CONTRIBUTIONS TO INDUSTRIAL
SAFETY METHODOLOGY

DISSERTATION

Presented in Partial Fulfillment of the Requirements
for the Degree Doctor of Philosophy in the
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By

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This study was undertaken to shed some light on the tremendously complex problem of accidents, and provide a different perspective toward this problem. Safety today is a subject of increasing significance in our society, affecting persons in all occupations. This work attempts to tie together past research on accidents and to develop a theoretical framework in which the myriad dimensions of the accident phenomena can be studied. In pursuing a problem of this magnitude, the sociological, psychological, mathematical, medical, and engineering aspects demand more explication than could be provided in this study. The intent here is to lay the ground work on which fundamental research in industrial safety can be developed, and to show where certain contributions in related disciplines are pertinent, and where additional contributions are required to better understand the accident phenomena. This study provides no answers for the safety practitioner, but it is hoped it will serve as a catalyst for future research effort which may eventually lead to greater insight into this critical problem. Only then will this work contribute to the minimization of accidents and their consequences.

Special acknowledgment must be given to Dr. Paul N. Lehoczky for providing the opportunity and the encouragement necessary to
bring this work to a conclusion. Dr. Loring G. Mitten's assistance in this work and his personal interest in the author's education has been particularly appreciated.

There is no way of measuring the inspiration, encouragement, and assistance of Betty Rockwell. Without her unselfish contribution as wife, editor, and typist, this work would never have reached its present development, or indeed have any meaning.

Thomas H. Rockwell
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Chapter 1.

INTRODUCTION AND ELEMENTS OF THE SAFETY PROBLEM
IN THE UNITED STATES

One of the most serious problems in our society today is the loss of life and productivity resulting from accidents. Accidents rank fourth among the leading causes of death for persons of all ages. The cost of accidents is conservatively placed at 10 billion dollars annually. Although the safety record in the United States has improved over the last 50 years, it still constitutes a serious problem. The total of 90,000 deaths and 9,000,000 injuries each year is indicative of our inability to live and work safely in our present society. It is paradoxical that a nation which has created such a high standard of living through great technical progress has failed to devise methods to protect its citizens. The accident problem is a universal one, touching persons of all ages, all occupations, and all nations. Considering the magnitude of the problem, there has been little research undertaken to effect a better understanding of the complex interrelationships of man, his environment, and the accident.

It is the intent of this research to explore a theoretical framework in which to study the accident phenomena. Emphasis will be given to industrial accidents although the analysis presented is generally applicable to any type of accident. Industrial safety has
been a stepchild of several disciplines—psychology, sociology, industrial medicine, and engineering. Because of the specialized efforts in these fields, research aimed at the whole problem has been conspicuously absent. In general, research in industrial safety has been avoided by industrial engineers, either because they consider the problem of safety only incidental to industrial engineering, or because safety is viewed in the same light as Time and Motion Study, where the role of the human operator acts as a deterrent to mathematical formulation and theory construction.

The initial part of this research brings the safety problem into focus, briefly tracing its progress from the turn of the century and tying together the scattered research contributions that have been made over this period. An attempt will be made to describe the basic philosophy in accident prevention today and to point out its weaknesses. Finally, a theoretical framework or model of the accident phenomena will be explored and its implications discussed.

It is not the objective of this study to review the safety literature or to consider any single aspect of the problem, such as accident proneness. The work which follows seeks to develop a model of the accident phenomena which relates the underlying mechanisms contributing to an accident; provide a framework for future study of the accident phenomena and suggest experiments to verify the hypotheses suggested by the model; introduce a logical basis for investment in accident prevention programs, and enlarge upon some of the potentially useful implications of the model which include criteria for comparing the
environmental hazard of various jobs, criteria for comparing safe operator behavior, and methods for maximizing safe job performance.

This study opens up an entirely new approach to the accident phenomena, demonstrating the relevancy of theoretical contributions in the associated fields of psychology, mathematics, and engineering. Sampling theory, statistical decision theory, human engineering, and feedback analysis play an important role in the interpretation of accidents. In its present development, the model offers no mathematical solution. Instead, it serves as a conceptual framework in which to better understand the mechanism behind accidents. In attempting to functionally relate the salient aspects of the accident phenomena, the tremendous complexity of the problem becomes apparent and in many instances formal structure is impossible. On the basis of the study, industrial safety emerges from the simple machine guarding problem to one of extreme complication involving engineering, psychology, and mathematics.

In general, it is hoped that this work will be a catalyst for further research on this and other models of the accident phenomena. Admittedly, theoretical research in this area is extremely difficult and less amenable to theory construction and measurement than other areas of industrial engineering. Nevertheless, the tools and methods of systems analysis recently developed in industrial engineering and operations research, together with progress in psychology and mathematics give promise of better understanding of accidents. The magnitude of the safety problem demands that fundamental research, using our best available techniques, be directed to this end.
Elements of the Safety Problem in the United States

Over-all accident problem

Each year there are approximately 9,000,000 injury accidents and 90,000 accidental deaths in this country. These figures include home, motor vehicle, and industrial accidents. On the average, there is an accidental death every six minutes and an accidental injury every three seconds of every day of the year. In the years of World War II, there were 300,000 Americans killed or reported "missing." In that same period, there were approximately 400,000 accidental deaths at home. War injuries totaled 650,000 while accidental injuries totaled 50,000,000 (31). In fact, there were more industrial casualties during the war years than there were military casualties.

Perhaps the repeated publication of staggering accident figures leads to public complacency and such apathetic statements as "accidents will happen." To most of us, however, any accident, whether a sprained ankle or one resulting in the loss of life, is a needless waste. For this reason the expression "carelessness" is often attached to accidents, not for purposes of establishing causal conditions, but to indicate an unnecessary waste of life or property. We no longer think of accidents as "Acts of God" as they were often interpreted prior to 1850. Despite the complicity in causal relations behind accidents, we know from retro-

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1The accident data presented in this section are estimates taken from The National Safety Council publication, Accident Facts - 1956 Edition (48).
spect that certain behavior or caution would have prevented most accidents. Perhaps it is the typical 20th Century American emphasis on efficiency in production as evidenced by our pride in being able to build hundreds of airplanes, air conditioners, and television sets each day that leads to the predominant attitude that accidents are wasteful and inefficient uses of our resources. This attitude is the foundation of the safety movement. The National Safety Council summarizes the motivation behind accident prevention:

The elimination of accidents is vital to the public interest. Accidents produce economic and social loss, impair individual and group productivity, cause inefficiency, and retard the advancement of standards of living. . . . On the practical side, there is the simple and obvious fact that accidents cripple industry and society. On the moral side, there are two related premises: the first, that needless destruction of human life is, of itself, evil; the second, that failure to take precautions against predictable accidents involves serious guilt. (49)

There can be no justification for accidents when it can be shown that they can be prevented. These moral and practical aspects of accidents are the basic motivating means for accident prevention, and are usually associated with humanitarianism on the one hand and the costs (usually dollar) of accidents on the other. This does not suggest that these two considerations which make up our present day attitude toward accidents are mutually exclusive. Needless waste suggests moral failure; destruction of human life involves a cost of lost production. The right to live and work without fear of injury is an accepted American way of life. Manifestations of this concern for the individual life can be found even in war machinery where United States military design heavily
accidents operational safety and comfort. United States jet aircraft are equipped with more fail-safe mechanisms, protective armor plate, and special arrangements to preserve the pilot's life (once the aircraft's loss is committed) than similar designs of other countries. Despite the American attitude toward the individual life, our record of violent and accidental deaths does not compare favorably with other countries of the world, as evidenced by the data in Table I. This data exclude automobile accidents which would be more unfavorable to the United States rate because of the 65,000,000 cars in this nation today. The favorable attitude toward the individual life is not compatible with the U. S. accident record. One might justifiably question the statistics and put forth questions regarding the kinds of accidental deaths included in the figures. One might also offer the suggestion that some of the countries possessing superior records are primarily agricultural and not industrial. Examples of this would be New Zealand, Italy, and Australia. However, the records for industrial nations as England, West Germany, and Japan are still better than the United States. Moreover, by U. S. records, agricultural accident rates are higher than the U. S. industrial average, which would suggest that this distinction is not particularly pertinent. One must conclude from the available data that the United States can take little pride in its safety record, despite the emphasis on the value of the human life.

The emphasis on the costs of accidents has lent greater pressure to accident prevention. Best estimates of accident costs place the 1955 figure at over 10 billion dollars, with 4 billion dollars in work
<table>
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<td>Saar</td>
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This latter figure is undoubtedly conservative since it uses an approximate 1:1 ratio of direct to indirect costs, and is taken from a sample of subscribers of the National Safety Council which primarily represents large companies and ones with progressive safety programs. Direct cost refers here to wages lost, insurance costs, and medical expenses. Indirect costs include the costs of lost production, time lost by workers other than those injured, and material and equipment damage. Studies by Heinrich (28) show a 1:1 ratio of indirect to direct costs. Other researchers in the field of accident costs indicate no ratio can be established to fit any one plant or industry type (60). In some situations an accident might idle a plant of several hundred workers. Most accident cost analysts, however, are convinced that a 1:1 ratio of direct to
indirect costs is conservative. The estimated cost of accidents has tripled in the past ten years. This is not the result of greater frequency and severity in accidents, but rather of the increased cost of living over the years. The cost of accidents from an industry or nationwide consideration is of little importance in motivating an individual plant. Enactment of workmen's compensation laws around 1912 provided a direct motivational element. Since insurance premiums in workmen's compensation laws are merit-rated on the basis of past accident claims, safe operation can result in a dollar payoff by the lowering of these rates. Such premiums constitute a considerable operating cost for many industries. Increased safety means a lower premium rate and consequently a direct savings to company operating costs.

Table II provides the best available picture of the United States accident record as measured by accidental deaths. Total deaths in themselves are not a true measure of the United States accident picture, since exposure to accident-causing environments has increased with the growth of the population, industry, and more important, the number of motor vehicles in use. The figure below shows the accidental death rate per 100,000 population from 1910 - 1955. Had the 1913 death rate persisted over the following 42 years, an additional 650,000 accidental deaths would have resulted. Despite this reduction in the death rate, accidents represent the chief cause of death for Americans of ages 1 - 36, and rank behind heart disease, cancer, and vascular lesion as the leading cause of death for Americans.
Accidents are typically classified by work, motor vehicle, public, and home. Public here refers to recreation, non-motor vehicle transportation, public building accidents, etc. Of the 93,000 accidental deaths and 9,350,000 accidental injuries estimated for 1955, work accidents accounted for 16% of the accidental deaths and 20% of the accidental injuries. Similar figures for the other principal classes are:

- **motor vehicle**: 41% of total deaths, 15% of total accidents
- **home**: 32% of total deaths, 45% of total accidents
- **public**: 11% of total deaths, 20% of total accidents

The total number of accidental deaths each year has increased slightly from 82,500 in 1913 to 93,000 in 1955. This has been the result of a 28% decrease in non-motor vehicle deaths and an 810% increase in motor vehicle deaths. On the basis of the death rate (deaths per 100,000 population) which reflects the population growth over this time, the
<table>
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*Change in death classification system, first figure comparable with earlier years, second figure comparable with later years.
over-all accident picture is somewhat encouraging. The death rate has decreased 29% from 1913, resulting in a 56% decrease in the non-motor vehicle death rate and a 500% increase in the motor vehicle death rate. The phenomenal increase in the motor vehicle death rate is better understood in light of a six-fold increase in the number of cars on the road from 1921 to 1955 (10.5 million to 65 million). Moreover, if vehicle miles are used as a measure of exposure, the mileage death rate has actually decreased from 25.3 deaths per 100,000,000 miles in 1926 to 6.4 deaths per 100,000,000 vehicle miles in 1956. The above figures suggest that although the total number of accidental deaths has remained relatively the same over the past five decades, the death rate has been decreasing. The safety movement over the past 50 years has directed considerable effort to reducing the severity of accidents. In industry, accidental deaths are rare events. In motor vehicle design, recent emphasis has been not to reduce the frequency of accidents but to lower the frequency of fatal accidents. Deep set steering posts, padded instrument panels, safety door locks, and seat belts represent this emphasis on minimizing the severity of motor vehicle accidents. More representative of the accident picture than fatalities is the frequency of accidents. In 1955 there were 9,350,000 accidental injuries in the United States. The National Safety Council estimates for accidental injuries from all causes have changed little over the past 13 years. The 1947 estimate was 9,800,000 injuries compared to 9,300,000 in 1955. This slight total decrease, however, means a considerable
decrease in the rate of accidental injuries in light of population increases and increased motor vehicle miles driven. Although present accident figures are gigantic in magnitude, some consolation can be given for the decreasing accident injury and death rates.

In summary, accidents in the United States are a far more serious blot against our nation's record than any of the past wars engaged in. Wars can sometimes be justified on the argument that they are defensive measures or attempt to make the world "safe for democracy." Accidents have no justification; they serve no purpose; the losses resulting from them are irretrievable. In number, accidental deaths and injuries have not changed perceptibly over the past several years. Injury and death rates have shown steady decrease since 1913. Increased safety at home and work has been offset by increased motor vehicle accidents. If the supposition that "accidents can be prevented" is true, then there appears to be considerable room for improvement in all areas of safety.

Work accidents

In 1955 work accidents accounted for 11,200 deaths and 1,900,000 lost-time injuries. A lost-time injury is defined as an accident which causes a worker to miss his next regularly scheduled shift. The National Safety Council estimates that 235,000,000 man-days were lost by injured workers and others who were forced idle because of accidents. This amounts to almost 1,000,000 man-years or approximately 1/60 of our total work force. (Agricultural deaths and injuries are not included in these estimates.) The average industrial accident costs the worker
$50 in wages lost, and all work accidents incurred an estimated cost of 4 billion dollars.

Of all the principal classes of accidents, industrial accidents have shown the most substantial progress in accident reduction over the past 50 years. The usual measure of accident frequency in industry is the accident frequency rate, which is defined as the number of lost-time injuries per million man-hours worked. The industry-wide frequency rate has dropped from 31.0 in 1926 to 6.95 in 1955. Before 1926 no adequate records are available, but samples from several industries indicate the frequency rate before 1926 was considerably larger than 31.0. The usual index of severity, the accident severity rate, shows a similar reduction since 1926. The accident severity rate is the number of days lost as a result of accidents per 1,000,000 man-hours worked. Special time charges exist for those permanent partial injuries based upon the expected decrease in worker productivity. (A permanent partial injury is one in which permanent loss of a body member is incurred.) For example, the loss of an arm is charged 250 days; an industrial death is charged 6,000 days. This latter figure resulted from a study which showed the average industrial death occurred to workers in their middle thirties who would have had approximately 24 more years or 6,000 days of work ahead of them had the death not occurred. The severity rate does not always reflect a true picture of the time lost by accidents since many accidents, such as partial loss of a finger, do not actually result in the time lost as set up by the table of time charges. However, the time lost on the day of the accident is not
included. This would have a tendency to offset some of the discrepancy caused by permanent partial injuries. The accidental frequency and severity rates are plotted in the figure below for 1926 to 1955. If the subscribers to the National Safety Council are representative of industrial organizations as a whole, then it would appear that considerable progress in accident prevention has been made in industry in the last 20 years.

Unquestionably one of the chief factors in this reduction in work accidents has been the influence of federal and state legislation. In 1913 several states passed workmen's compensation laws which in effect placed the responsibility and liability for accidents on the employer, and guaranteed a fixed compensation for the injured worker and payment of all medical expenses. Today all states have workmen's compensation laws which require the employer to insure himself against accident claims, either privately or through state insurance funds. The fixed compensation levels, however, vary among states. Payment of insurance premiums is dictated by two factors:
1. the present claim experience for the particular industry
2. the accident experience of the particular employer as measured by the total claims paid out to his employees over the past 1-5 years

This method of insurance against accidents provides a direct dollar motivation to the employer. Fewer accidents mean fewer claims, which in turn mean a lowering of premiums. In some hazardous industries, such as tunnel excavation, these premiums amount to 50% of the total labor cost. In all industries such premiums must be considered as a significant operating cost.

Prior to 1913 employers resorted primarily to three common law defenses against accident claims made by their employees. First, they argued that the employee assumed the risk of being injured when he accepted employment and hence had no claim if injured on the job. Second, the employer often argued that the employee was negligent in the performance of his work and contributed to his own accident. Third, in many cases the employer pleaded that a fellow employee was responsible for the accident, and that suit should be made against this employee rather than the company. The use of these common law defenses resulted in few successful claims against the employer. Employees could not afford to hire legal assistance in the pursuit of their claim, and even if one were fortunate enough to win a suit against his employer, the award usually was one to two years after the accident, during which time the employee was often a burden on public or private charity.

The validity of state workmen's compensation laws was soon put to test. In 1913 - 1915 the United States Supreme Court ruled in the
White versus New York Central Railroad case that the individual states did have the right to protect their citizens through workmen's compensation. The decision of the court was unanimous. The court argued:

... neither in rendering employers liable irrespective of common law defense... nor in depriving the defendant of higher damages which might be recovered under common law doctrine can the compensation law be said to violate due process. Since such matters of compensation for disability or death... is of direct interest to the public, the liberty of the employee and the employer to agree upon such compensation is subject to be restricted by the state police power... In the opinion of the court, common law defenses are based upon fiction and unapplicable to modern conditions of employment because accidents are so complex and obscure it is impossible to ascertain facts and form accurate judgments. The process of common law is so expensive and prolonged that it defeats natural justice. (64)

Unlike other social legislation, workmen's compensation laws were rarely tested again in the Supreme Court. Regardless of blame, the employer was responsible for all accidents in his plant. In addition, the states set up codes to maintain minimum safety levels in industry. These codes applied to special processes, machines, materials, building construction, and operating procedures. Failure to meet these codes resulted in fines and possible closure of the plant.

