4.

Safety Hazard Identification

LIST OF TABLES

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Safety Hazard Identification;

Many safety hazards are obvious: a punch press ram that descends every five seconds, a wet floor, an unstable ladder. This is true at least for the causes of acute injuries, though it is not necessarily true for cumulative injuries. In either case, what is often unclear is the complex of events through which the potential of the hazard is realized and an injury occurs. During this century the theory of the cause of injuries has evolved, and is still evolving, from attributing most injuries to "unsafe acts" of workers, to identifying conditions that increase the probability of an injury occurring. Under the first approach, the preventive remedy is to install perfect workers in jobs. Under the second—by identifying all possible contributing factors—preventive strategies can be applied, or at least considered, in different ways.

The causes of work-related injuries can be examined at two levels. The "macro" approach uses aggregate statistics, such as those produced in the Bureau of Labor Statistics' Annual Survey, to examine the distribution of various types of injuries according to several variables: industry, occupation, size of establishment, sex of worker, and others (see ch. 2, Working Paper #l). These distributions provide general clues to injury causes. The "'micro" level identifies specific injury causes. An epidemiological approach analyzes sets of similar injury-related incidents to find common circumstances contributing to their cause. At the most specific level, individual injury-related incidents are examined to determine cause; several methods have been developed at this level.

The nearly 4,100 work-related fatalities (including heart attacks) that occurred in private sector workplaces with 11 or more employees during **1982 were not evenly distributed over all industries (see table 4-1). Mining, accounting for 2 percent of employment, had 11 percent of the fatalities, Construction, 5 percent of employment, accounted for 18 percent of reported on-the-job deaths.** The wholesale and retail trades represent **25** percent of employment, but recorded only 12 percent of the fatalities. Finance, insurance, and real estate, along with the service industries, accounted for 31 percent of employment, but only 12 percent of fatalities.

A further breakdown reveals the injuries that resulted in death by industry categories, both by the distribution of causes within an industry category (see table 4-2), and by the distribution of each cause across all categories (see table 4-3). Overall, motor vehicle accidents account for 27

Table 4.1.–On-the-Job Fatalities by Industry Division, in Private-Sector Units with 11 Employees or More, 1982

	Annual average employment		Fatalities	
Industry division	Number	Percent	Number	Percent
Private sector (total)	62,629,000	100	4,090	100
Agriculture, forestry, and fishing	729,000	1	180	4
Mining	1,070,000	2	440	11
Construction	2,898,000	5	720	18
Manufacturing	18,267,000	29	770	19
Transportation and public utilities	4,629,000	7	970	24
Wholesale and retail trade	15,603,000	25	490	12
Finance, insurance, and real estate	4,252,000	7	100	2
Services	15,181,000	24	420	10

NOTE Because of rounding, components may not add to totals

SOURCE (608)

Table 4-2.—Causes of On-the-Job Fatalities in Private-Sector Units with 11 Employees or More, by Industry Division, with Distribution by Industry, 1981 and 1982[a]

Cause[b]	Total[c]	Agriculture, forestry, and fishing	Mining—oil and gas extraction only	Construction	Manufacturing	Transportation and public utilities[d]	Wholesale and retail trade	Finance, insurance, and real estate	Services
Total—all causes	100	100	100	100	100	100	100	100	100
Over-the-road motor vehicles	27	18	26	15	20	52	20	35	29
Falls	12	12	9	31	10	6	5	9	10
Heart attacks	10	6	8	8	10	6	12	23	16
Industrial vehicles or equipment	10	27	21	17	9	3	4	0	9
Nonaccidental injuries	7	3	<1	<1	2	2	30	8	15
Struck by objects other than vehicles or equipment	6	1	9	5	8	3	12	0	2
Electrocutions	6	16	4	11	5	6	1	0	5
Caught in, under, or between objects other than vehicles or equipment	6	1	3	4	5	9	8	17	2
Aircraft crashes	4	2	5	1	3	6	1	7	7
Fires	3	8	7	1	6	2	<1	1	<1
Plant machinery operation	3	1	1	2	10	<1	1	0	<1
Explosions	2	0	2	2	4	2	1	0	1
Gas inhalations	2	1	3	1	4	1	1	0	1
Another	3	4	3	3	4	2	3	<1	3

