufficient to provide maximum safety? We need more sophisticated measures of safety effectiveness to tell us what we can expect from our efforts.

Measures are needed which are sensitive to noninjury accidents. This would be particularly valuable in hazard categories where the results of accidents exist on a continuum from no injuries or "near misses" to disabling injuries and even deaths. Accident causal factors revealed by an analysis of noninjury or low severity accidents could be used to guide our accident control activities.

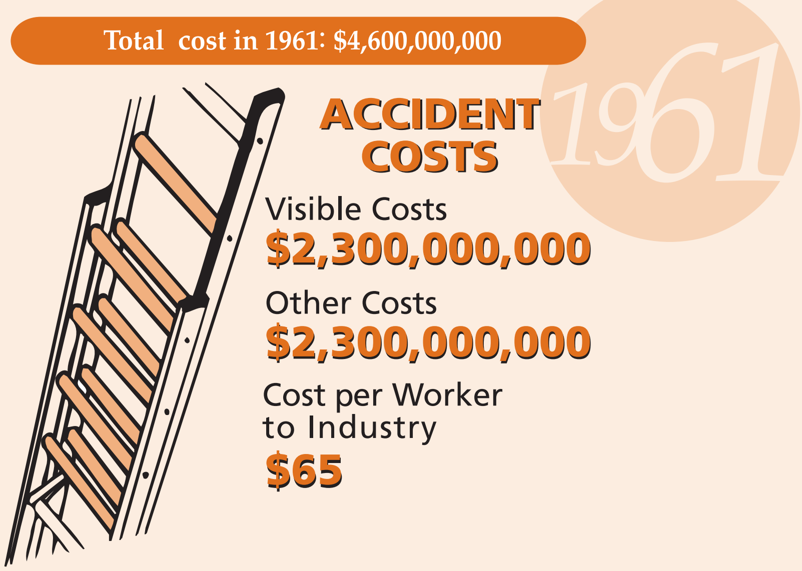
Measures are needed which will enable us to quantify personal factors influencing industrial safety effectiveness. Objective techniques are needed for use in evaluating the influence of top managers, first-line supervisors and union leaders on the workers' safety effectiveness. Some method is needed which will enable us to measure the interactions of individuals in these positions with the industrial workers in a given industrial climate.

Solutions Must Be Found

Solutions to these measurement problems should be sought by the safety engineer if the prediction, control and ultimate optimization of safety success is to be achieved.

It has been suggested that the primary approach to the achievement of safety success should be to engineer environments so that accidents cannot occur or will not have severe results in spite of thoughtless acts by individuals.

A first step toward optimizing safety success is the application of environment modification or engi-



**Other costs shown here include the money value of damaged equipment and materials, production delays and time losses of other workers not involved in the accidents.*

National Safety Council *Accident Facts*, 1962 edition.

neering techniques. Regardless of the attention given to other phases of an accident prevention program, if hazardous conditions continue to exist, human failures will eventually produce accidents.

While certain industries may require specialized engineering training for their safety specialists, it has been suggested that the contemporary college industrial engineering curriculum provides the best preparation for general safety engineering work. This course is designed to integrate systems of men, materials and equipment, and to specify, predict and evaluate the results to be obtained from such systems.

Accident Problem Perception

The practicing safety engineer is expected to possess, as a result of his training and orientation, an accident problem perception capability which will enable him to recognize situations where engineering solutions can be applied. The main justification for his existence rests with his ability to recognize problems and provide decision-making information for line management so that managers, being in direct control of the operating functions, can direct the accomplishment of the solutions.

We have barely scratched the surface in the application of engineering techniques to industrial safety problems. We should now direct our attention toward making the conceptualization of the safety engineer's work more explicit. What are the next steps?

Curriculum content with regard to safety engineering training should be explicitly defined. The responsibility of education should be to provide a sound basic engineering course with emphasis on human behavior as an important component of the industrial man-machine-environment system. The existing industrial engineering curriculum has been suggested as a framework for the academic development of future industrial safety engineers.

New areas such as human factors engineering, industrial loss control and operations research should be explored to determine how they may best contribute to the furthering of safety accomplishment. Continual attention should be given by the safety engineer to the development of improved measurement techniques so that accident prediction and control can be maximized.

And finally, research should be conducted to develop new techniques, new approaches and sound data which will reveal the truths of the industrial accident phenomenon. As the methods of production become more complex, research results should be ready to provide the guidance needed for optimum safety success. ■

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