Compared to state influence, federal legislation has played a minor role in accident prevention. Certain acts, such as the Davis-Bacon Act of 1933, stipulated government contracts could be awarded only to those plants which demonstrated an adequate safety staff. Wage and hour laws for women and children have contributed to safe operation. The federal government in general acts as a clearing house for safety information, maintains accident statistics, provides
assistance to states by way of technical training, and promotes research.

Table III shows the variation in frequency rates between industries and the difference between the two data sources, the National Safety Council and the Bureau of Labor Statistics. Note the Bureau of Labor Statistics frequency rate is higher than the National Safety Council frequency for 77% of the 40 industries reported. In almost all cases, the Bureau of Labor Statistics sample size of reporting industries is larger than the National Safety Council. Table III is also remarkable proof that extensive accident prevention programs can pay off with low accident frequency and severity rates. The automobile industry which for years has accentuated safety measures, has a frequency rate less than half the industrial average. Certain industries, by virtue of inherent hazards, have high frequency and severity rates, such as lumber and underground mining. The cement industry has a relatively low frequency rate and a high severity rate. The average time charge per accident was 500 days. This is characteristic of an industry with a small number of severe accidents. On the other hand, the leather industry has a relatively low severity rate and an above average frequency rate, which suggests many lost-time accidents of a temporary or minor disability. Examination of frequency and severity rates can often point to the emphasis needed in an accident prevention program. Because of their complicity, accidents are difficult to predict from such mass statistics. In general, these statistics present an average picture for an industry. Plant to plant,
<table>
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<td>Wood Products</td>
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Source: The National Safety Council publication, Accident Facts - 1956 Edition (46), and Ohio Industrial Safety Record, Issue No. 4, 1956 (52)
state to state, and department to department variations exist because of the functions performed, processes used, type of labor force, etc. Examination of the Ohio Industrial Safety Record (52) reveals that there is considerable difference between state industrial frequency and severity rates and National Safety Council and Bureau of Labor Statistics rates for the same industry. (See Table III) Much of this difference might be ascribed to sampling error and to the emphasis given toward safety in the individual state. Mass statistics are rarely useful as a basis for action by an individual plant, but serve rather as a basis for comparison and for insurance purposes.

In summary, the industrial accident record has become progressively better over the past 20 years with decreases in both accident and severity rates, but there is considerable room for improvement. The yearly total number of work injuries and deaths over the past years has remained relatively constant at approximately 11,000 deaths and 9,000,000 injuries. The decreased rates result primarily from the increased worker population. Accident costs are rising with the spiraling wage and price indices. As industry becomes more automated, shutdowns in production as a result of accidents will become increasingly more costly. Improved safety designs and better medical attention have been in large measure responsible for the decrease in accident severity, but the staggering figure of 235,000,000 man-days lost from industrial accidents leaves much to be desired. The figures presented above have been given primarily to emphasize the magnitude of the problem, and in some sense to justify the need for basic research in the accident
phenomena. In a country as advanced as ours, there is no justification for disdain of human life or the needless loss of productivity. Individual plants demonstrate each year that accidents can be prevented. Many industries can show plants that have exceeded 15,000,000 man-hours without a lost-time injury. Even in industries known to be hazardous, such as construction, as much as 7,000,000 injury-free man-hours have been worked. Studies have been made indicating that safety and efficient production are highly correlated (28). The old notion that "safety first means production last" has been successfully dispelled by countless cases of companies with low accident rates. Aside from its humanitarian aspects, accident prevention is just good business and a sensible means of cutting operating costs.
Chapter 2.

CURRENT INDUSTRIAL SAFETY METHODOLOGY

The prime objective in the field of industrial safety is to develop operating procedures, design equipment and work areas, and elicit worker behavior which will minimize the frequency and the severity of accidents. Safety methodology presently consists of the assignment of remedial action once an accident has occurred, in order to prevent ones of a similar type in the future, and the establishment of long range programs on the basis of past accident information which will prevent future accidents. The first might be considered symptomatic, the latter preventive. Accident prevention methods are based upon the accident diagnosis. This diagnosis in essence is a qualitative analysis of the events surrounding the accident. Those conditions which are directly responsible are corrected. Those conditions which appear indirectly in many accidents are modified through either engineering changes, education, or disciplinary action. Present-day safety methodology is characterized by several distinguishing features:

1. It is deterministic -- accidents are caused by specific job conditions and specific worker acts. Removal of these conditions and/or acts removes the accidents. It has a cause and effect basis, using qualitative classifications.

2. Decisions to initiate various accident prevention programs are not based upon an expected dollar return, because the costs of accidents have rarely been adequately estimated.
3. In terms of its methodology, accident prevention is essentially an art rather than a science.

4. Most accident prevention programs attempt to modify accident behavior on a mass basis rather than on an individual case, seeking to maximize the over-all gains (reduction in total accidents) rather than "individual performance."

5. No adequate records exist to properly evaluate possible predictors of accident behavior that could be administered upon hiring.

6. No descriptive model of the accident phenomena exists which can establish explicit environmental and behavioral interrelations.

7. Remedial action as a result of accidents is predominantly trial and error.

Faced with such an extremely complex phenomena as accidents and the pressing need to reduce their number, accident preventionists have understandably resorted to a rather straightforward approach to accidents and necessary remedial action. The position taken by most specialists in industry is that the typical accident results from either an unsafe act on the part of the operator, an unsafe condition, or more likely, both of these situations. Studies have been made which suggest that 85% of all accidents are the result of unsafe acts and 15% are the result of unsafe conditions. The National Safety Council, in the examination of the accidents of their subscribers, found that in 95% of all accidents reported, both an unsafe act and an unsafe condition were present.

Considerable emphasis in safety today is concerned with this causal classification of accidents. Behavioral subcauses, such as worker attitude, job knowledge, etc., which precipitate unsafe acts have also been explored. The National Safety Council has endorsed
this classification of accidents and the American Standards Association
has prepared the code, ASA-Z16.2, "The American Recommended Practice
for Compiling Industrial Accident Causes," which classifies unsafe acts
in the following general categories:

1. using defective or unsafe tools or using tools unsafely
2. unnecessary exposure to danger
3. overloading, crowding, poor arrangement
4. failure to use safety or protective devices
5. working on moving or dangerous equipment
6. operating at unsafe speeds
7. operating equipment without authority
8. distracting attention, teasing, abusing
9. making safety devices inoperative

Although such uniform classifications provide a common basis for comparing accidents, certain problems arise regarding the use of such information in accident prevention programs. Does knowledge of an employee's unsafe act indicate the remedial action? Does operating at unsafe speed dictate education, discipline, placement, or dismissal as the cure? Is there any reason to suspect that the operator's behavior is manifested only in this type of unsafe act? Accident prone theorists would argue that if the worker were removed from his environment and placed in a position where he could not operate equipment at unsafe speeds, his behavior would be exhibited in some other kind of unsafe act. It is doubtful the unsafe act involved in the typical accident could be classified in a particular category. It is more likely
to be a complex combination of unsafe acts. The categories given by the American Standards Association are not necessarily independent nor collectively exhaustive.

Three of the paramount problems in safety are the measurement, the control, and the prediction of accidents. The latter does not imply that one must understand the underlying mechanism behind accidents. Companies have initiated safety campaigns and achieved predicted results from them without knowing completely how these results came about. In safety as exercised in industry today, the prediction problem is usually avoided and emphasis is placed upon control or methods to reduce the number of accidents.

The measurement problem is usually concerned with counting the number of accidents in the causal categories. An accident is defined as an unplanned event which interrupts production and could or did cause personal injury. This definition, proposed by Simonds and Grimaldi (60), is one which does not meet general acceptance in industry today. The measurement of no-injury accidents is rarely made. There are several practical reasons for this. Often the operators are not aware that a particular event could cause injury. Moreover, few companies see the value in maintaining records on "close shaves" or events in which no accidents occur, since these happen with regularity on many jobs. Actually, whether or not production is disrupted may not be a justifiable criterion for identifying an event as an accident. Simonds and Grimaldi suggest that this distinction is to avoid compilation of minor cuts and bruises
which do not require absence from the job. A real problem exists in determining whether an event might have caused personal injury. The operator might significantly change his behavior in risk-taking situations and it would be difficult to attach a probability of injury to that event. Most available accident records include only those cases where injury results. In fact, many companies maintain records only on lost-time accidents. Those minor injuries which require first aid can be measured by trips to the first aid station in the plant if one can be assured that the employees would use such stations. In the small plant the employee will often self-administer the injury or completely ignore it. Moreover, studies in large plants indicate that as high as 60% of the dispensary calls were for non-accident reasons such as hangovers, headaches, and upset stomachs. Under present methods of accident reporting, use of first aid cases as a measure of safety would require careful screening.

Direct measurement of past accidents is not necessarily ideal. Theoretically, a behavioral prediction would allow early remedial action to avoid the occurrence of accidents. Some studies have been made to measure the safety level of a plant by the proportion of unsafe behavior observed rather than the actual number of accidents. By optimizing the worker's behavior, one can minimize the probability of an accident. The practical problem here is to be able to measure unsafe behavior. Some acts are obvious instances of safe behavior, while others are clearly instances of unsafe behavior, e.g., failure to wear safety goggles on a bench grinding operation. Between these
extremes there are instances of behavior which would be difficult
to classify as either safe or unsafe. The idea of measuring be-
havior and not the result of this behavior is particularly promising,
and will be considered in more detail later. An analogy to measurement
of behavior rather than accidents applies to the measurement of potential
unsafe job conditions rather than the possible effect of these conditions.
Inspection often plays the role of ascertaining future unsafe conditions.
Inspection of cables, hoists, machine guards, etc., serves to detect the
unsafe condition before it occurs or before it becomes serious. Just
as inspection in quality control is performed to minimize the production
of poor products, so also safety inspections are performed to minimize
unsafe conditions and the resulting accidents. Except in progressive
companies, the usual measurement in safety is not the conditions which
could lead to accidents, but the accident itself.

Accident measurement consists principally of describing the
accident and tabulating the relevant events associated with it. Chief
among these are such pieces of information as time, place, part of
body injured, agency, type of unsafe act, past operator experience,
etc.

Remedial action on a company's part takes place at either the
immediate operational level or at the plant level, and either immediately
following the accident or later, after information from several accidents
has been analyzed. The typical post-mortem procedure is to apply im-
mediate corrective action after the accident. This often consists of
discipline, hurried fabrication of a guard, change in operating pro-
cedure, or in some cases, cessation of similar operations. Action of
this type is based usually on a single sample. Where the cause of
the accident is obvious, such action is desirable to minimize like
accidents in the future. Unfortunately, this approach is based on
limited information about the accident and relies upon judgment rather
than data. Underlying causal mechanisms behind this and previous acci-
dents often go undetected. This particular method of accident prevention
is not necessarily efficient, since it occurs after the accident and on
the basis of limited information. This is typical of the approaches
taken by small firms where the front line supervisor is responsible for
safety in his department. Remedial action at this level is often not
communicated to other departments in the plant and this type of accident
may be repeated elsewhere at a later date.

For those organizations with safety directors or safety staffs,
remedial action, unless absolutely required, is withheld until the
specific accident can be related to past accident information. Often
no action is taken until sufficient information becomes available to
warrant a rather broad policy for all operating levels. Moreover, as
specific accident behavior becomes identified in many accidents in the
plant, special safety campaigns may be launched to adjust this behavior.
Typical of this situation is one in which an extensive "safety goggle"
campaign is initiated after several eye accidents. Although this ap-
proach to accident prevention is based upon a larger sample size of
surface information, it is still "after the fact." It assumes that
causes of an accident are identified, and that remedial action will
minimize or eliminate those causal situations which lead to accidents.
Essentially, most accident prevention programs attempt to modify behavior and only indirectly to reduce accidents. It is usually the function of the engineering department working in conjunction with the safety department to maintain safe working conditions. In most plants it is almost impossible to design accident-free job conditions for any type of operator behavior. Even with guarded equipment, workers will still have accidents, either by removing the safety device or by eliciting behavior which results in accidents in spite of mechanical guards.

Because control measures in accident prevention are essentially trial and error methods, and accidents are described by causes rather than measured relationships, prediction of future accidents is practically impossible. Prediction is possible when one views the plant or industry as a whole and uses as a criterion measure the accident frequency or severity rate. Even on these gross terms the reduction in accident frequency as a result of a specific safety program cannot be successfully predicted in advance. The difficulty in the prediction of accidents is not hard to understand in light of the present state of the art. Considerable theoretical development, better description of the accident phenomena, and more meaningful measurement are required before accurate prediction of accidents is possible.

The traditional safety methodology described above is essentially empirical. Its basis is an estimation of conditions preceding the accident event. If \( A \) is the accident event, and \( Y_1 \ldots Y_n \) are a set of conditions (variables) surrounding this event, \( Y_1^* \) is said to be causally related to \( A \) if \( Y_1^* \) precedes \( A \) and is highly correlated with \( A \). This
assumes that errors are uncorrelated, i.e., all other variables influencing $Y_i$ are uncorrelated with all other variables influencing $Y_i^*$. This rules out the condition of $Y_i^*$ being an intervening variable which would correlate with $Y$ and the true cause $Z$. On-the-spot safety diagnosis and prescription is based upon a single size sample and hence correlation of $Y_i^*$ to $Y$ is an implied or subjective one based upon the experience of the person prescribing the remedial action. It is certainly possible that such on-the-spot prescriptions are accurate. The difficulty enters when one wishes to extend this analysis to other accidents or to form a policy for action in the future.

More advanced safety departments have used larger sample sizes on which to direct action at the plant level. Here the correlations may be statistically computed, or more commonly, subjectively derived. Again the assumptions of the precedence of $Y_i^*$ to $Y$ and uncorrelated error must be made to imply a causal relation. Generally speaking, the conditions surrounding accidents are not accurately measured and hence statistical analysis of the dependence of the two variables is rarely attempted. In fact, in the case of industrial deaths, the usual situation is one in which the person capable of describing the accident is permanently unavailable.

The formal approach to accident analysis which is rarely undertaken involves the construction of a model describing the accident and any cogent variables associated with it. These variables are manipulated mathematically to produce relationships which can be tested experimentally or corroborated by past data. Much of the work in accident prone theory
makes use of this approach. Unfortunately, it is difficult to design controlled experiments simulating the accident situation. Consequently, most hypotheses on accident phenomena have been developed in retrospect, based upon a mass of accident data from a particular plant over the previous years. Serious problems result in attempting to extend these results to other industries.

The search for causes is a teleological problem and one which is traditionally avoided by scientists. In accident analysis, it is almost impossible to test causal hypotheses. The general methods of determining causes are:

1. The method of agreement -- A series of different accidents all involved a common factor, e.g., excessive operating speed.

2. The method of differences -- Two jobs differ in only one factor. The one containing the factor has a high accident rate while the other has a low rate.

3. The method of concomitant variations -- Variation in illumination results in a parallel variation in accidents for the same job.

These are exercised on intuitive rather than objective grounds. Despite the mathematical and scientific limitations with causal analysis, it still represents the primary methodology in safety. Its difficulty is severely increased by the general lack of understanding of the accident phenomena.

The present-day approach to accident prevention can be classified by time and direction. Time-wise, accident prevention methods are applied

1. immediately following an accident
2. after the occurrence of "n" like accidents
3. at regular time intervals
4. with upward changes in frequency or severity rates

These methods are directed toward a particular type of job, a series of related jobs, complete departments or the plant in general, or specific types of equipment. The cause and effect model described might be illustrated in the figure below.

**Fig. 3.** - The cause and effect model of accidents
If there exists a set of environmental states of the job $E_i$ consisting of a set of operator responses $U_j$ and a set of job conditions $C_k$, then for each $E_i$ there is associated with it a probability $P_{ir}$ of an accident or severity $r$. Each $E_i$ is composed of response $U_j$ in a job setting $C_k$. Each $U_j$ is functionally related to an $S_p$ which is a set of behavioral subcauses. In the usual accident analysis, the environmental condition is dichotomized as either safe ($P_{ir} = 0$) or unsafe ($P_{ir} = 1$), (usually an accident or a no-injury accident.) For those which are classified as unsafe, the specific $U_j$ and $C_k$ which make up these $E_i$ are identified and described, according to the American Standards Association code. Those $S_p$ which are identified with $U_j$ are hypothesized. The action taken as a result of such identification is to modify $S_p$ to effect changes in $U_j$ which will in turn bring about safe environmental conditions ($P_{ir} = 0$). On the other hand, engineering action may be evoked to elicit changes in $C_k$ to effect a change in $E_i$ to a more favorable (safer) state.