[a]It is impossible to estimate year-to-year changes precisely because at the industry division level sampling errors are large Therefore, the results are for both Years rather than a comparison between them.
[b]Cause is defined as the object or event associated with the fatality.
[c]Excludes coal metal, and nonmetal mining, and railroads for which data are not available
'Excludes railroads
NOTE: Because of rounding, percentages may not add to 100
SOURCE (608)

Table 4-3.—Causes of On-the-Job Fatalities in Private-Sector Units with 11 Employees or More, by industry Division, with Distribution by Cause, 1981 and 1982"

Cause[b]	Total[c]	Agriculture, forestry, and fishing	Mining—oil and gas extraction only	Construction	Manufacturing	Transportation and public utilities[d]	Wholesale and retail trade	Finance, insurance, and real estate	Services
Over-the-road motor vehicles	100	3	6	10	18	37	11	4	11
Falls	100	4	4	47	20	8	6	2	8
Heart attacks	100	3	5	16	24	11	18	7	16
Industrial vehicles or equipment	100	12	14	32	23	5	6	0	9
Nonaccidental injuries	100	2	<1	<1	6	5	63	3	20
Struck by objects other than vehicles or equipment	100	<1	10	16	33	8	31	0	3
Electrocutions	100	12	4	34	21	18	3	0	8
Caught in, under, or between objects other than vehicles or equipment	100	1	4	12	21	30	20	9	3
Aircraft crashes	100	2	9	6	22	32	6	5	19
Fires	100	12	15	8	46	14	1	2	2
Plant machinery operations	100	1	2	11	78	2	7	0	<1
Explosions	100	0	5	14	47	20	8	0	6
Gas inhalations	100	2	9	10	48	14	12	0	5
All other	100	6	5	18	33	13	16	1	8

[a]It is impossible to estimate year-to-year changes precisely because at the industry division level sampling errors are large Therefore, the results are for both Years rather than a comparison between them
[b]Cause Is defined as the object or event associated with the fatality
[c]Excludes coal metal, and nonmetal mining, and railroads for which data are not available
'Excludes railroads
NOTE Because of rounding, percentages may not add to 100.
SOURCE (608)

percent of fatalities, but in transportation and public utilities the figure is 52 percent. In construction, falls were responsible for a greater proportion of deaths (31 percent) than were over-the-road motor vehicles (15 percent), although *industrial* vehicles and equipment were associated with 17 percent of deaths.

Nearly half of all fatalities (47 percent) resulting from falls occurred in the construction industry (see table 4-3). Most fire- and explosion-related deaths in the work force (46 percent) and deaths from plant machinery (78 percent) occur in manufacturing. Additional sources of aggregate injury statistics are described in Working Paper #l.

Aggregate statistics can guide injury prevention by highlighting general hazard categories in specific industries. Immediate or underlying conditions related to an individual injury can only be determined through case study.

BASIC THEORIES OF INJURY CAUSATION

Traditional Approach—Unsafe Conditions or Unsafe Acts

In the 1920s, Heinrich proposed a theory of injury causation that many safety professionals have followed ever since. Simplified, the theory states a domino sequence:

- Injuries are caused by accidents.
- Accidents are caused by unsafe acts of persons or by exposure to unsafe mechanical conditions.
- Unsafe acts and conditions are caused by faults of persons.
- Faults of persons are created by the environment *or* acquired through inheritance.

Using this approach, Heinrich analyzed 12,000 cases of injury from insurance claim records plus 63,000 cases from the records of plant owners, for a total of 75,000 cases. Seventy-three percent of the injuries were classified as due to "unsafe acts" by workers. Heinrich noted that 25 percent of the cases examined would, according to the usual methods employed at the time, have been charged to defective or dangerous physical or mechanical conditions. However, he concluded that many cases in this group of 25 percent were caused either wholly or chiefly by worker failure, and only partly by physical or mechanical conditions. He decided to classify as "unsafe conditions" only those cases that were *wholly caused* by physical or mechanical failure. The injuries not wholly due to physical or mechanical failure (15 percent) were grouped with the 73 percent of cases that involved only "'unsafe acts." Thus he produced a well-known and often cited figure that 88 percent of injuries are due to "unsafe acts" by workers (380). Heinrich attributed only 10 percent of injuries to unsafe conditions and considered the remaining 2 percent of injuries to be unpreventable (207).