In most safety departments the tendency is to assume single valued functions for $E_i$ to $U_j$ and $C_k$, and $U_j$ to $S_p$. The problems associated with this oversimplified model of the accident phenomena are many:

1. It assumes all the pertinent $U_j$, $C_k$, and $E_i$ can be listed and identified. In some accidents they may be easily identified, e.g., a cable breaks, a grinding wheel disintegrates, an operator fails to wear protective clothing, etc. In those situations in which the
operator regulates the job conditions, it is more difficult to specify a cause. For some unsafe acts there are various degrees of risk involved, and in many cases behavior is manifested by several interdependent unsafe acts. In particular, specification of the $S_p$ which is said to cause the $U_j$ is presumptionous. Attitude, for example, may be the consequence of rather than the cause of certain responses. Attempting to find the cause behind behavior is not as simple as the model would suggest. The science of psychology, which is concerned with the problem of human behavior, has yet to unravel the causal mechanism behind behavior.

2. The mechanisms used to modify the behavioral subcauses are only intuitive and based upon past experience. It is virtually impossible to predict the effects of safety educational programs on the frequency of particular unsafe acts. Psychologists argue that certain programs may create a negative rather than positive effect. The classic instance of this is the use of morbid pictures; although they may have a salutary effect on workers with a strong self-preservation drive, they may terrified others and produce jumpy, uncontrolled responses.

3. The causal model assumes no interaction between job conditions and operator responses. Operators often attempt to speed up slow acting equipment. Others may
unduly relax in their vigilance when machines are equipped with guards. Such overconfidence may result in unsafe responses.

4. The unsafe response attributed to an accident may be only an intervening variable of the true cause. An untrained operator might operate equipment at excessive speeds. This might result in the addition of speed governors where the real emphasis belongs in job training.

5. The causal model is deterministic since it assumes a single $E_i$ results from the combination of $U_j$ and $C_k$. It admits no probability in the accident phenomena. It seems likely that a given $U_j$ and $C_k$ will produce a distribution of $E_i$ with probabilities of accidents associated with each.

6. The model provides no explicit temporal relationship between the responses, the job conditions, and the achieved environmental state.
Chapter 3.

THE ROLE OF ACCIDENT PREVENTION PROGRAMS

IN INDUSTRIAL SAFETY

A natural outgrowth of the causal analysis of accidents is the use of accident prevention programs. An accident prevention program is simply a large scale extension of the on-the-spot remedial action taken with the single accident. It differs not only in scope, i.e., plant-wide corrective action versus single operation, but also time-wise, and in approach. Usually one associates accident prevention programs with organized long-run efforts by the safety staff to reduce accidents. The program may be carried for a week, a month, or even on a continuous basis. In addition, it very often attempts to modify the behavioral subcauses behind unsafe acts. This indirect approach is exemplified by large scale educational programs, safety contests, and worker safety committees. Some programs place emphasis on severe accidents and attempt to reduce plant severity rates. Punch press safety programs are indicative of this latter approach. By their nature, punch press accidents usually result in permanent partial injuries and cause above average disablement. When so-called unsafe conditions are combated with accident prevention programs, they are usually assigned to engineering or maintenance departments. These unsafe conditions are ones which appear to be significant over
many accidents, although not directly responsible for any one accident. Examples of this might be an order to increase factory illumination, or reduce the noise level by plant maintenance.

Generally, accident prevention programs are designed to combat those situations which are conducive to accidents, but not the immediate cause of accidents. Such programs are preventive in that they seek to abrogate conditions which would evoke future accidents. Accent upon modifying worker behavior plays a dominant role because of the major influence of behavior in accidents. Obvious unsafe conditions demand immediate correction and should not be construed as part of accident prevention programs. Accident prevention programs might be classified into the following types:

Type A. - Effort directed toward changing future worker behavior.

1. Desired result -- The minimization of future unsafe acts

2. Examples:
a. safety training films
b. safety contests
c. propaganda through the medium of posters, plant newspaper, pay envelope reminders, etc.
d. weekly safety committee meetings with employee participation

Type B. - Effort directed to minimize specific unsafe acts.

1. Desired result -- The elimination of specific unsafe acts

2. Examples:
a. campaigns to protect eyes through use of safety goggles
b. special safety courses for punch press operators
c. personal hygiene instruction
d. general enforcement of the use of protective clothing
Type C. - Effort directed toward minimizing the severity of accidents and occupational diseases.

1. Desired result — The minimization of accident severity, and the detection of occupational diseases at early stages

2. Examples:
   a. first aid training
   b. campaigns to get employees to report minor non-disabling injuries and early warnings of occupational diseases

Type D. - Effort directed to optimizing general plant working conditions.

1. Desired result — The establishment of safer working conditions

2. Examples:
   a. good housekeeping campaigns
   b. reducing over-all noise levels by better maintenance and employee participation

Type E. - Effort directed to improving specific working conditions (generally a non-employee approach).

1. Desired result — The elimination of specific unsafe working conditions

2. Examples:
   a. programs devoted to the attainment of 100% machine guarding
   b. improving illumination levels

These types are not mutually exclusive or collectively exhaustive.

Many programs are a composite of the above. The classification is presented to provide a background to the material which follows.

There are three basic decisions that must be made in establishing accident prevention programs:

1. the specific type of program
2. when to initiate the program
3. the level of effort to be expended
The pattern of these decisions varies in industry from plant to plant. In smaller plants, there is not likely to be any organized accident prevention program. In large industries, parent companies, on the basis of accident information from several plants, may initiate formal programs for all plants. Accidents of high emotional nature will often dictate a safety program. A large automotive firm might spend millions of dollars on punch press guarding, not because punch press accidents are the most frequent or incur the largest claim costs, but because of the dramatic nature of such accidents. In this case the program is justified, not on a direct dollar basis, but as a means of improving employee morale. The type of program is often dictated by the most frequent type of accident, unsafe act, or unsafe condition reported. In other situations, those accidents incurring the largest direct and/or indirect costs will indicate the kind of program. In large firms which regularly allocate funds for accident prevention programs, the emphasis may shift periodically, not because of a particular need, but rather to keep the employees safety-minded. The direction of effort may be dictated by the available budget. All-out plant safety training may be prohibitive with small safety budgets. Where the employee is to be paid during safety education, the costs may become extremely large. Suppose an aircraft company with 12,000 direct labor personnel provides for one hour per month for safety meetings, films, demonstrations, etc. At an average of $2.00 per hour, this amounts to $24,000 a month, or $288,000 a year for this general educational type program.
The timing of accident prevention programs may be critical. Failure to eliminate particular unsafe acts or conditions immediately results in longer exposure and increases the chance of accidents. For educational value, a program should closely follow the occurrence of known accidents which the program seeks to minimize. The decision to initiate a program very often is dictated by available budget, expected return of investment, and pressure on management. Whenever management discovers that public relations have fallen off because of accidents, cost factors may be overruled and action takes place immediately. The time to initiate a safety program of a general nature (Type A) is dictated by a general criterion measure of the safety progress on the plant. When the accident frequency rate and the accident severity rate increase above their usual average, a safety program is often called for.

Perhaps the most important decision in accident prevention programs involves the level of effort, or practically speaking, the dollar effort. This factor often dictates the timing and the direction of effort. In a few exceptional cases, the safety department may get a blank check from management, especially if management is motivated by reports of poor public relations or weakened employee morale. In general, management expects expenditure on safety programs or safety equipment to be of "value" to the company. Value may be the reduction in accidents and their costs as a result of the program, or attainment of certain intangibles (e.g., prestige, increased morale, better public relations, etc.). The key to an accurate determination of
optimum safety expenditure is a realistic estimate of past and predicted accident costs. Direct or insured costs are usually available from premiums paid to insurance carriers. Indirect and uninsured costs must be estimated from past accident records. For the purposes of this discussion, accident costs refer to costs to the employer only. The cost items involved here include the following:

1. the cost of wages paid to onlookers of the accident, and production lost by those other than the injured
2. the cost of overtime required to make up lost production
3. the cost of training a replacement for the injured worker
4. the cost of damaged equipment and materials
5. the cost of wages paid supervisors while their time is required for activities necessitated by the accident
6. the cost of lost profit (in the case of irrecoverable sales)

An excellent treatment of accident cost estimation can be found in Simonds and Grimaldi's "Safety Management" (60). Unfortunately, there is no universally accepted method of obtaining exact accident costs. For years the National Safety Council used Heinrich's 4:1 ratio of indirect costs to direct costs. This ratio was developed from a study by Heinrich in 1926 (28). It represents gross estimates only. This ratio has limited value when dealing with accident costs at the individual plant level. Individual cases can easily be conceived which would render ratios far different from 4:1, e.g., a construction worker is killed from a fall near the end of the shift.
Direct costs equal $10,000 to $12,000. Indirect costs would be far less than $40,000 to $48,000. A worker who gets his finger jammed in an assembly line conveyor belt is likely to halt production for hours and incur only first aid attention. Indirect costs here would be far in excess of $1. A major difficulty with this method is in the fact that a ratio must depend upon the type of work, the kind of workers, locale, type of industry, etc. Because of serious accuracy limitations by this ratio method, Simonds and Grimaldi recommended a new system of accident cost estimation which was recently adopted by the National Safety Council. This system divides accidents into four types: lost-time accidents, first aid cases, medical or doctor's cases, and no-injury accidents. For a period of time an individual company maintains detailed records of the uninsured costs as listed above for each type of accident. At the end of this so-called pilot study, average uninsured costs for each type are computed. In subsequent periods, the total accident cost is computed from the total insured costs and the frequency of each accident type is multiplied by the average cost of each accident type developed in the pilot study. This method has the advantage of applying specifically to the company involved. In its proposed use, it provides only estimates for the total accident cost. Any specific accident would involve a detailed study similar to the one from which the averages were developed. The average uninsured costs would need revision periodically as processes and production methods change. In addition, these averages would require continued adjustment to keep in line with current wage and
price changes.

For those small plants which lack the accident frequency to establish realistic averages, Simonds and Grimaldi have computed averages for certain types of industry. Their sampling error in many cases negates the use of these published averages. In one type of accident, the sample mean of 25 cases was $200 with a standard deviation of $100. The small sample size reported poses serious questions regarding the representativeness of the data. Moreover, the size and kind of operations in the companies studied (although not reported) must be equivalent to those plants wishing to make use of such averages. Regardless of the methods used to estimate accident costs, such costs are necessary as a basis for decisions in accident prevention programs. In addition to the difficulty in estimating uninsured costs, there is the problem of assigning dollar value to the so-called intangible, e.g., employee morale, public relations, etc. This will be discussed in more detail later.

Decision-making in accident prevention expenditure can be approached from two standpoints. We might be interested in descriptive decision theory, i.e., formalizing in some fashion the way in which executives do make decisions regarding the allocation of funds for accident prevention. Since this is a form of executive behavior, psychologists are particularly interested in this approach to decision-making. On the other hand, there is the study of normative decision-making, namely, the development of a basis for how decisions should be made, based upon some criterion measure. At this point we shall describe a normative theory to illustrate the salient problems in decision-making, the kinds
of data required, and in general to suggest a framework in which the basic model of the accident phenomena to be described in Chapter 5 can be related.

We must first start out with a set of simplifying assumptions regarding the conditions under which decisions are made.

1. The cost of an accident can be given a dollar value.
2. The decision-maker acts to minimize total costs.
3. All accidents can be classified into discrete categories which possess average costs. These categories might be typed by severity, agency, part of the body injured, etc.
4. The effect of safety expenditures on the frequency of accidents of a given category can be predicted. Stated in another way, the decrease in accident frequency of particular accidents as a result of a safety program can be predicted.
5. Costs of safety programs can be allocated to particular accident categories.
6. The time value of money is not a significant factor in the short range decision. This is not necessarily a realistic assumption, but it promotes simplicity at this point. In general, the return from safety expenditures must be equivalent to the return on a similar investment with current interest rates. This comparison is difficult when one begins to assign costs to intangibles.

Let \( C_T \) = the total cost of accidents for a given time period

\( C_T^\prime \) = the expected accident costs after the safety expenditure

\( \bar{C}_i \) = average cost of the \( i \)th type accident

\( f_i \) = average frequency of the \( i \)th type accident

\( f_i^\prime \) = expected frequency of the \( i \)th type accident after the safety expenditure

\( I_i \) = average intangible cost of an \( i \)th type accident
\[ I_T = \text{total intangible cost} = f(f_1 \text{ or } f_1') \]

\[ W_i = \text{accident prevention expenditures directed to the } i\text{th type accident} \]

\[ W_T = \text{total cost of the safety program} = \sum W_i \]

The total accident costs before safety expenditure is then

\[ C_T = \sum_{i=1}^{n} \left[ f_i(C_i + I_i) \right] \]

With the expenditure of \( W_i \) the resulting total cost is

\[ C_T' = \sum_{i=1}^{n} W_i + \sum_{i=1}^{n} f_i'(C_i + I_i) \]

If \( C_T' \) is less than \( C_T \), the safety program will result in a savings to the company.

Theoretically, each type of accident could be investigated and \( W_i \) compared to \((f_i - f_i')(C_i + I_i)\) to determine if the expenditure is worthwhile. In most cases, since safety programs aim to reduce accidents in general, a gross approach would be to compare \( W_T \) with

\[ \frac{\left( \sum f_i - \sum f_i' \right) \sum (C_i + I_i)}{n} \text{ or } W_T \text{ with } C_T - C_T'. \]

Two major problems exist here. One must be able to predict \( f_i' \) or \( \sum f_i' \) for a given \( W_i \) or \( W_T \) and some procedure must be provided to yield dollar estimates to \( I_i \) or \( I_T \). Unless the accident categories are independent, it would be difficult to find the functional relationship between \((f_i - f_i')\) and \( W_i \). If one treats accidents by departments or by machine groups, the effect of \( W_i \) on \( f_i \) might be determined from past experience. This would better apply to unsafe working conditions.
rather than unsafe acts. The installation of punch press guards could be evaluated against the change in punch press accident frequency. This assumes no change in worker behavior over this time. As was pointed out earlier in discussing the causal model, the installation of guards might well affect operator safety behavior. A somewhat easier problem would be to compare $W_T$ with

$$\left( \sum f_i - \sum f_i' \right) \frac{\sum C_i + I_i}{n} \quad \text{(i.e., } W_T \text{ with } C_T - C_T' \text{)}$$

This is the usual procedure in many companies except that intangible costs are usually omitted. In addition, the accident costs considered are frequently only the insured costs, i.e., premiums to insurance carriers. Using the method suggested by Simonds and Grimaldi, indirect or uninsured costs could also be included. It is unlikely that the relationship of $W_i$ to $f_i - f_i'$ or $W_T$ with $\sum f_i - \sum f_i'$ would be linear. One would expect small changes in accident frequency with small expenditures on safety. As $W_T$ was increased, $\sum f_i - \sum f_i'$ would increase and level off at some maximum value near the point where $\sum f_i - \sum f_i' = \sum f_i$. Further expenditure beyond this point would not be economically feasible. It should be noted that safety expenditures might result in an increase in accident frequency. This might occur if unexpected behavioral reaction to safety propaganda occurred, or a general safety apathy developed with the installation of a few machine guards. In the latter case, machine accidents might be reduced at the expense of
other types of accidents. The effect of $w_i$ on $f_i$ can be better evaluated only by a better understanding of the accident phenomena itself.

Whenever one investigates the decision-making problem, the measurement of value frequently represents a major obstacle. In a field such as safety, emotion as characterized by humanitarianism plays a significant part. Even though safety expenditures could not be justified on the basis of the expected change in estimated accident costs, safety programs would still be initiated as a demonstration of the company's concern in safety for purposes of increasing employee morale, public relations with the community, or both. There may be other motivating factors behind the decision to spend money on accident prevention. There are three methods of assigning a dollar value to these intangibles.

1. The individual decision-maker might study companies whose safety and production records he considers to be outstanding. Using the basic equation above, he might find out what these intangibles are worth to these companies, and use an average of these values adjusted to his own plant.

2. The decision-maker might initiate a study to evaluate the consequences of accidents on the ability to hire, plant turnover, employee grievances, etc.

3. The decision-maker might simply assume various value schemes, note the decision rules which develop from
them and select the rule and value scheme most compatible with over-all company policy. On the other hand, various decision rules might be hypothesized and the value system for these intangibles computed for each rule. Top executives might then rank these rules or systems in order of preference.

This brief examination of the philosophy and mechanism behind accident prevention programs points out the need for better understanding of the accident phenomena. By study of the interrelationship of working conditions and worker behavior, and the approaches necessary to modify this behavior, considerable progress could be made in developing a realistic basis for accident prevention programs. The general lack of understanding in the accident phenomena is typified by the failure in industry today to design jobs in light of known human engineering information. Instead of blaming the operator for errors in machine operation and spending money to change his attitude, increase his vigilance, and train him in the function of his equipment, the answer often lies in redesigning the equipment so that the average worker can safely operate it. Understanding of the accident phenomena is a first prerequisite to selection of the approach to be taken in accident prevention programs.
Chapter 4.

AN OVERVIEW OF RESEARCH RELATED TO INDUSTRIAL SAFETY

In view of the magnitude of the industrial safety problem as described in Chapter 1, there has been little research to advance the understanding of the accident phenomena. This fact has been recognized by the Committee on Research in the President's Conference on Industrial Safety. The 1950 report of this committee emphasized the inadequacy of knowledge for dealing with accident prevention and the little that was being done about it. The smattering of activity that can be called research has been directed along practical rather than theoretical lines. Research to revise and develop safety standards is a continual effort sponsored by the American Standards Association and the National Safety Council. Research on machine guards, punch press operation, safety footwear, and chemical toxicity are indicative of research efforts in industry. On the academic scene, the paucity of research is appalling. The fragmented efforts by psychologists and statisticians on accident proneness and studies in occupational diseases by industrial physicians make up the primary research activity. What is conspicuously lacking in industrial research is any emphasis along theoretical lines of the accident phenomena itself, and the relationship between the behavior
of man and his environment in the accident situation.