Critique of Traditional Approach

Arndt (24) has noted that, although there has been little research published to support Heinrich's theory of injury causation, Heinrich's ratio of 88 percent unsafe acts to 10 percent unsafe conditions is commonly cited. In fact, the published research on this topic uniformly refutes Heinrich's theory.

Heinrich himself pointed out two other studies. The first, by the National Safety Council (NSC), concluded that unsafe acts contributed to 87 percent of the cases examined, while mechanical causes contributed to 78 percent. The total of 165 percent is due to NSC's considering multiple causes of accidents. An analysis in 1940 by the State of Pennsylvania showed that an "equal number" of injuries resulted from unsafe acts and mechanical causes. Heinrich recognizes the discrepancy, which he attributed largely to the fact that the NSC and Pennsylvania studies allowed both an unsafe act and an unsafe condition to contribute to a single injury. Heinrich's methodology did not permit such multiple assignment of cause (207),

Table 4-4 presents a summary of other research aimed at apportioning injury causes between unsafe acts and unsafe conditions. Heinrich's study is the only one to attribute more than 35 percent of injuries primarily to unsafe acts by workers. The other research has generally categorized most injuries as resulting from a combination of unsafe acts and unsafe conditions.

Arndt **(24)** examined nearly 1,000 injuries associated with mechanical punch presses. He developed eight mutually exclusive categories to describe the circumstances of the injury. These included operator timing errors, inadvertent tripping of the press, other operator errors, tripping of the press by a second person, and machine malfunctions. He found that 53 percent of the injuries resulted from something other than machine malfunctions. All of that 53 percent would be attributed to "unsafe acts" in a dichotomous system, like Heinrich's, for recording causes of accidents. The machine malfunctions, including broken parts and accidental recycling of the press, which would generally be labeled "unsafe conditions, " amounted to 18 percent of cases. Arndt was unable to classify **29** percent of the cases because of a lack of information.

Thus, under the traditional breakdown between unsafe acts and unsafe conditions, about three times as many injuries in Arndt's study would be classified as due to unsafe acts rather than unsafe conditions. But Arndt observes that a very large number of those classified as "unsafe acts" occurred on presses activated by a foot pedal, by a one-hand control, or automatically. These presses allow operators to insert their hands inside the "point of operation" of the press. It is not surprising, then, that someday someone places a hand or arm inside such a press to adjust the piece being worked on or to clear a jam, and then is unable to remove it quickly enough. For example, if a press operator produces 5,000 pieces a day, then the operator's hands are placed in front of the press ram every 5 seconds, which means about **25,000** times per week or 1.2 million times a year (24). It may be only a matter of time before an operator commits an "error" and loses a finger in the press.

There are, however, machine designs that can reduce and nearly eliminate this particular hazard. Machines can be designed to operate with two-handed controls, so that the operator must have both hands on the controls. In Arndt's analysis, 60 to 70 percent of the injuries from presses activated by foot pedals, by one-handed controls, or automatically were related to "unsafe acts, " and only 10 to 20 percent related to "unsafe conditions. " For presses with two-handed controls, the fraction due to "unsafe acts" was only 35 percent. "Unsafe conditions" were cited in about 54 percent of these cases. Arndt's paper does not present any information on the injury rates associated with the various kinds of presses because data on the total numbers of each control type are not available. But it is clear that the design of the press has a dramatic affect on the number and percentage of cases attributed to "unsafe acts. "

The traditional partition between unsafe acts and unsafe conditions unfortunately often draws

Table 4-4.—Estimated Percentages of Accidents Due to Unsafe Acts versus Unsafe Conditions

Study	Percent due to unsafe acts	Percent due to unsafe conditions	Percent due to combination	Percent unknown
Furniss	—	16	84	—
Pennsylvania Department of Labor	2	3	95	—
National Safety Council	19	18	63	—
Mintz and Blum	21	—	79	—
Hagglund [a]	26	58	2	13
Hagglund [b]	35	54	4	7
Henrich [c]	88	10	—	—

[a] Investigations of reported fatalities.
[b] Random sample of accident reports
[c] Henric h classified 2 percent as 'unpreventable "

SOURCES (30,37,207,316)

attention away from the job or equipment redesigns that can remove or minimize hazards. In the 1959 edition of his textbook, Heinrich himself cautioned safety professionals not to neglect workplace conditions. He expressed confidence that safety professionals would not "ignore the very first common-sense step. . . of safeguarding [the] mechanical environment" (quoted in 462).