No studies singularly devoted to this problem were found in the available literature. Some psychological research has touched along these lines, but the tacit impressions left by the writers imply that the science of psychology is not far enough along to explicitly explain the accident phenomena.

Difficult as it will be, the real payoff in accident prevention must result from a theoretical basis and not empirical findings. The more understanding we have of the accident phenomena, the better we can design safe equipment, prescribe safe operating procedures, select safe operators, promote safe behavior, and, in general, reduce the frequency of accidents. The progress made in safety over the past 20 years, in light of what is known about accidents, is certainly encouraging and justifies the hope for even greater progress as more insight into the nature of accidents is discovered.

Industrial safety research might be arbitrarily divided into the following classifications:

1. Research concerned with the so-called causal conditions behind accidents. This research essentially follows the causal model described in Chapter 2. Machine guard design, the preparation of safety regulations, fail-safe mechanisms, etc. are examples of this research.

2. Research on accident prone theories.


4. Quality control and statistical procedures applied to accident measure and control.
5. Peripheral research areas. This is a general classification of research not necessarily dictated by safety considerations, but the results of which have application to industrial safety. This omnibus category would include research studies in psychology, sociology, and operations research.

Early research in industrial safety was devoted to the problem of assigning cause. In 1906-1907 a group of research workers studied one year's industrial fatalities in Allegheny County, Pennsylvania (20). Their conclusions were that both employer and employee were equally responsible for the accidents. Carelessness of the employee was reported to be the largest single cause of accidents, with "Acts of God" second. The category "want of guards" amounted to less than 1% and gave rise to the emphasis on the human factors in accidents. This emphasis still persists today. Heinrich's 1937 study again accused worker behavior by assigning the cause of 85% of the accidents studied to unsafe acts (28). Each year the National Safety Council publishes data that attempts to assign causes to accidents. Although this research has been of value to industry, attempts to assign causes on the basis of past accidents is a difficult task. The accuracy of accident reports, the inability to describe the behavior of the injured worker, and the fact that rarely can an accident be assigned to one cause lead one to place little more than genuine interest in these statistics. Pilz, a noted safety expert in Germany, proposed the following model with respect to the argument of unsafe acts versus unsafe conditions (58):
\[ U = f\left( \frac{G - S}{V}\right) \]

where

- \( U \) = accident frequency
- \( G \) = magnitude of the accident risks
- \( S \) = technical measures of prevention of unsafe conditions
- \( V \) = safe habits of the exposed worker

The above formula is qualitative rather than quantitative. The author concludes from his model that:

1. Regardless of the safe habits of the worker, absolute safety is not guaranteed since the denominator can never be infinite.

2. Every risk which is allowed to subsist will eventually lead to an accident, since accidents can only be delayed by safe behavior.

3. Theoretically at least, safety can be attained by technical measures alone. This, in essence, means the construction of fool-proof guards.

A different and somewhat more rigorous research effort which began in the early 1900's and continues today concerns itself with the problem of accident proneness. The concept of accident proneness holds that individual differences exist in accident behavior as in most other human qualities, and furthermore, that a small proportion of the population can be held to account for the majority of accidents that occur. Stated more simply, the accident prone possess a personal trait causing them to have more accidents when subject to the same risk as others. As originally coined by Chambers and Farmer (10), accident proneness was defined as a personal liability to accidents. Thus accident proneness is just the personal factor in accident liability. The letter term
Involves all risks on the job, personal and environmental. Engineers, mathematicians, and psychologists have been attracted to the notion of unequal liability in accidents and the potential benefit from such a theory. Some of the first studies were conducted by Greenwood, Woods, Chambers, Yule, and Farmer in conjunction with the British Industrial Health Research Board (10, 11, 26, 27). Using a large sample of industrial accidents, they concluded that accident liability among workers differed statistically from chance. Two basic assumptions were necessary to explain this unequal personal liability. The first was that job liability (the inherent risk of the work) had to be the same for all workers studied, and that those workers who incurred a high frequency of accidents during the first time period maintained this high frequency in the second time period. Marbe (11), a Bavarian psychologist, supported the general notion of accident proneness in 1926 with his "law of recurrence." This so-called law stated that the probability of a person meeting with an accident can be estimated by the number of former accidents of which he has been a victim. It was Marbe's contention that apart from environmental conditions, every person displays a definite individual personal accident tendency which remains relatively constant.

Since the time of Marbe, accident prone research has followed two distinct though not independent paths:

1. The statistical analyses of accident data to verify the existence of personal accident liability. These studies involve fitting accident frequency data to
theoretical distributions such as the Poisson and negative binomial distributions, correlating frequency distributions over successive time periods, and formulating theories of accident liability with probabilistic models.

2. The search from empirical studies of recognizable individual differences which could be used to separate the accident prone from the safety prone. This work has been carried out principally by experimental, industrial, and clinical psychologists. One of the prime objectives of such research is to be able to build a battery of psychological tests that could separate the accident prone worker at the hiring stage to allow safer placement in the plant.

In one of the first statistical studies, Greenwood and Woods (26) in 1919 proposed three hypotheses for accident distribution:

1. Simple chance hypothesis: This suggested that all workers are equally likely to have an accident. Past or future accident records have no affect on this probability. This assumes equal job liability, i.e., the accident risks on all jobs are the same. (Accident liability is considered the derivative with respect to time of the probability of at least one accident.) Arbous and Kerrish (2) have shown that if an accident distribution is Poisson, the population is considered to be homogeneous with respect to liability. This implies both personal and environmental liability. The converse of this is not true.
2. Biased distribution: This assumes that each worker begins with equal liability to accidents, but upon occurrence of an accident the worker will become more or less liable to future accidents. The simple contagion hypothesis suggested by Newbold (51) proposes that the worker learns only after the first accident, and his liability to accidents shifts to a higher or lower value thereafter. Beyond this point his personal liability remains relatively constant. A positive linear contagion hypothesis suggests that the accident liability of a person increases with each accident (analogous to the failure of electronic equipment). The negative linear contagion model suggests that accident liability decreases with each accident. Jacobs (32) reports that the resulting distribution of this hypothesis is the typical binomial distribution. The contagion time effect model investigated by Polya (54), Bates and Neyman (4), and Jacobs (32) assumes that liability to accidents increases linearly with each accident, but decreases with time (free of accident). The resulting distribution is found to approximate the negative binomial distribution.

3. Unequal initial liability: This hypothesis forms the basis for the accident prone theory. It suggests
that certain people, because of some personal characteristic, have a greater initial probability of an accident than others.

Arbous and Kerrish (2) present a very comprehensive review of the accident proneness problem with particular emphasis on its mathematical treatment. Their analysis of the original work by the British Industrial Health Research Board does much to clear the air of misconceptions on the subject. In the study of Chambers et al., (10, 11, 26, 27), the theoretical accident frequency was described by three distributions presented above. If the chance hypothesis were true, then a Poisson distribution of accidents would follow. The difficulty is that even if a Poisson distribution results, this is not proof that the chance hypothesis is true. There may be other hypotheses which will give rise to the same result. Accident data divided into two groups, each of which follows the Poisson distribution, taken together may be represented by the negative binomial distribution. The biased distribution is explained as one in which the probability of accidents might increase or decrease after one accident as a result of learning, fear, etc. This hypothesis is rejected because it is "opposed to actual observed experience." Whenever the Poisson distribution does not fit the accident distribution, an alternative distribution known as the negative binomial is tried. One of the hypotheses which gives rise to this distribution is the unequal initial liability or accident proneness. In the classic study by Chambers (10), the
fact that other hypotheses could result in a negative binomial was completely ignored. One of the basic assumptions of the accident prone theory is homogeneous environment. If the workers were grouped so that job liability within each group is the same, i.e., the mean number of accidents which represents the liability is the same, then the distributions within each subgroup will follow the Poisson distribution.

Irrespective of the underlying hypothesis giving rise to the unequal distribution of accidents to a group in any observed period, a practical advantage would be gained if one could predict in any subsequent period which individuals are going to sustain the majority of the accidents. This information would be imperative for future accident prevention policy. If it is assumed that unequal liability is responsible for the observed distribution, then, provided personal factors remained unchanged, there should be a correlation between an individual's accident records for the observed and future periods.

When considering the findings of various research workers in the field of accident proneness, it is essential to draw a distinction between major and minor accidents. Many researchers failed to make this point clear in their reports, and as a result certain bias has entered the picture, especially in regard to minor accidents. Empirical data require close scrutiny, because some researchers report all minor accidents while others do not. Major accidents, those which incapacitate the worker and are usually
reportable under workmen's compensation, are almost completely free of this bias.

Arbous and Kerrish (2) conducted correlation studies on separating the data into four distinct groups. These groups were
1) correlation between minor accidents in two successive periods,
2) correlation between major accidents in two successive periods,
3) correlation between major and minor accidents in a given period, and
4) correlation between different types of accidents. The conclusion drawn from the results of groups 1) and 2) was that there was some correlation between two observed periods, especially in regard to minor accidents. The results of group 3) showed that no prediction of major accidents (which industrialists are primarily interested in) can be made from a minor accident record. Group 4) had equally disappointing results, the conclusion being that no individual correlation was shown between industrial and other types of accidents, although a slight general correlation was noticed.

Bates and Neyman (3), on the assumption that accident frequency is distributed according to a Pearson Type III Law, developed a model correlating light and severe accidents. They identify the joint distribution resulting from their study as a multivariate negative binomial distribution. Their fundamental hypothesis was that for particular individuals in the population, the expected number of light accidents in an earlier period is a fixed multiple of the expected number of severe accidents in a subsequent period. Although no empirical data were available to test this hypothesis, the investigation of analogous situations seemed to indicate the model had
promising potential. By noting the number of light accidents in a
given time period, particular employees could be transferred or
dismissed to avoid the expected severe accidents. Certain diffi-
culties exist in getting empirical data to support the hypothesis.
Very often severe accidents are not survived by the victims, and
exposure to possible further severe accidents is not possible.
The model also requires a large number of light accidents in the
first period. This requires either a very long period of observa-
tion, or some artifice to increase the exposure of workers to
light accidents over shorter periods. In another study the same
authors developed a model which uses the time effect between acci-
dents instead of the number of accidents as the basis for distinguish-
ing accident prone personnel (4).

Mintz and Blum (45) in 1949 called for a re-examination of the
accident proneness concept. They insisted that derived accident
distribution be compared to the Poisson distribution before es-
tablishing the claim of accident proneness for a given group of
workers. Moreover, it was their contention that it was often diffi-
cult to separate chance from unequal liability. As a matter of fact,
if some people have three accidents before others have one, this can
be explained by chance, and hence accident proneness concepts can
reveal the same results that chance would dictate. They believe
that personal accident proneness has been overemphasized. Their
studies revealed that only 20% of the total variance in accident
records can be attributed to differences in accident liability.
In reply to Mintz and Blum, Maritz (42) argued that a perfect Poisson fit does not exclude accident proneness, nor does a negative binomial fit to the accident data indicate proneness. The author then demonstrates with a set of accident data on railroad workers how different the conclusions would be using two statistical approaches. When the entire data were fit to a Poisson distribution, the resulting agreement was good, suggesting a chance liability. When the data were divided into two time periods and individuals compared with correlation analysis, the resulting correlation coefficient was high, indicating that persons who were high accident repeaters in the first period were also those in the second. The general conclusion was that correlation of accident records in two successive time periods is indispensable as evidence of accident proneness.

Webb and Jones (68) attempted to reconcile the two positions by pointing out that both methods of investigation yield the same reliability coefficient despite different assumptions. Poisson curve fitting assumes that the degree of proneness is the difference between the theoretical and observed distribution mean and variance. In correlation one assumes that in a chosen period of time a person is as prone to have an accident in the first part of the period as the last part. The correlation between periods is a measure of a person's consistency of accident performance above and beyond factors distributed independently of the individual's performance.

In general, despite differences in statistical approach, there
seems widespread agreement that empirical studies do reveal unequal personal liability to accidents among various workers. The precise interrelationship of this liability to time and contagion effect must await further accident data. Many descriptive models have been formulated but not yet verified by actual accident data.

The other basic research approach to accident proneness begins with the supposition that this phenomena exists, and effort is directed toward describing how accident prone individuals differ behaviorally from the non-accident prone. The bulk of the research attempts to answer the question of the traits of the accident prone, and how he can be distinguished from others. Clinical, industrial, and experimental psychologists and psychiatrists have studied accident repeaters and arrived at rather general behavioral characteristics, few of which are agreed upon. The approaches vary in objectivity. The Freudian psychologist interprets the behavior of the accident prone as a fear of castration. Other clinical psychologists explain accidents in terms of "death wishes." At the other end of the scale, industrial and experimental psychologists have sought predictors of the accident prone person. Such tests for reaction time, intelligence, mechanical aptitude, distance judgment, vision, etc., have correlated rather poorly with accident frequency. Ghiselli and Brown (25), however, have indicated some success has resulted from psychological tests, and it appears that here lies the real potential in the accident prone concept. In isolated situations such as taxicab driving, foot reaction time and distance
estimation have shown to be fair predictors of accident frequency. It appears that physical and intelligence factors are useful predictors only in those occupations where these factors are critical in the performance of the job.

LeShan (37), a clinical psychologist, concludes that the accident prone is an impulsive, impetuous person who concentrates on immediate pleasures. He is usually above average in general health, although much concerned about it, and is a sociable, happy-go-lucky individual. He resents authority. In fact, as a result of childhood rebellion against authority, he retains a guilt reaction and an accident is not only a price of atonement, but a permission to indulge in the same guilty acts. The accident prone maintains only superficial ties with others, and is frank and abrupt in his attitude toward family and sex.

Moorad (46), a psychiatrist, has developed a slightly different approach to the accident prone. He first distinguishes between the accident prone and the epileptic, the mentally unbalanced, and those with neurological disorders. The latter must be detected upon hiring by proper medical examination, and placed in jobs which are suited to them. Dr. Moorad's hypothesis is that accidents are the direct effect of external pressures coupled with resulting inner psychological pressures. Mass production, foreman pressure, speed, tight standards can lead to serious emotional problems. The author opines that a man needs to exercise certain mental functions for safe performance on the job. These are:
1. awareness
2. mental and mechanical co-ordination
3. attention to details
4. concentration
5. alertness
6. quick thinking and prompt action

If one or more of these functions is lacking, an accident is likely to happen. Prominent types of emotional and mental disorders that are evident and recognizable by the psychiatrist are:

1. the hypomanic—happy, carefree, overconfident, overfriendly, overactive, overtalkative, and egotistical
2. the depressive—slow, sad, depressed, and discouraged
3. the paranoid—suspicious and distrusting
4. the malingerer—does not cause accidents, but capitalizes on them
5. the psychopathic—clever, brilliant, but emotionally dominated
6. the psychoneurotic—immature and dominated by infantile emotionalism (this type represents the largest group)

Whether these disorders are permanent or temporary, or whether they exist to a degree in all of us, is not discussed. The general recommendation is to seek out these types (since they all possess some emotional unbalance) by proper medical examination and apply industrial therapy by removing excessive incentive, instilling confidence, etc.

A similar medical approach is suggested by Shulzinger (57). He emphasizes the importance of the diagnosis and treatment of the pre-accident patient. Physicians have a great opportunity to spot the accident prone during pre-employment medical examinations, by ascertaining the emotional equilibrium of the patient. Treatment of the accident
syndrome can then be initiated to help the person diffuse his uncontrolled aggressiveness and assist in his adjustment to the work environment. Shulzinger contends that the physician can categorize the prospective employee into three categories:

1. those who are safe for exposure to hazards
2. those who are safe for limited exposure
3. those who are unsafe for any exposure

This medical approach could be validated by comparing the accident experience of treated patients with that of untreated controls.

The crux of this approach seems to rest on two optimistic assumptions, namely, that such diagnosis is possible, and that specific treatment can be prescribed.

The Moorad hypotheses are contrary to a study in a large steel plant by Whitlock and Crennel (70) who found that accident repeaters were less neurotic and introverted than the non-accident prone. This study involved testing both accident prone and safety prone workers in personality traits. Scores on these tests correlated poorly with accident frequency. In fact, the accident prone seemed to be distinguished only by low empathy scores. Empathy here refers to the ability to put oneself in another's position, anticipate his feelings, etc. Jenkins (34) attempts to summarize the accident prone syndrome. The accident prone

1. is easily distracted from his work
2. shows less personal restraint
3. is unwilling to cooperate
4. scores low on personality traits which measure sensitivity
5. has a confident attitude
6. is aggressive in his relations with others
7. is less likely to be affected by pain

As noted from some of the above research, there is no generally accepted view on the personality traits of the accident prone. The problem has probably attracted more research than any other aspect of industrial safety, and is without doubt one of the most controversial subjects in the field. Much of the theory remains to be verified by actual accident data. It is entirely possible that accident proneness is a characteristic which varies with time or perhaps with occupation. An accident prone taxicab driver may be a safe bus driver. At present we do not know if accident proneness is an innate characteristic or the product of environment.