The catchall category of "unsafe act" or "human error" has greatly restricted advances in injury research and the application of control techniques in workplaces (380). The label "unsafe act" has, unfortunately, often led to a failure to recognize how the design of workplace equipment can minimize the occurence of "unsafe acts" or reduce the probability and severity of human injury.

The seriousness of this limitation is clear from one commonly used system for recording information about injuries. The American National Standards Institute (ANSI) Standard Z16.2, *Method of Recording Basic Facts Relating to the Nature and Occurrence of Work Injuries*, used widely for employer injury investigation and recordkeeping. ANSI itself sees inadequacies in its method, as the text of Z16.2 indicates:

> It is recognized that the occurrence of an injury frequently is the culmination of a sequence of related events, and that a variety of conditions or circumstances may contribute to the occurrence of a single accident. A record of all these items unquestionably would be useful to the accident preventionist.
>
> Any attempt to include all subsidiary or related facts about each accident in the statistical record, however, would complicate the procedure to the point of impracticability. The procedure, therefore, *provides* ***for*** *recording* ***of one pertinent fact about*** *each* ***accident in each of*** *the* ***specific categories or classifications.*** To insure uniformity in the selection of items to be recorded in each category, the items are specifically defined in terms which eliminate any necessity for decision as to the relative importance of multiple items falling in the same category (emphasis added).

Instead of collecting information on all the circumstances leading to the accident, the ANSI Standard Z16 allows "only one pertinent fact" to be recorded concerning the nature of the injury, the source of the injury, the type of accident, the hazardous condition present, and any unsafe act. This standard facilitates the administration of injury data collection because of its simplicity, but it is inadequate for research on causation. Unfortunately, the most common entry under this system is simply to attribute the injury to "worker error. "

According to Purswell and Stephens (380), attributing responsibility for accidents to human error, with no significant information as to why the error **was** committed, is not limited to the ANSI system. It is found in other workplace-injury data collection systems as well as those for collecting data on non-workplace injuries. For example, researchers in the field of highway safety have noted that there is no place on standard police forms to record many items that relate to features of the vehicle or the road that contributed to the injury. For the most part, these forms are oriented around recording information on the driver (41).

OTHER MODELS OF INJURY CAUSATION

Purswell and Stephens (380) describe a number of other models of injury causation and investigation. These include behavioral models, management models, epidemiological models, and ergonomic or human factors **models.**

Behavioral Models

The underlying concept of behavioral models is that of the "accident proneness" of individuals. Some safety specialists believe that a disproportionate number of injuries are incurred by a handful of individuals who are especially prone to accidents. Accident proneness has been, at one time or another, ascribed to recent immigrants to the United States, to certain ethnic/racial groups, or to certain personality traits (380). Thus efforts were made to identify these workers and either fire them or not hire them in the first place. Later researchers have been unable to find similar traits that will reliably predict which workers will be injured. Unfortunately, the belief that there are "injury-prone" workers is still commonly held. According to a Bureau of National Affairs (78) report, 65 percent of the businesses surveyed stated that their safety programs attempted to identify "accident-prone" individuals.

Other behavioral models have considered motivational factors, the rewards of working safely, and the level of satisfaction received from working safely *(368).* It has been observed that many workers perceive little positive reward for working safely.

Management Models

Bird (58) revised Heinrich's domino theory to emphasize management's responsibility for injury causation. His revised domino theory is:

- Injuries are caused by accidents.
- For each accident there are immediate causes that are symptomatic of problems in the overall system.
- There are basic causes in the overall management of the system that produce the immediate causes of the accident.
- The lack of management control permits the basic causes of accidents to exist in the system.