The moral and social implications of this theory, if it becomes universally accepted and capable of measurement, are not easily answered. What does one do with the accident prone? Should he be refused the right to operate motor vehicles? Should he be given special insurance rates? Will organized labor support management in placing this person in less hazardous employment? Even if the accident prone could be identified and dismissed, the reduction in accident costs might be inconsequential. A recent study by Jacobs (33) seems to bear this out. He found that with perfect prediction of accidents, the expected gain in accident
reduction by rejecting various proportions of the population (namely, the accident repeaters) was not particularly significant. His conclusions strongly suggest the possibility that proneness research may have much less promise in terms of potential application and payoff than other forms of accident research.

A third avenue of research in industrial safety is that directed to the identification, control, and treatment of occupational diseases. These diseases include radiation exposure, occupational deafness, dermatoses, solvent and metallic poisoning, silicosis, etc. Industrial physicians and toxicologists are continually conducting research on new industrial processes and products so that adequate preventive measures can be taken. It is not the intent of this paper to discuss this highly technical research, but it should be mentioned that the field of safety stands on much firmer research ground in the case of occupational diseases than with accidents. The causes, tolerance levels, treatment and prevention of most occupational diseases are well supported by both research and industrial practice. Although occupational diseases are treated separately from accidents by safety experts, some of the conditions causing these diseases may also contribute to accidents. Excessive noise and vibration, in addition to causing deafness, can also impair the behavior of the operator and in many cases prevent the detection of accident warning signals. One particular aspect of research on occupational diseases will have a tremendous impact
in industry. This concerns present work on the affects of ionizing radiation. As more radioactive materials are put to use in industry, the more important this kind of research will be. At present no one is sure just how much radiation a person can tolerate. Open disagreement by chemists, physicists, and geneticists has added public emotion to the problem. Interestingly enough, radiation tolerance levels have consistently been reduced over the past 30 years.

Considerable research in the last decade has been concerned with applying statistical quality control techniques to the measurement and control of accidents. Deile (17) has used quality control charts to detect changes in accident hazards and measure the effects of safety programs. This approach views accidents as defective performance and plots an adjusted accident frequency rate with two or three sigma control limits on the traditional control chart. Deile uses the number of accidents (including first aid cases) per 10,000 man-hours worked as a yardstick of performance. Each week the frequency rate is plotted and compared to some standard of performance, the running average of the plant frequency rate, or the previous year's rate. Sudden shifts outside of the control limits call for closer study to determine the assignable cause. Although two sigma limits often create false alarms, they do permit earlier detection of increases in accident hazards. Use of this approach requires considerable exposure to accidents, so that the time periods chosen can be short enough to detect shifts in accident frequency and still have sufficient exposure to provide a meaningful frequency rate.
Schreiber (56) has gone one step further in the quality control approach by using instance of unsafe behavior and not accidents as the measure of safety performance. For a given department the types of unsafe acts are identified. Using work sampling techniques, the proportion of total acts that are unsafe are computed daily. This proportion is used as the population defects in safety performance, and is plotted on a control chart. With this measure the effect of nearby accidents, safety propaganda, etc., on a department's safety behavior can be quickly evaluated in statistical terms. Use of this method in Naval Shipyards yielded surprising results. The work samplers were dressed as materials handlers and made their observations without operator knowledge. Of the behavioral acts observed, 27% were considered unsafe. This approach has tremendous potential. The notion of measuring the behavior that precedes accidents rather than accidents themselves is a significant advancement in industrial safety thinking.

In addition to rapid detection of upward shifts in the accident rate, quality control techniques offer an objective method of determining the effectiveness of accident prevention programs. This will do much in optimizing the effect and direction of such programs in the future. Although statistical quality control procedures yield valuable information about changes in accident frequency or safety performance, they offer little assistance in providing means to reduce "out of control" rates. By these methods we can determine if safety education has an effect on safe operator behavior, but the reasons for this effect are still unknown.
The remaining classification of research in industrial safety might be termed "peripheral research" since its approach is not necessarily concerned with accidents, although results are applicable in many instances to industrial accidents. It would be a tremendous effort to organize and compile this research, and a task which is beyond the scope of this paper. However, certain areas should be mentioned to provide an insight to the nature of this research.

Working with the Commission on Accident Trauma of the Armed Services, McFarland (43) (44) conducted extensive research on the human factors in Vehicular Design and Operation, and those in Air Transport. These studies have been concerned with such problems as visual fatigue and performance, optimum instrument design, and the psychophysiological aspects of stress and its effect on performance, including the consequences of such environmental effects as humidity, temperature, vibrations, and motion. The National Research Council's Survey of Human Factors in Undersea Warfare (50) has also provided some interesting information on the effect of stress on human performance which has indirect application to industrial safety. Other contributors to this problem include Bartlett (5), Welford (69), and Craik (16).

Fitts and associates (23) have conducted several interesting studies in motor skill performance and human engineering, with results that are applicable to accident prevention in industry. Of particular interest to the study of accidents is the critical
incident technique used by Fitts and Jones (24) to describe the
effect of cockpit display and control design on "near accidents"
to air force pilots. This technique is particularly useful as
a research approach to problems in which little information is
available. It consists of interviews of persons exposed to criti-
cal incidents. An incident is a segment of human behavior which is
complete enough for the investigator to make some inferences and
predictions about the person involved. To be critical, the incident
must occur in a situation where the purpose or intent of the behavior
is clear to the observer, and where the consequences of the behavior
are definite enough to leave little doubt about its effect. The
technique is admittedly subjective, but nonetheless provides im-
portant information on which to initiate more specific investigation.
In the classification of 277 "pilot error" experiences, it was found
that 40 resulted from misreading the altimeter. This information led
to subsequent study and redesign of this instrument. Commenting on
this technique in the study of near accidents, Chapanis (12) warns
of its limitations, and in particular emphasizes that this method
relies on selective recall by the observer, the error of which can-
not usually be determined.

Vernon (65), McFarland (43) (44), and Muscio (47) have per-
formed studies which show the effect of environmental stress such
as heat, vibration, successive hours of work, glare, etc., on accident
frequency. This type of research is especially important if opti-
mum environmental conditions are to be provided in industry. In
the area of equipment and work area design, commonly called human engineering, research studies have yielded valuable information on how people see and hear, and what controls and displays they can operate most effectively. The results of these studies can be found in texts by Woodson (73) Chapanis, Garner and Morgan (13), and the Tufts Handbook on Human Engineering Data (62). This particular field is just now beginning to be recognized by industrial safety experts. Accidents which were previously charged to unsafe operator behavior are now being interpreted as the result of equipment which makes excessive performance demands of the operator.

As industry moves toward automation, the injury type accident will become less significant, since the operator will play the role of the monitor of machines. However, operator error can result in substantial property loss. Human engineering knowledge in these situations will provide a basis for control and display design, length of work periods, and optimum environmental conditions which will maximize monitor performance. Some research has been conducted on the subject of the human monitor. Studies by Broadbent (8), Mackworth (10), and Howland (30) represent some of the contributions in this ever expanding field. The safety implications of the human monitor have not been explored.

Recently the British psychologists, Cohen, Hansel and Dearnaley (14), conducted an interesting study on risk and hazard in the performance of bus drivers. Their task was to determine at what levels bus drivers would risk an accident and the proportion of successful
risks at these levels. The risk in the experiments performed was to drive a bus between two posts a fixed distance apart. Both experienced drivers and trainees were used in the study. The conclusions were that trained drivers had tendencies to take less risk, become involved in less hazard, and make more realistic estimates of bus performance capabilities. The trainees took more risks, even when there was no chance for success. The trainees were also more optimistic about the probabilities of their success. Although such experimental risk taking situations are not real life, they are useful in comparing operator performance and relating concepts of risk and hazard.

The field of industrial safety is so broad that it cuts across many disciplines, such as psychology, industrial medicine, sociology, engineering, statistics, physics, and chemistry. Research on better materials handling methods, new product development, group and individual value schemes, reaction time, descriptive decision-making, learning theory, fatigue, preventive medicine, illumination, to name a few, concern operator safety either directly or indirectly. Perhaps the reason that industrial safety has not progressed further today is because there is no unifying framework in which these other research studies can be organized and utilized. The tendency in the United States today toward specialization often encourages safety specialists to retreat behind the present narrow confines of their field and prohibits them from taking advantage of the wealth of research in these related fields.
The Need for a Theoretical Framework for the Study of Accidents

The previous review of the research efforts in the field of industrial safety reveals two significant aspects. First, since the turn of the century, the understanding of the accident phenomena has only slightly advanced, leaving us with a 20th century problem of vast importance to be combated by a 19th century knowledge. The position in this field is evidenced by an almost total lack of basic research aimed at a better understanding of the mechanism behind accidents. The position taken by most safety practitioners today is almost identical to that held by the pioneers in the safety movement some 50 years ago. The same declarations of inadequate knowledge to effectively attack the accident problem that were announced in 1900 are voiced today by the foremost authorities in the field (63). The second aspect is the lack of a unified research effort in dealing with the accident problem. The specialized research efforts in the various disciplines are indicative of this dilemma. Psychiatrists, sociologists, industrial physicians, engineers, and safety practitioners approach the same problems under different premises and the net result is a composite of contradictory conclusions and subsequent confusion in many cases.

Our thinking on the subject of accidents still reflects the causal, deterministic philosophy of the 1900's. To be sure, there have been some advancements. "Acts of God" have been eliminated as a meaningful cause of accidents, and have been replaced by the realistic
position that accidents are the outgrowth of our present society. The approach by accident preventionists is still a trial and error one. Accidents are assigned causes which serve as the basis for preventive effort. Carelessness and blame are still often associated with accident causes. Assigning blame for an accident does not help prescribe the solution. Carelessness, like fatigue, is a descriptive term and cannot of itself cause anything, nor does such information assist us in preventing accidents. Present safety efforts are still influenced by mass statistics published by the National Safety Council and the Bureau of Labor Statistics. These statistics are basically for insurance and propaganda purposes, and usually cannot provide an individual plant with information on which to justify an accident prevention program. Moreover, the universally accepted accident frequency rate is not a true indicator of the safety level of a plant, since it is a consequence of worker behavior and the risk level of the operations performed. If accidents are probabilistic in occurrence, then accident frequency is not necessarily a valid measure of safe operation, since under identical plant conditions the observed accident frequency might vary considerably.

If we assume that the basic elements of an accident are

1. the environmental state of a job with its attendant risk
2. operator behavior in response to job stimuli, specifically his risk acceptance
3. the changes of the above with time
4. the admixture of certain states of 1 and 2 such that an unplanned event occurs which disrupts production and could or did cause personal injury,

then several fundamental questions arise:

What are the temporal aspects of the accident situation?

How does behavior change with time?

Does the probability of an accident increase with exposure to unsafe behavior, and/or unsafe environment?

If operator behavior is influenced by other accidents, safety programs, etc., how long does this effect last?

How does the length of exposure to unsafe situations affect the frequency and severity of accidents?

How is operator behavior and his environment interrelated?

How does the operator respond to changing environmental conditions?

Safety-wise, what degree of control over his environment does the operator have?

How does one measure the extent of risky behavior on the part of the operator?

How does one measure the hazard level of a job?

How are expected frequency and severity rates related?

How can hazard be measured along some scale for purposes of comparison?

What constitutes a job hazard in light of the operator's ability to change environmental states?

How can we separate accidents of omission from those of commission?

What is the nature of risk acceptance and what methods can be used to reduce the magnitude of an operator's risk acceptance?

How does an operator learn to be safe?
How does this learning take place and how can its temporal effects be measured?

What is the role of the psychologist, sociologist, engineer, and physician in the prevention of accidents?

What are the boundaries of each of their domains?

How does equipment design affect safe performance?

What are the effects of stress on safe operator behavior?

Although answers might be proffered to some of the above questions, we are forced to admit that satisfactory solutions to the problems posed by these questions do not exist. These problems are not theoretical ones which are only of academic interest. They are real deficiencies in our understanding of the accident phenomena. Before we can efficiently tackle the accident problem, we must first acquire a firm theoretical foundation on which to base our efforts. The above questions point to a very definite need for basic research on the accident phenomena to provide a framework in which our present knowledge of accidents can be oriented and by which the gaps in this knowledge can be explored and filled in. It is the intent of subsequent chapters to suggest a framework in which to relate the present scattered information on accidents.

The reason that there has been little basic research to provide answers to these challenging problems are not difficult to find. This does not imply that we are justified in our ignorance, but rather that we understand how industrial safety has reached its present predicament, so that ways of altering this situation can be suggested.
One of the chief reasons for the lack of basic research is explained by the nature in which research in safety is initiated. As a rule, the emphasis is upon applied research, i.e., research directed toward a specific safety problem. As the frequency of punch press accidents increases, management becomes alarmed and orders that specific study be made to minimize this type of accident. Those industries in a position to sponsor research are more interested (and rightly so) in getting answers to their own specific safety problems, rather than support research of a general nature. The National Safety Council and the American Society of Safety Engineers, organizations in a position to encourage basic research, have generally followed the path of immediate answers to immediate problems. Consequently, one finds the National Safety Council supporting research on safety footwear, eye protection, and safety codes, instead of research on the accident phenomena. The American Society of Safety Engineers, composed of practicing safety engineers, also reflects the general industrial attitude toward basic research.

Perhaps another explanation for the paucity of basic research lies in the fact that much of the better research in the past 30 years has been directed toward areas which offer immediate payoff. Research in automobile accidents and accident proneness are examples of this. As was discussed earlier, the controversial nature of accident proneness has encouraged spirited research efforts by physicians, mathematicians, and psychologists. While this type of research extends our knowledge in this problem and represents in many cases real
contributions, its basis is primarily empirical and spelled out in terms of the implied causal model of the accident.

Another reason for our predicament is the fact that many people in the safety field believe that no real problem exists. These self-styled experts oversimplify the accident phenomena to an extreme point. Some hold that discipline is the answer to the problem. Others insist education is the answer. Short-range results from the use of safety propaganda are apt to create a safety engineer who is convinced that he has the solution to all safety problems. Moreover, the popular slogan that "accidents can be prevented" encourages those in safety to simply find the cause of accidents and eliminate them. This attitude is certainly not conducive to basic research.

A more logical explanation of the problem stems from the fact that safety cuts across several established disciplines. It is not only impractical but also impossible to compartmentalize accident prevention into self-sufficient activities, such as psychology and safety engineering. Safety has so many ramifications that to combat the problem properly, one must have access to psychological, sociological, medical, and engineering knowledge. To establish a theoretical foundation for the study of accidents, a concerted effort by these disciplines is necessary, not as in the past by several independent studies, but by an interdisciplinary approach where the many facets of the problem can be explored. Recent developments in team research on systems problems, called Operations Research, appears to have application in this field.
The pressure in industrial safety as in many other areas in industry is to get immediate answers to problems. Faced with a particular series of accidents, management is only willing to spend money on efforts to end this particular problem. There are many aspects of safety that are in need of research. We need research on the optimum direction and level of effort in safety programs. We need to revise the concept of machine guarding so that realistic guards can be designed which maintain the protection of the operator and are still not a bar to incentive. Research is vitally needed in employee selection methods so that workers can be optimally placed in industry. We need much more research on occupational deafness. Realistic noise tolerance levels are required as well as means to protect exposed operators. We need research on the effects of ionizing radiation and control and treatment of exposure to such radiation. We need research on the general problem of dermatoses. Although minor in severity, this disease represents 50% of all occupational disease claims. We need a continual re-examination of safety codes and regulations so that they can keep pace with modern developments in products and processes. These are just a few potential research areas that compete with fundamental research. Because they offer more immediate payoff, the tendency is to relegate basic research to an academic position and concentrate on meeting existing problems.

The initial step in remedying the present safety enigma is to promote the realization that basic research is vitally needed to
1. serve as a basis for relating the many facets of the safety problem

2. provide a better understanding of the accident phenomena so that subsequent research and accident prevention programs will be maximally effective

What is required in this initial research is a model which describes in precise language the interrelation of operator behavior, environment, and accidents. Such a model is proposed in Chapter 5. A second step is the establishment of an interdisciplinary team of research workers to assist in building a framework for accident prevention, and to carry out research to answer problems suggested by the model. The conspicuous absence of such team research in the past is partly responsible for the lack of unity in present industrial safety methodology. The growing importance of the safety problem demands an understanding of the accident phenomena on which to build the techniques of its prevention.
Chapter 5.

A FEEDBACK ANALOGUE OF THE ACCIDENT PHENOMENA

A model is a physical or mathematical representation of a particular process or system. In the case of a mathematical model, it essentially describes in precise terms the functions and interrelationships of the components in the process. Models allow system manipulation to reach optimum operating conditions without physically disturbing the system. In general, models can be characterized by the functions which they perform. They can be used as a descriptive framework in which the ordering of complex relationships can be established to effect a better understanding of the phenomena described. They can also be used as a precise structure of the phenomena permitting mathematical abstraction and manipulation to arrive at optimum system conditions. Models may possess both of these characteristics to various degrees. For complicated systems models are often used initially as conceptual framework in which to study the problem. Later increased understanding of the problem permits more formal structures from which specific parameters can be mathematically evaluated. With a phenomena as complex as accidents, a model will primarily serve as a descriptive tool. In fact, its broad descriptive capabilities often prohibit explicit formalization because the number and nature
of the variables involved overreach existing mathematical procedures. In accident analysis, a model can provide not only a conceptual framework in which the various factors of an accident can be related, but also suggest testable hypotheses from these relations. In abstracting the accident phenomena, as we shall see later, the model suggests what kinds of accident data are required and what kind of experiments are necessary to substantiate the derived hypotheses. In the final analysis, the value of any model is determined by its ability to further the search for lawful relations within the system it attempts to describe.

In analyzing the accident phenomena, it is proposed to use a feedback control system analogy. This system has been selected because of its past usefulness in describing human motor performance, because it ties together known facets of the accident phenomena, and because it can be represented by a mathematical structure or model. A feedback control system establishes certain relationships between a variable $X(t)$ called an input signal and a variable $Y(t)$ called the output signal. The energy associated with $Y(t)$ is not derived from $X(t)$. The function of the input signal is to provide information which can be used in governing the output. A control system may be opened or closed. If it is open, the input is unaffected by the nature of the output. In effect, signals are transmitted in one direction only. In a closed system, the output signal is fed back for comparison to the input. The signal which controls the system is some function of the difference between these two signals. This
difference is usually referred to as "error."

The basic components of a feedback control system are the system (defined by its boundaries), the output, the input, a control source, a mechanism for the detection of the output, and a comparator which integrates information on the output signal and the input signal, and directs the control source to adjust the system. If the input signal is constant, then the system is defined as a regulator. An example of this would be the typical house thermostat. If the input is a variable, the system is called a follow-up system.

The figure below represents the typical closed loop control system.

Fig. 4. - A closed loop control system
Note the chief characteristic is the feedback loop wherein a function of the output signal is fed back for comparison with the input signal. This comparison is the difference between some function of the output and input and is the basis for action of the compensator which adjusts the process to bring the output in line with the input. The load, shown in the figure, acts upon the process affecting the output. Any functional form of the output signal and input signal can be supplied to the comparator. Similarly, any functional form of the error can be supplied to the compensator. The input and load affect the behavior of the system (in particular, output and error), but are themselves unaffected by its behavior. Hence, variables not included in the loop may be regarded as independent and may assume any arbitrary time paths.

A servomechanism, then, is a system unilaterally coupled with an input and a load, with one or more feedback loops whereby the output is compared with an input, and with a source of energy controlled by the error that tends to bring the output in line with the input.

Control systems may be subject to 1) "perturbation," the disturbance of desired relations of the input and output signal, 2) lag, a time lapse between output shifts and subsequent correction through the control circuit, or 3) oscillation of the output signal as a result of over control through the action of error signals. In the analogy to human performance, lag, in part, corresponds to reaction time.

A control system may be an on-off system, a continuous system, or a sampling system. In the on-off system, there are only two forms of operation. When the magnitude of error exceeds a preset value the
control system goes on. Otherwise it is off. In the continuous system, the output is measured continuously and the resultant error is fed to the control mechanism which maintains continuous correction. In a sampling system, the amplitude of the output is measured at periodic intervals. The sampling period is a characteristic of the system, and may or may not be independent of the magnitude of the error. Although its action is intermittent, the sampling system differs from the on-off system because its corrections are dictated by time and not error magnitude, and the correction is graded in amount.

Hicks and Bates (29), Walston and Warren (67), and Birmingham and Taylor (6) have proposed the use of the sampling system as an appropriate model for describing human motor response. Man's response mechanism appears to be well suited to this system. Fitts (23) reports some of the evidence for this conclusion. Human error records often exhibit periodicities that are not present in the input (stimuli). Eye movements dictate intermittent observations of man's environment. Man's reaction time is so great that if he tried to function as a continuous servo, his resultant error would be large. This excessive reaction time would be much less of a handicap if man functioned as a sampling servo mechanism.

The conclusion that the human functions basically as a sampling servo has considerable theoretical implications. In the accident situation, the human may sample to get better estimates of the risk level of the environment. This level may dictate the frequency with
which he makes his observations. His rate of sampling is in effect a measure of his alertness to the hazards of the job. His judgment of his own lag (reaction time) and the speed at which the job situation may change will dictate the type of response required to insure safe operation. All this, of course, presumes rational behavior. A further interesting possibility is the notion of man as a predictor of future job conditions. Most important, if it can be demonstrated that man acts as a sampling servo in the maintenance of safe behavior on the job, then some of the wealth of mathematical treatment already known about such systems may provide not only qualitative descriptions but quantitative measures of the interrelations of man, his environment, and the accident.

The Basic Model

Although the sampling type servomechanism appears to be an appropriate model of the accident phenomena, it should be noted that the traditional concepts of servo theory do not exactly meet the requirements of the accident phenomena. The extreme complexity of the accident situation necessitates the use of servo theory in a rather broad sense, making use of its basic structure, but not the specific mathematical relationships that are normally considered part of servo theory. Some adaptation, then, of the traditional servo model will be necessary in describing the accident phenomena. The problems of oscillation, instability, and transient conditions which are of primary interest in servo theory do not play a significant
role in the analogous accident situation. Traditional servo theory customarily deals with continuous systems whose input characteristics are known, permitting lawful relationships using differential equations. In the accident situation we are concerned with stochastic inputs and outputs and intermittent operation. Adapting a basic model to meet the needs of the system to be described is not unique in model construction. Rarely is one able to make direct use of conventional systems as models of complex phenomena. The departure from traditional servomechanisms will become evident in the exposition of the model that follows.

The general approach here will be to introduce the feedback interpretation of the accident phenomena in successive stages. An oversimplified model will be presented initially, followed by enrichment at successive stages until all the desired ramifications of the accident phenomena are included. Crude functional relationships of the various components of the model will be introduced to facilitate a general understanding of the system's operation. In a subsequent section, a more formal exposition of these relationships will be presented.

Consider an operator in charge of a machine which generates a product with varying characteristics (diameter, weight, etc). At periodic intervals, the operator samples the output of this product generator and compares it with a standard or reference value of the desired output. The difference between the standard and actual output determines whether a change in the setting of the machine is
necessary to bring the process output under control. This simple feedback system is shown below.

![Feedback System Diagram](image)

Fig. 5. - Accident phenomena - Stage 1 of the feedback analogue.

Note that the energy to bring about changes in machine settings is independent of the process. Also, the energy which drives the generator is unspecified and not under operator control. The reference value may be fixed or variable. The distinguishing characteristic of this system is that the output is fed back for comparison with the reference value, and this comparison serves to correct the output. The system does not meet the requirements of the traditional servomechanism, since there is no input to the process generator other than the adjustment of the process and outside energy (beyond control of the operator).

Consider the same system in the accident context. We will assume the industrial climate of the operator can be classified in
a series of discrete categories which are called environmental events.\(^1\) At any one time the operator works under one and only one environmental condition (event). Each event is composed of a set of states such as:

1. the state of operator behavior (his responses)
2. the state of the job climate—heat, light, ventilation, noise, etc.
3. the state of the mechanical aspects of the job
4. the state of conditions incidental to the job but which have a potential influence on operator behavior
5. the state of social and managerial influence
6. all other states relevant to job safety

Under this description an infinite number of events would be possible. For purposes of this study, we are interested only in those events with different magnitudes of accident risk. Risk here is the probability of an accident under a given event. In this manner we can group events in terms of their risk (over constant exposure). An accident will be defined as an unplanned event which disrupts production and could or did result in personal injury. It is assumed that only one accident can result from a given event since risk implies an event change to an accident event where production is terminated. Referring to our previous example,

\(^1\)The terminology here is taken from Savage (55), where an event is a description of the real world. An event is made up of a set of states. This differs from the terminology of Feller (21) and others, who identify the real world as states in describing stochastic processes.
we can say that the process generator is an event generator. The settings on this generator are operator responses. At some time \( t \) the operator samples his environment, \( E_1 \), and transmits this information back to a decision-making component which elects an appropriate response. To maintain safe operation, the operator must ascertain existing conditions and the risk involved, and select those responses which keep risk at a minimum. The reference value might be considered in this simplified scheme as a preassigned event which minimizes risk. Two additional components can be added to this structure. The mechanism which measures the existing event is called the receptor, and may involve visual, auditory, or kinesthetic determination of the event. The effector is the response mechanism—the means to evoke changes in operator behavior (and in some cases, non-behavioral states). The effector acts upon information regarding the difference between actual and desired output (events). The distinguishing feature of the outputs of the event generator is that the distribution of events is stochastic. This means that there is a probability of an event, \( E_1 \), obtaining at time \( t \). This probability changes with time. Since the behavioral state can be specified by action of the effector, the stochastic distribution of events results from the stochastic nature of the non-behavioral states. The unusual aspect of the generator is that many of the non-behavioral states are beyond the control of the operator. Hence, he must select those behavioral states which, with expected non-behavioral states, provide low risk events. This
condition necessarily removes our consideration of the accident phenomena from traditional servo systems where the output and input is usually a prescribed function (e.g., sine wave). The basis for assuming that non-behavioral states are stochastic in origin stems from reflection of the kinds of states involved. We would expect a probabilistic interpretation to machine failure. However, since machine failure depends upon other factors such as operator usage, line voltage, quality of material, etc., we cannot expect this probability of failure to be constant over time. Moreover, states involving operator distraction, foreman pressure, etc., occur with probabilities that change over time.

The accident model is shown below:

Fig. 6. - Accident phenomena - Stage 2 of the feedback analogue.
If event \( E_i \) occurs at \( t \), then \( I(t + \tau_1) = f\left[ E_i(t) \right] \)

where \( I \) is the information reported on \( E_i(t) \) with a detection lag \( \tau_1 \). \( I(t + \tau_1) \) is compared with \( E_s \), the reference value of \( E_i \). \( R(t + \tau_1 + \tau_2) = f' \left[ I(t + \tau_1) - E_s \right] \) where \( R \) is the response arising from the comparison of \( I \) and \( E_s \). \( \tau_2 \) is the response time.

As yet we have not discussed the nature and source of the reference value. The decision-making aspect of the system will be termed the goal setting mechanism. We will hypothesize that this mechanism performs two functions:

1. It assigns a utility \( (u) \) to each reported event, \( I \).

2. With a prescribed principle of choice and this utility, it dictates a decision rule to evoke responses given \( I \). (The decision may be to maintain a given response.)

The principle of choice referred to here involves such rules as maximization of expected utility, minimization of expected loss (of utility), etc.

Leaving aside for the moment the question of how and how much information is to be obtained by the detector (receptor), we note that \( E_i(t) \) depends upon \( R(t) \) and the generated non-behavioral states. Not all \( E \) are equally desirable. If \( E = \{ E_i \} \) is the set of all possible events, and \( \mathcal{U} = \{ u \} \) is a utility space (set), we can define a utility function \( U \) over \( E \), that is, \( U(E_i) = u \). If \( \mathcal{U} \) has a sufficiently defined metric, then \( U \) will impose some type of ordering on \( E \) which permits a comparison of the desirability of the various \( E_i \). \( \mathcal{U} \) may be highly restrictive, e.g., \( \mathcal{U} = \{ u_a, u_n \} \).
where $u_a$ is the utility of an accident and $u_n$ equals the utility of "not an accident." $U$ here would be simply a partition of $E$ into two subsets $E_a$ and $E_n$. ($E_a, E_n \subseteq E$). The assignment of $u$ to $E_i$ is accomplished by the goal setting mechanism. The notion of utility is not confined to the particular event involved, but to various durations of exposure to the event. Moreover, utility can be associated with the detection, decision, and response aspects of the system. Certain responses, for example, may make excessive demands of the operator and hence have undesirable utility. The decision rule follows from the choice principle. If decisions are based on the principle that $R = f[U(E_i)]$; $u(E_i) \geq k$, where $k$ is an arbitrary value of utility, this means that appropriate responses will be made to produce $E_i$ which have utility $\geq k$. Hence, the reference value used earlier may be a fixed or variable utility requirement. At this point we shall not be concerned with how this utility for $E_i$ is derived. We merely assume that responses ($R$), or the lack of them, are based upon the operator's estimation of utility. This does not presume logical behavior on the part of the operator. His utility structure may be erratic and based upon poor information about $E_i$.

The figure below illustrates inclusion of the goal setting mechanism. Note that the sampled information is also connected to the goal setting mechanism. We would hypothesize that utility evaluation would be affected by sampled information about the job. The role of the comparator now becomes more precise. Given a utility
level to maintain and established utility for each $E_i$, then the comparator compares $u_g$ (utility desired; either constant or established for each $I$) with $u(E_i)$ and issues instructions to the effector to change $E_i$ to an $E_j$ ($j \neq i$) which has utility $u_g$.

![Diagram of the feedback analogue.]

Fig. 7. - Accident phenomena - Stage 3 of the feedback analogue.

Manipulation of responses, given certain non-behavioral states, can under certain circumstances restrict $U(E_i)$ to high utility regions of $\mathcal{U}$ for broad classes of admissible decisions. It should be noted that these are not the only methods of maintaining safe operation. Although the non-behavioral states behave stochastically, some of these states (such as equipment and material) can be altered to produce more favorable conditions. Instances of fail-safe mechanisms, machine guards, and warning devices are examples of this. The goal setting mechanism is by no means completely explicated by the above comments; for in a sense we are attempting to explain human behavior,
a task which has eluded scientists since the beginning of man. Our hypothesis at this stage of development is simply that the operator places value on operating under certain events, and this value or utility assignment is the basis for his behavior. What principle of choice is used, when it is used, and how utility is assigned can only be hypothesized. Carefully designed experiments offer some hope of answering these questions.

A final enrichment of the model is to introduce an intervening variable called internal stimuli. This mechanism is added to explain those unintended responses, mental blocks, instances of failure to use sampled information, etc., which play an important role in what we know about accidents. As with the goal setting mechanism, we are not prepared to completely describe functional operation, physiological bases, and the causes of internal stimuli. We can, however, qualitatively describe its effect on the model developed at this point. Internal stimuli might be considered the reservoir of non-job experiences which compete with the cognizant goal setting mechanism. Internal stimuli can introduce noise into the system at three points. It may be static which distorts transmission of information, or a complete closure of the control link involved. Internal stimuli may block or mix with sampled information from the receptor. It may block response or elicit responses. It may also affect the goal setting mechanism and comparator such that, although sampled information is received, no use of this information is made. Moreover, internal stimuli may act to provide distortions of the utility
structure. The inclusion of internal stimuli is shown below.

![Diagram of feedback analogue](image)

**Fig. 8.** Accident phenomena - Stage 4 of the feedback analogue.

Note that internal stimuli action has no direct effects on the events generated. If we let \( N(t) \) be the contribution of internal stimuli at time \( t \), then the alterations of the previous equations follow.

\[
\begin{align*}
I(t + \tau_1) &= f \left[ E_1(t) + N'(t) \right] \\
U \left[ I(t + \tau_1) \right] &= f \left[ I(t + \tau_1) + N''(t + \tau_1) \right] \\
R \left[ t + \tau_1 + \tau_2 \right] &= f \left[ U I(t + \tau_1) + N'''(t + \tau_1 + \tau_2) \right]
\end{align*}
\]

\( N'(t), N''(t + \tau_1) \) and \( N'''(t + \tau_1 + \tau_2) \) may be either responsible for distorting the intended functional relationships, or have the effect of cancelling out the other term in the right side of the expression.
The various components of the system will be described in more detail in the subsequent section of this chapter, together with a discussion of the relationship of time, probability, and severity. Finally, a formal treatment of the model will be proposed.

The Components of the Feedback Accident Analogy

The goal setting mechanism

The function of the goal setting mechanism is the determination of operator behavior. By the assignment of utility to any event, this mechanism provides a signal input to the comparator which in turn dictates a response. The input is not necessarily fixed since operator's utility for various events may change with time. In the simplest case we might view the utility structure or payoff matrix as the ranking of all possible events in terms of their utility to the operator. Hence, for every \( E_i \), we hypothesize that the operator assigns value or utility \( u_i \). The decision rule is based upon this utility assignment. Whenever the receptor detects event changes as a result of changes in job states, the comparator selects the response which returns the event to one of desired utility.