Bird's approach therefore shifted the emphasis from the worker as the cause of injuries to the management system in which the worker exists.

Zabetakis (684) of the Mine Safety and Health Administration Academy added the idea that injuries are due to an unplanned release or flow of energy, again following the approach of the domino theory. Energy release is considered in the general sense—mechanical, electrical, chemical, thermal, or ionizing radiation. Since unwanted energy flow is a fundamental source of injuries, Zabetakis claimed, a system maybe evaluated and improved by studying:

- the sources of energy existing in a system,
- the means available to reduce the energy levels,
- the means of controlling the flow of the energy, and
- the methods available for absorbing the energy should loss of control or improper flow occur.

The next major outgrowth of the domino theory was based on the idea that multiple factors can combine in a random manner to produce accidents and injuries. Such causation models focus not only on unsafe acts of the injured person, but also on unsafe acts of coworkers and unsafe conditions that existed at the time. Attention is ultimately drawn to failures in management systems that permit the multiple factors to converge and produce an injury.

One of the best known management-oriented approaches to accident causation is called the Management Oversight and Risk Tree (MORT), developed by Johnson (235) for use in the analysis of complex systems related to atomic energy. It could also be called a systems model (discussed later in this section). MORT employs a large schematic to inductively trace events of a work-related injury back in time, to identify the sequence of unwanted energy flow, and to evaluate the adequacy of barriers to unwanted energy transfer to persons or equipment. Along the route, hazards arising from specific accident circumstances, from risks acknowledged or assumed by management, and from general management systems and policy weaknesses are identified.

Still, several difficulties exist in adopting MORT to general injury investigation or applying it to most industrial workplaces. Its use as an industrial injury investigation procedure is limited by its complexity. The method is more suitable for investigating large-scale incidents, especially situations holding the potential for public disaster, such as nuclear powerplants. While it is an excellent approach for these situations, in its present form it is much less useful for explaining most work-related injuries. But it may be useful as a blueprint for the optimal allocation of resources for building a safety program (380).

Epidemiologic Models

Epidemiology has been described as the search for causal association between diseases or other biologic processes and specific environmental experiences or exposures. The epidemiologic model applied to injury research seeks to explain the occurrence of injuries within the system of host (injured victim), agent (means of injury), and the environment (physical, psychological, and social factors related to the event).

Using such a model, it should be possible to identify features common to a set of injuries or accidents, and either identify causes directly or find clues to causation. This approach has advantages over investigating each incident separately, Looking at a group of off-the-road industrial vehicle accidents, for instance, it might become apparent that one company's products are involved in a disproportionate number of incidents **(40).**

Gordon **(187)** and McFarland **(295)** were two early proponents of epidemiologic models of injury causation. Haddon (197) was successful in implementing an epidemiologic approach to transportation accidents while directing the National Highway Traffic Safety Administration. Baker and her coworkers (40) have successfully used epidemiologic techniques to describe work-related deaths in Maryland.

The epidemiologic method requires the collection and study of far more information about the host, the environment, and their interactions than the behavioral and management models do. This approach, which recognizes the interactive nature of the injury process, is a significant advance over earlier models. In fact, it has provided a framework for the application of many systems approaches that incorporate human operator variables, environmental factors, and task demands. The National Institute for Occupational Safety and Health is currently conducting two epidemiologic studies to evaluate the role of personal, managerial, and work environment factors in the etiologies of fall-from-ladder accidents and accidents that result in fatal injuries. Both are case-comparison studies that should produce a scientific assessment of these causal factors.

Systems Models

The emergence of systems engineering as a discipline in the 1960s gave rise to many new applications of systems theory, including systems safety. The various models that have been used include "failure mode and effects analysis" and "criticality analysis." Both these are largely oriented towards assessing the reliability of hardware and equipment. Another systems model, "fault tree analysis," involves building a logical "tree" of events that can lead to undesirable outcomes. The analyst examines component failures, which can include both hardware and human errors, and attempts to learn what might cause these failures and what effects on system safety they might have.

The systems-safety models have been applied most extensively in military and aerospace endeavors with the focus on potential failure points in system hardware. Few quantitative data exist about human error rates, so including the human component of this system is frequently precluded.