The action of the goal setting mechanism on the comparator might be hypothesized in three ways. The comparator is given a set of appropriate responses to be evoked when certain events are reported. The criteria for appropriateness could be to maximize event utility, seek events with low risks, seek events with high expected
gain, or low expected loss, or combinations of these. The simplest type of order to the comparator would be to maintain a certain event. From any existing event, \( E_1 \), the desired event, \( E_s \), could be obtained by certain responses. The system would function essentially as a regulator detecting shifts and making responses to return the environment to the standard event. A somewhat more unrealistic hypothesis would be to suggest that each event detected would be assigned a utility and this value compared with the utility of all other possible events which could be evoked with proper response. This implies that before any response is made, the goal setting mechanism must evaluate the existing event and make a series of comparisons of all other events on the notion of utility. This action does not permit the occasion of learned response patterns to existing events. A third hypothesis would propose that an emergency response is to be used whenever particular undesirable (low utility) events are detected. The basis for this response would again be the utility of the resulting event and the existing event. The situation may be such that for the majority of events detected, a standard response pattern is immediately effected. Other events require utility assignment and comparison with other events before a decision is made. The latter would arise if unusual events occurred. If utility dictates the operator's selection of an event, then two problems arise:

1. How does the operator attach utility to an event?

2. What is the operator's principle of choice which dictates his decision rule?

Some studies on descriptive decision-making in the face of uncertainty
which might describe the basis for operator behavior have recently been attempted. Coombs and Beardslee (15) suggest that a subject acts to maximize his expected utility. In a gambling situation, the operator associates the acquisition of some prize with a certain probability and the possible loss of some stake with one minus this probability. Each response attempts to maximize the expected utility. It is difficult under the consideration of accidents to associate a prize or gain with safe operation under a particular event. Some events constitute higher production rates and hence have more utility than others. The prize might also be a reflection of social influence. There may be prestige associated with operation under a particular event. The potential loss with operation under an event is more easily understood since we can attach an expected loss to exposure to a certain event, this loss being the product of the expected severity of an accident and the probability of an accident with this exposure. Hence, we might hypothesize that event utility is the difference between expected gain and expected loss. Stated formally:

If \( \beta_i^t \) = subjective probability of an accident under exposure of time \( t \) to event \( E_i \)

\( U_i^t(P) = \) utility of the prize if no accident occurs with exposure of time \( t \) to \( E_i \)

\( U_i^t(S) = \) utility of the stake (e.g., an arm or finger lost as a result of an accident) resulting from exposure of time \( t \) to \( E_i \)

then the expected utility with exposure of time \( t \) to \( E_i \)

\[ U_i^t = U_i^t(P)(1 - \beta_i^t) - \beta_i^t U_i^t(S) \]
The significance of this hypothesis is that $\beta_i^t$ is the subjective counterpart of $p_i^t$, the actual probability of an accident with exposure to $E_i$. An operator might attach excessive utility to $E_i$ because he underestimates $\beta_i^t$ or $U_i^t(S)$, or overestimates $U_i^t(P)$.

The above is just one model of the operator's value scheme. $U_i^t$ might simply be $U(P) - U(S)$. Regardless of the way in which the utility of an event is developed, it is certain to change with time. Using the expected utility notion above, we would expect that $\beta_i^t$ would vary with the operator's own experience and the experiences of those around him. A nearby accident on a similar job might suddenly increase $\beta_i^t$. Thereafter $\beta_i^t$ might decrease with further accident-free exposure in some functional manner (e.g., exponentially). $U_i^t(S)$ would appear to be influenced sharply by the operator's personal experience and the experience of those about him. The severity of nearby accidents might likewise influence $U_i^t(S)$. In addition to the problem of determining the sensitivity of the utility attached to an event, there is the problem of the choice principle of the operator. He might maximize expected utility, base his decision on the event with the highest possible prize, select that event with the highest $(1 - \beta_i^t)$, the probability of no accident, or act to minimize the maximum possible loss. In terms of practicality, our only method of evaluating the criterion the operator uses for selection of an event is to present him with a series of events and from his response selections make inferences about his decision criterion. This still does not put a yardstick on individual utility. In the
accident problem we can only infer the "goodness" of a utility structure on the basis of observed performance. Those operators who elect to operate at high hazard levels must be assumed to have either a defective utility structure (defective in terms of minimizing accidents), or a sound structure which is influenced in some way by internal noise (internal stimuli). Despite the fact that the notion of a value or utility structure in the model is an intervening variable and has no direct measurable characteristics, it does aid in the ability of the model to describe the aspects of the accident phenomena. For example, if an operator's exposure to high hazard levels can be traced to his utility structure, we can suggest methods of changing this structure, such as job education. Moreover, we can design experiments to compare $\phi^t_i$ and $p^t_j$, and begin to develop criteria for comparing the safety qualifications of operators. If $\phi^t_i$ is a factor in personal utility, then we might be able to apply some of the recent learning theories and seek ways to modify this utility and operator behavior.

**Internal stimuli**

In dealing with explanations of human behavior in the accident situation, it is realized that the mechanism which brings about this behavior cannot be specified completely. The notion of a utility structure and decision criterion implies cognizant operation. In actuality, humans make responses (or fail to make responses) which are not always consciously elected. The operator often "turns off" his conscious state and drifts into emotional preoccupation or revery.
Daydreams are indications of this departure from the real world. Responses are often elicited which cannot be recalled immediately afterwards. To account for this type of situation, another intervening variable called internal stimuli was added to the model. As shown in Figure 8, it is capable of signaling the effector mechanism to enact certain responses, or of directly influencing the utility structure. Non-job experiences are stored here and may be selectively recalled. An unpleasant experience at home might reflect itself in aggressive action on the job. This omnibus device has the ability to simply turn off the feedback process or jam the comparator. Internal stimuli action may only partially affect the goal setting mechanism, introducing various amounts of "noise" into the system. Operators are often reported to be completely oblivious to job surroundings. At other times, the operator may sample his environment, detect a high hazard event, but fail to make use of this information. Internal stimuli may also dictate unintended responses, or ones in which the operator had no cognizance. This does not refer to reflective responses since we would hypothesize that the latter are preset by the goal setting mechanism specifically for certain situations. While in an emotionally preoccupied state, the operator might be capable of performance which could not be explained or even recalled in retrospect. In terms of separating internal stimuli from operation of the utility structure and decision rule, it may be possible to separate the former by assuming its effect is a random input to the system. In a compensating tracking task study, Walston and Warren (67)
described this component of behavior as random noise and treated it as unexplained variance in performance. The inclusion of this mechanism into the model is to provide explanation of any kind of accident behavior. The ability to isolate it will depend upon how adaptable the entire model is to measurement, control, and prediction.

The receptor mechanism

The feedback model of the accident phenomena is based on the operator performing as a sampling servo. At periodic time intervals the operator samples his existing environment. The information about this environment is fed back to the comparator for any desired action. The ability of the receptor mechanism (visual, auditory, or otherwise) to properly detect the existing event is dependent upon the states which make up the event and the physical condition of the receptor. Detection necessitates a certain set of physical requirements such as adequate illumination, proper eyesight, good health, etc. Moreover, the states must be detectable. Gauges must be easily readable and in a position to be read. The time to identify an event depends upon the number of states that must be detected. An important facet of the model is operator over-all response time (reaction time) which is made up of:

1. the time to identify the event
2. the time to apply the decision criteria
3. the time to physically make a response

The identification time will limit the minimum reaction time possible.
This characteristic of the human is rarely measured in industry. Inefficient detection of states made with a sample might explain excessively long reaction time. This function of the receptor mechanism would appear to be adaptable to controlled experiments using techniques such as motion pictures of eyeball position. It is apparent that simple reaction time tests are not appropriate in dealing with identification of hazardous events. The feedback model suggests a complete re-evaluation of reaction time accident studies. Detection is not always possible. There is a probability of correct identification associated with each sample, since physical requirements of detection will vary with time and the existing job states themselves resist identification. The operator essentially must filter from all the activity about him only that information that is relevant to job safety. In view of this, it becomes important that the design of a job facilitates its identification.

Human engineering considerations enter at this point. If information displays are involved, they must be designed to allow rapid and accurate identification. This is an area where designed experiments could be set up to find the best possible environmental conditions for identification. Since there is a large number of possible states, there must be a procedure to restrict the sample to those key states which affect event hazard and ones which are likely to change with time. It is apparent that certain states, although affecting event hazard, have such a small probability of occurrence that for practical purposes they could be omitted. The state of the plant roof is important
to the safety of the job, since with its collapse a very high hazard event would result. This change in state is so remote that samples of this state would hardly be efficient use of operator time. Another critical element in the receptor mechanism is the time at which samples are taken. The factors which make up the sampling plan will be discussed later.

Throughout this paper it is assumed that when a sample is taken, the event is correctly identified. Actually, for any sample there is a probability of being able to detect the states which make up the event because of varying physical requirements and the nature of the states themselves. Some interesting considerations develop with these notions. How does one increase the probability of an accurate identification? How does one specify for a given job the states to be identified? The roles of placement, plant medical examinations, and human engineering become significant with this aspect of the model. The physical requirements for proper sampling are dependent upon the nature of the process involved. For this reason, the time and state distribution for the environment must be ascertained before we can specify what is to be sampled, when it is to be sampled, and how it is to be sampled. The three problems are interrelated, with the first problem primarily dictating the approach taken with the others. In terms of applying the model to specific jobs, it would be necessary to specify all possible events and the states which make up these events. As will be pointed out in a later section, the decision to sample depends upon the other factors competing for the
operator's time. The effect of psychological and physiological stress on the probability of accurate identification of the existing event offers the possibility of interesting laboratory experiments along this line.

**The effector mechanism**

That part of the system which transmits instructions into physical responses is called the effector. The effector is capable of a wide variety of responses, from simple avoidance reflects to complicated manipulation of equipment. The operator's behavioral state may be a single response or a set of responses organized into a definable pattern. The response can either change the behavioral state or both behavior and job states. The latter would result if a response consisted in the adjustment and control of equipment or machines on the job. Driving an automobile is an example of responses which change non-behavioral states. The pedestrian who jumps to the curb and safety is changing his behavioral state, but not (to him) the state of the highway environment. On the other hand, his action does affect the state of pedestrian activity to an oncoming driver. This example illustrates the fact that the model applies at any one time to a given operator (or group of similar operators). It is the operator's ability to change job states with certain responses that makes prediction of environmental events difficult.

Just as there is a probability associated with the detection of the existing event and its component states with a given sample, there is a probability of the effector carrying out the desired response or
set of responses. The factors which affect a given response and the time required for its performance are:

1. the physical state of the operator—his health, his resistance to fatigue, etc., his ability to function under various conditions of stress, such as heat, humidity, noise, etc.

2. the states of the job which could prohibit the response (it may be such that crowded job conditions prevent certain responses)

3. the number and nature of states which must be altered by the response—certain equipment may be difficult to control or be such that incorrect changes of its state are possible

This last function refers to some of the problems in human engineering. Controls may be difficult to actuate. They may be massed together so that it is easy for the operator to select the wrong control. One of the outstanding failures in present day accident prevention has been the lack of human engineering considerations in the study of accidents, both with respect to information displays and operation of controls. Many times operators are expected to operate so many controls that frequent selection errors result. Very often the nature of the job and responses required to alter job states produce an extremely complex over-all response task. It may be impossible to accomplish the intended response, or at least necessitate excessive time for its performance.

Considerable research, principally by psychologists, has been conducted in the areas of human response, control of equipment and the psychological factors which influence the accuracy and time required to make responses. Since exposure to high hazard events is dependent upon response time, these studies should prove valuable in prescribing the optimum controls and environmental settings for particular jobs.
Although a given instruction for a response is assumed to be fulfilled by the effector throughout subsequent developments of the model, it must be re-emphasized that the three factors above may be present to various degrees in any one situation, and hence we can actually only ascribe a probability to the fulfillment of a response instruction. As pointed out above, response time is just one of the factors affecting over-all reaction time. Yet, it does control the minimum reaction time possible, since the response to an instruction must be completed before a second instruction can be acted upon. If this is not the case, variation in performance may result from correction during detection and instruction.

The Relationship of Temporal, Probabilistic, and Severity Aspects of Accidents in the Framework of the Model

In terms of the feedback model there exists the problem of relating time, severity, and probability before we can discuss more completely the various facets of the accident phenomena. The notion of severity and probability is encompassed in the term "event hazard." For an individual operator and a specific event the term probability has no meaning. Either an accident will or will not occur. Yet, the complexity of the problem suggests that every state cannot be explicitly defined, and hence chance plays a role by virtue of our inability to predict with certainty the outcome of an event. Certain events may be said to have a high probability of accident. Broadly speaking, this means that for a large number of operators working under a certain event for a given exposure, we can expect a large number of accidents.
Our own experience tells us that driving 80 miles per hour is a hazardous situation. Any number of changes in the operation of the car or in highway conditions can lead to an accident—a tire blowout, an oncoming car crossing the center line, etc. Strictly speaking, these are changes in states and hence event changes. Yet, these changes cannot be predicted with certainty each time a person drives at this speed. Hence, in the long run, there is only a chance of an accident resulting from operation in a given event. Thus an accident may occur with a given event because:

1. The event is only broadly described and small variations in any of the non-behavioral states which make up the event could result in an accident event.

2. The event is explicitly defined, but a change to an accident event may develop so rapidly as a result of changes in non-behavioral states that for practical purposes the operator has no control over them (ability to make responses to avoid the accident).

3. The specified event includes a state of operator behavior, but this behavior when applied to a group of operators has slight variations which, together with certain non-behavioral states, could result in an accident event.

Note that probability or risk is associated with an event, which includes a description of all states of that event, including operator behavior. This suggests that risk is the probability of a shift from
any event $E_i$ to $E_a$, an accident event. An accident event includes either a state of non-production or a state of operator injury, or more commonly, both of these states.

Thus we can say that with a given event there is a probability of an accident. This probability is the risk of a given event and is associated with a definite length of exposure to the event. Actually, event risk refers to the probability of progressing from that event to an accident event in a given time period. Any intermediate events that might occur would be dictated by the transitional probability of changes in non-behavioral states. The specific relationship between risk and time would require extensive data since there is no reason to expect this relationship to be the same for each event. With this general notion of risk we can introduce the severity aspect of the accident. The probability of an accident means that certain types of accidents will occur, each with some relative frequency. To each of these accidents is associated some severity. The accident may be a death, or merely abrasion to particular parts of the body. It may result in a 15 minute delay, or shutdown of the plant. This severity could be expressed as:

1. part of the body injured

2. length of time for recovery (or specific time charges in the case of a permanent partial injury)

3. cost of the accident in terms of lost wages and medical expenses to the injured party

4. the cost to the company as a result of the accident, including lost production, insurance premiums, damaged equipment, etc.
5. total costs to both company and worker, i.e., the sum of 3 and 4

6. social costs including loss of consumer purchasing power, community losses, etc.

Considerable data from plant accident files and insurance carriers exist for items 2, 3, and 4. Item 1 of itself is not an objective measure of severity, since there is no way of comparing the magnitude of loss for the various injured members, e.g., which has a greater loss, an injured toe or an injured finger? We cannot say which is the best measure of severity. It depends primarily on the use. If we want to study the value structure of the operator, then we want to measure the time or dollar consequences to him as a result of the selection of a given event. If we want to study the company's decision to invest money to reduce accidents, then the company is concerned with losses described in item 4. If we view accidents as a social disease, then we might be interested in the sum of items 5 and 6.

For purposes of showing the relationship of time, probability, and severity consider the following restrictive condition. Suppose we are in a position to record every event the operator is exposed to and the duration of each exposure. Suppose further that we focus our attention on a small segment of operator activity, the exposure of $t_1$ to event $E_1$. Our task is to evaluate the consequences of the exposure.

Let $L_{ij} =$ the expected loss in time or dollars from a $j$th type accident that could result from exposure to $E_i$

$$L_i = \sum_{j} L_{ij} = \text{the average expected loss from any accident resulting from exposure to } E_i$$
$p_{ij}^t$ = the probability of an accident of the jth type from exposure of $t_i$ to $E_i$

$P_i^t = \sum_j p_{ij}^t$ = the probability of any accident with the exposure of $t_i$ to $E_i$

then $H_i^t = p_i^t L_i$, the hazard or expected loss from exposure of $t_i$ to $E_i$

$p_i^t$ is the risk associated with exposure to $E_i$ and might be viewed as the transitional probability of $E_i$ to $E_a$ (the accident event) in time $t$. Note that risk but not loss is dependent upon $t_i$. We would expect $p_i^t$ to increase with increasing $t_i$ in most instances.

The same general relationship can be used in considering larger intervals of time and the hazard associated with an operator's decision. Assume that at time $t$, the operator takes a sample of the environment and elects to operate under $E_i$ until the next sample is to be taken at $t + t_i$. During $t_i$ there is a probability of going from $E_i$ to $E_a$. There may be intervening events between $E_i$ and $E_a$. These would depend upon: 1) the changes in job states; the behavior state is assumed to remain the same (barring unelicited responses) until the next decision point, and 2) the magnitude of $t_i$. In this case $H_i^t$ is the hazard (expected loss) from exposure of $t_i$ given the event $E_i$ at $t$. $p_i^t$ is the probability of an accident over time $t_i$, when the initial event is $E_i$. The above relationships are idealized ones based on a microscopic view of the job. Gross approximations of the total hazard on a job would be possible, using work sampling techniques and crude estimates of $L$ and $p_i^t$ from existing accident records and accident claim reports.

When viewed by an observer, a work situation undergoes a series of event
changes, some of which result from variations in operator behavior, i.e., his responses, and others as the result of changes in non-behavioral states. The events may follow a random pattern, a cyclical pattern or one which is dictated by predetermined job states. The duration of any event may also vary in time. Events that recur do not necessarily have the same duration. If time were fixed we would have transitional probabilities of going from event $E_i$ to event $E_j$ ($j \neq i$). But our system becomes more complicated since these transitional probabilities changes with time and are dependent upon past events and their duration, and specific operator responses. Mathematically, the system becomes very difficult to describe. The general description of this process involves "Chapman Kolmogorov Equations" (if time assumes integral values only). In this case

$$P_{in}(\tau, t) = \text{conditional probability of finding the system at time } \tau \text{ in event } E_n \text{ given at a previous instant, } \tau, \text{ the event was } E_i.$$  

$P_{in}(\tau, t)$ is meaningless unless $\tau < t$. The difficulty in adequately describing the changes in events arises from the factors which influence these events. We might broadly classify the factors which simultaneously influence the event changes as:

1. behavioral states
2. non-behavioral states

If the operator's response had no influence on the occurrence of an event or its duration, we would still expect the occurrence and duration of the events to vary in time. Machines go through cycles, occasionally jam or fail. Heat, light, and ventilation may vary in
time. Other operators or operations which affect the given job may change, resulting in state changes and hence event changes.