Ergonomic/Human Factors Models

The injury causation models developed by human-factors engineers or ergonomists attempt to provide insights into the problems of "unsafe acts" or human error that are lacking in other injury causation models.

Ergonomists generally analyze the interactions between workers and their machines for the sources of injury causation. The limits of human beings to perform consistently and without errors are important issues to the ergonomists. Rather than viewing operators' errors as merely "unsafe acts" that can only be addressed through training and motivation, the ergonomic approach looks to see if various features of the machine or the design of the work might themselves be inducing worker errors. These features can include the presentation of information to workers through displays, the design of machine controls, and the relationships between displays and controls. In addition, ergonomists analyze the physical capacities of workers, such as lifting or reaching ability, to determine whether the task places undue stress on specified parts of the body or leads to excessive fatigue.

Because of the importance of this discipline for the prevention of both acute trauma and cumulative trauma, as well as its potential usefulness in the field of general workplace and equipment design, ergonomics is discussed in greater detail in chapter 7.

CRITIQUE OF INJURY CAUSATION THEORIES AND MODELS

The inherent simplicity of Heinrich's domino theory and its historical availability no doubt account for its widespread acceptance. A minimum amount of training is required to understand its application and it does provide an answer to the question of "cause," even if it is a superficial one. Since most injuries are classified as resulting from "unsafe acts," it unfortunately allows more fundamental features of workplace design that lead to injuries to be ignored.

Behavioral models initially contributed to our understanding of the human component of injury causation, although approaches based on studying "accident proneness" have contributed little or no useful information for prevention. It is unfortunate that many firms still expend resources trying to identify "accident-prone" individuals, rather than pinpointing features of workplace design that lead to injuries.

The adaptations of Heinrich's theory that place the responsibility for unsafe acts and unsafe conditions on the management system of the enterprise represent a major step forward in preventing occupational injuries, The causal explanations are still too simplistic, although these approaches do provide a limited ability to predict the occurrence of hazards in the workplace.

The chain-of-events or multiple events models (MORT is an example) recognize that many factors influence injury causation and thus represent progress over single-event models. However, the current models do not have a sufficiently simple organizing structure to make them useful across a wide range of industries.

The epidemiologic model has value as an organizing framework for the systematic study of the factors related to various types of injuries. It is limited in that, in general, it cannot adequately explain why injuries happen or how corrective measures can be identified and applied.

The systems models have been developed primarily to evaluate system, subsystem, and component failures. The primary focus has been on nonhuman or hardware failures. Although the potential exists for incorporating human error rates into these analyses, the data to do so are currently very limited.

The human factors/ergonomics models focus on the human/machine interface and thus provide a much-needed emphasis on understanding the interaction of worker and machine in order to achieve a safe working environment. The thrust of the practice of ergonomics is designing the ***work tusk,*** rather than merely installing machinery and letting the worker find a way to adapt. Thus injury prevention can bean integral part of job design. The principal shortcoming of this model is the absence of any analysis of hardware failures beyond the human/machine interface. However, compared with the injuries that occur at that interface, hardware failures are relatively rare.

Purswell and Stephens (380) conclude that no single model provides a wholly satisfactory approach to explaining the various facets of injury causation. They suggest that, for the present, the epidemiologic model is useful for identifying major categories of causal factors in the workplace, and that these major categories should be studied in-depth using the human factors/ergonomics model.

The quest for causal models should not be the sole object of research on injury prevention. What is even more important is the design of interventions to eliminate or reduce the injury hazards faced by workers. In fact, one distinguished researcher has concluded that the search for causal models for injuries may ultimately be fruitless. Singleton has recently stated that "there can never be a theory which will predict an accident and even accident rates are subject to too many variables for prediction to be meaningful." But he adds:

> It does not follow that we must abandon hope of controlling accidents. The same problem occurs in other complex practical situations. The physician, for example, is often faced with a patient with a disease which he cannot readily identify. . . However, this does not mean that nothing can be done, The physician has certain general principles; the temperature must not be allowed to get too high, the body must not get dehydrated and so on. He can take action on the basis of these principles without waiting to identify the cause of the symptoms. Similarly in accident prevention we can take action to increase safety without waiting for a theory of accident causation (442).