The operator's behavior is the second major contribution to the complexity of the event changes. By certain responses the operator changes his behavioral state and hence the event. His decision to do this is based on his utility structure, including the expected loss he places on operation under an event $E$, which in turn is dependent upon past events. The operator's sampling scheme will affect the duration of any event, and this same sampling scheme may be influenced by personal estimation of non-behavioral transitional probabilities based on past samples of events. Further complexities arise if we consider that the ability to detect an event with a sample is probabilistic. A vicious circularity may evolve. A high frequency of changes to undesirable events independent of operator response leads to changes in the utility structure and the operator's sampling plan, which may result in more responses and more event changes.

The intricate nature of the accident phenomena makes a simple description of it prohibitive even with the aid of the feedback model. However, one can begin to get a better understanding of the problem if initially the problem is viewed in an oversimplified setting. This increased understanding will eventually promote more explicit definition of this complex phenomena. Permitting, then, a restricted setting, the following description helps tie in some of the ramifications of the problem that were already indicated. This description attempts to interpret various event changes in terms of the notion of hazard.
discussed above. If we assume for the moment a linear function of $p_i^t$ with $t$, then the following diagram (Figure 9) describes how a section (in time) of the job might be described. We hypothesize that the duration of any event such as $E_1$ is made up of:

1. **undetected time**, i.e., from time of the shift until detected by a sample

2. **elected time in the event**—a function of operator utility structure (and internal stimuli)

3. **the response time** required to effect a change in events once the decision has been reached to do so (reaction time)

The reason for the increasing hazard in $E_1$ and $E_2$ is that with extended duration we assume $p_i^t$ increases. The process might be described chronologically as follows:

1. At time zero, the event had no hazard since $p_0^t = 0$;

2. at $t_1$, the operator sampled the situation and decided no change in response was necessary;

3. at $t_2$, a shift in events to $E$ occurred by virtue of a change in non-behavioral states;

4. this shift remained undetected by the operator until his next sample at $t_3$;

5. the operator elected to remain in $E_1$ until $t_4$, at which point a response was made to return the process to $E_0$. The response required $t_5 - t_4$ time to execute.

The election to remain in $E$ for $t_4 - t_3$ may have been the result of a decision rule dictated by the utility structure or by the cessation of the decision-making apparatus because of a jamming action by internal
Undetected time in $E_1 = t_3 - t_2$
Sampling periods = $t_1, t_3, t_6$
Response periods = $t_5 - t_4$, and $t_7 - t_6$
Non-response shift = $t_2, t_8$

Elected time in $E_2 = t_4 - t_3$
Response shifts = $t_5, t_7$
$E_A$ = an accident event
$E_0$ = no risk event

Fig. 9. - A sample time sequence diagram of event changes
stimuli (emotional preoccupation, etc.).

6. At $t_6$ another sample is taken and a response is dictated which shifts the process from $E_0$ to $E_2$. This could be the result again of either:

   A. a cognizant decision to do so because of some value associated with operation at this event, or

   B. an unintended response as a result of a signal from the internal stimulator.

This covers the broad category of unintended responses which the operator has no intention of performing, but result more or less from some emotional preoccupation, revery, etc. Above is the safety gamble on the part of the operator who may or may not realize the hazard involved. This response is completed from $t_6$ to $t_7$.

7. Finally at $t_8$ a change in state to the accident event occurs. This might be another unelicited response (since we would presume the operator would not intentionally have an accident), or more likely a change in some job state which, coupled with the existing response of the operator, results in an accident event.

8. The dotted lines represent the input to the comparator from the goal setting mechanism. This in effect is the standard event, the desired operating level (from the operator's standpoint). Since the standard has shifted after $t_6$, we can say the operator elected to operate at $E_2$ rather than inadvertently make a response which resulted in this event.
The above description, while only providing a qualitative picture of the operator, his job, and the accident phenomena, suggests the salient features of minimizing accidents in terms of the feedback models. Those periods of operation at high hazard levels stem from:

1. shifts in non-behavior states, resulting in high hazard events
2. failure to rapidly detect these shifts because of a poor sampling scheme, or an adequate sampling scheme but inability to detect accurately the existing event
3. exposure to high hazard events because of response time necessary to change events--if the number of shifts is large over a short time interval, this will increase the total exposure
4. operator responses which result in high hazard events, either intentional or unintentional
5. operator election to maintain operation at high hazard events by virtue of a distorted utility structure or a jamming of the comparator by action of internal stimuli

With a general notion of the feedback model and how it operates, and the ability to specify the hazard of a given event, we were able to describe in a qualitative sense the model's interpretation of the dynamic nature of the accident phenomena. This description was developed from one removed from the actual job, observing the event changes and hypothesizing the complex interrelations of man and his environment. This description will be followed by a formal statement of the accident phenomena under certain restrictive assumptions. In subsequent chapters we will divorce the man from his environment and consider the factors which constitute a hazardous job. This will necessitate either using

1) a completely safe operator, one who possesses an optimum sampling scheme and utility structure (i.e., one which seeks to operate at
minimum hazard events), or 2) an average (to be defined) operator.
What is desired here is to develop an objective basis for comparing
the hazard of any job independent of operator behavior. We will also
look at the accident situation in terms of the operator, given a
certain job. Here we will be interested in relating the factors
which will dictate the operator's exposure to \( E_i \), that is:

1. the operator's sampling scheme
2. the operator's utility structure

From these we will propose a basis for comparing safe operation
behavior.

A Formal Statement of the Accident Phenomena
in Terms of a Feedback Model

The general description of the mechanism of the accident
phenomena described earlier expressed qualitatively the interre­
lations of the various components of the feedback model. The time
sequence diagram presented the relation of hazard (expected loss)
with the temporal changes in the environmental events. With this
background of the model, the following material attempts to express
the accident feedback phenomena in a more formal fashion. The intent
here is not to develop a set of equations which will permit one to
solve for expected loss given a utility structure and a distribution
of non-behavioral states, but to present a mathematical structure
which will permit a broader interpretation of the feedback model.
This formal treatment serves two important purposes:
1. It requires explicit statements about the functional relationships of the system variables.

2. It necessitates the stipulation of the assumptions underlying the model as presently conceived. (Often such assumptions are overlooked in a qualitative description of the system.)

In addition, a formal statement of the system often brings to light various facets of the problem which enrich the interpretation and understanding of the model and of the accident phenomena.

The high degree of complexity in the feedback model results from the nature of the components of the system and their interdependency. The difficulty arises not in attempting to describe the changes in the non-behavioral states of the environment, but in describing accident behavior explicitly. In fact, we find ourselves trying to formally structure human behavior in general. Accident behavior is just one facet of human behavior, one of the myriad dimensions that constitute human action. The prospect of quantifying human behavior has occupied the interests of social scientists, philosophers, and mathematicians for two centuries. Our intent here is not to tackle the problem which has eluded scientists until now. Our chief concern will be to formally describe the feedback interpretation of the accident phenomena in an oversimplified approach so that we can better evaluate the usefulness of the model.

Consider the physical environment of a job (job states), together with the behavioral states of operator performance as an environmental event $\mathcal{E}$. Only the physical states of the operator are included in $\mathcal{E}$. 
Note that under this definition of $\mathcal{E}$, infinite number of events is possible. For purposes of this discussion, each event is treated individually. For practical purposes, events could be grouped on the basis of the probability of a change in time $t$ from any non-accident event to an accident event. Psychological aspects will be discussed in terms of decision rules underlying responses. Let $E = \{E_i\}$ be the set of all possible events of $\mathcal{E}$, and let $\mathcal{M} = \{m_k\}$ be the set of all transitional probability matrices, i.e., $M_k = [k \neq E_i, E_j]$ where $k \neq E_i, E_j$ is the probability of going from event $E_i$ to event $E_j$ in some specified time interval when transitional matrix $k$ is used. The discrete time intervals between changes are assumed to be of equal length, although they may be made as small as desired. We will also require the following simplification of the problem:

1. Over $T$ time intervals, the event changes are described by a Markov process with a single absorption barrier (namely, the accident event).

2. With a given matrix $M_k$ in operation, the event changes are the result of changes in non-behavioral states.

Over the time in which $M_k$ is in effect, a single behavioral state exists.

Each time the operator makes a response he may change the existing event and may or may not put a new transition matrix into operation. (His response may be to continue with the existing event.) A response here is interpreted as one which influences the event $E_i$. A Markov process conceptually is the probabilistic analogue of the process of classical
mechanics where future development is completely determined by the present state and is independent of the way in which the present state has developed.

Mathematically, a Markov process is a sequence of discrete valued random variables which for every finite collection of integers $n_1 < n_2 < \cdots < n_t$ the joint distribution of $X^{(n_1)}$, $X^{(n_2)}$, $\cdots$, $X^{(n_t)}$, $X^{(n_t)}$ is defined in such a way that the conditional probability of the relation of $X^{(n)} = \alpha$ on the hypothesis that $X^{(n_1)} = \alpha_1$, $X^{(n_2)} = \alpha_2$ $\cdots$, $X^{(n_t)} = \alpha_t$ is identical with the conditional probabilities of $X^{(n)} = \alpha$ on the single hypothesis $X^{(n)} = \alpha_t$. Here $\alpha_1$, $\cdots$, $\alpha_t$ are arbitrary numbers for which the hypothesis has a positive probability (21).

Assumption 1 and 2 above remove the dependency of event changes on operator behavior. In essence, the work period consists of a series of discrete processes initiated and terminated by operator changes in responses.

If the Markov process exists, then standard formulas permit us to compute $M_k(\tau) = \sum_{E_i} E_j$ where $M_k(\tau)$ is the probability of going from event $E_i$ to event $E_j$ in $\tau$ time periods when transitional probability matrix $k$ is used. The following example will demonstrate the operation of $M_k$. Consider four possible environmental events whose transitional probabilities are tabulated in the following matrix. Each cell is $p_{E_i E_j}$, the probability of going from event $E_i$ to event $E_j$ in a unit time interval. For example, the probability of going from event 2 to event 3 is .05.
Note that event 4 is an absorbing barrier. Once the process goes to event 4, it remains there. Event 4 is interpreted as the accident event. With the occurrence of an accident, work ceases and no further event changes take place.

\( J_{E_i E_j} \) can be explained in terms of the above matrix. Let \( T = 2 \), \( E_1 = 2 \), and \( E_j = 3 \).

\[ J_{E_i E_j}^{(2)} = J_{E_2 E_3}^{(2)} = \sum_{k=1}^{4} J_{E_k E_3} \]

Each term in the right side of the expression is a path by which event 3 can occur at the second time period when the initial event was 2.

To get higher order probabilities in this case, one can simply square the matrix to get \( J_{E_i E_j} \); square the squared matrix to get \( J_{E_i E_j}^{(2)} \) and so on. An interesting facet of the Markov process is the steady state probability, the probability of eventually winding up in a particular event. This steady state is so-called statistical equilibrium. Direct procedures exist for determining these values, given the original matrix. The interesting aspect of this situation is the absorbing barrier. It can be shown that the steady state probability for an absorbing state is one. The theoretical implications
here are significant. If the operator worked under a situation
where a single Markov process dictated the transitional probabilities
and if there was some chance of going from each event to an accident
event, then in the limit an accident would be a certainty. This, of
course, assumes no change in states as a result of a response during
this time. The time at which this steady state probability of the
absorbing state would obtain depends upon the values in the original
matrix. What this suggests is that the operator must be vigilant
enough to detect the approach of this condition and make appropriate
response to put a new matrix into effect, or return the original
matrix to its initial condition in time.

If $E$ is considered to be the accident event then $\mathcal{F}^\epsilon E$ is
the probability (risk) of an accident over a unit time interval. If
$L_i$ is the expected loss (dollars or time) of an accident on the
particular job under operation in event $E_i$, then the expected loss
over a unit interval of time is $\mathcal{H}^{(1)} E_i \mathcal{F}^\epsilon E_i L_i$. This is the
hazard associated with an initial event $E_i$ in a unit time in $M_K$.
For $T$ time intervals the expected loss or hazard $\mathcal{H}^{(T)} E_i \mathcal{F}^\epsilon E_i L_i$
Note that $L_i$ is independent of $T$. $\mathcal{H}^{(T)} E_i \mathcal{F}^\epsilon E_i$ is dependent upon $L_i$, $T$, and
$E_i$, the initial state. ($\mathcal{F}^\epsilon E_i$ is equivalent to $p^t_i$ used earlier in
this chapter.) The use of a Markov process allows us to describe the
relationship of risk ($p^t_i$ used earlier) and time. This relationship
depends upon the values in the matrix. For the above matrix

$$p^t_i = 0.2$$
$$p^t_i = 0.2 \times 1.00 + 0.5 \times 0.05 + 0.2 \times 0.2 + 0.2 = 0.36$$
These would give us 2 points on the curve of $p_{11}$. Additional higher values of $p_{11}$ could be computed to complete the plot. The shape of this curve would dictate to some extent the optimum time for a change in response. Note that $p_{11}$ is the probability of going from event 1 to event 2 in 2 time periods. It would also be interesting to compute the probability of going from the initial event to an accident event in either the first or second period. In this case

$$p_{11}^{(1)} = p_{11}^{(0)} + p_{11}^{(1)} \left(1 - p_{11}^{(0)}\right) = 0.2 + 0.3 \times 0.3 = 0.488$$

This would appear to be a more meaningful estimate of $p_1^t$ than $p_{11}$.

On the basis of the assumptions behind the formal statement of the model, several interesting relationships develop from consideration of $p_1^t$ and $t$. If the job consists of several discrete Markov processes, then within any process the risk or the probability of an accident will eventually be 1, since this is the steady state probability of an absorbing barrier in a Markov process. This accentuates the need for sampling and response before this condition happens. The change in $p_1^t$ with time depends on the values in the transitional matrix. Moreover, with extended time periods, the initial events become less important in the over-all hazard of the total time period. With each new sample the risk of all previous events vanishes and future risk is dependent only on $E_i$ and $M_i$. This would suggest that with each correct sampling, the operator renews the process and $p_1^0 = 0$. Past events serve only to identify the values in $M_i$.

A sampling, $S_{E_i}(t)$ is a statement (possibly false) that event $E_i$ obtains at time $t$. Let $S(t) = \left\{ S_{E_i}(t)/E_i \in E \right\}$ be the set of all possible samplings given an event $E_i$ from the set $E$ where $S_{E_i}(t)$ is an element of $S(t)$. Let $P_{E_i}(t) = P_{E_i}(t/E_i)$ be a probability measure defined over $S(t)$.
with \( p_{E_j}(t/E_i) \) the probability (density) of \( S_{E_i}(t) \) conditional on \( E_i \) being the event that actually obtained at \( t \). Also \( P(t) = \{ p_{E_j}(t/E_i) \} \).

Let \( S_m(t) \) be the statement (again, possibly false) that transition matrix \( M_k \) obtains at time \( t \). Further let \( S'(t) = \{ S_m(t)/M_k \} \) and 
\[
p_f m_k(t) = \{ p_{M(t)/M_k} \} \quad (k \neq 1)
\]
where \( p_{M(t)/M_k} \) is the probability density of \( S_{M(t)} \) conditional on \( M_k \) being the matrix which actually exists at \( t \). Also, let \( Q(t) = \{ p_{M(t)/M_k} \} \).

The above statements refer to the sampling situation. The operator not only attempts to identify the existing event, but also the existing \( M_k \). As mentioned earlier in this chapter, there is a probability associated with his ability to make a correct identification of either \( E_i \) and \( M_k \). This is dependent upon what must be identified, design of information displays, past events and the like.

A response \( R_{M, E_i, E_j}(t) \) at time \( t \) is a transformation that takes \( M_k \) into \( M_k ' \), i.e., \( M_k ' = R_{M, E_i, E_j}(t) M_k \) and \( E_i \) into \( E_j \); \( E_j = R_{M, E_i, E_j}(t) E_i \).

For each \( E_i \) there exists a response \( R_{E_i, E_j} \) which transposes the event to \( E_j \). A decision \( D_{M, E_i, E_j}(t) \) at time \( t \) is a transformation which carries \( S_{E_i}(t) \) and \( S_{M_k}(t) \) into \( R_{M, E_i, E_j}(t + \tau) \) where \( \tau \) is a positive integer whose value may depend on \( E_i, E_j \). \( \tau \) may be a random variable with a distribution function \( \tau \sim \{ E_i, E_j \} \).

With \( S_{E_i}(t) \) and \( S_{M_k}(t) \) there is also the decision to assign a value to \( r \) which is the interval between samples.

\[
r = f \left[ S_{E_i}(t) S_{M_k}(t), D_{M, E_i, E_j}(t) \right]
\]

The basis of \( D_{M, E_i, E_j}(t) \) is \( \bigcup_{E_i} \). The apparent utility of operating for \( T \) time periods given the initial event \( E_i \) and matrix \( M_k \). The apparent utility of \( M_k \) and \( E_i \) for \( (T + 1) \) periods is

\[
k^{U_{E_i}(\tau + 1)} = k^{U_{E_i}(\tau)} + \sum_{E_j} k^{U_{E_i}E_j} k^{P_{E_j}E_j}
\]
Let $R(t)$ be the set of all possible responses at time $t$;

$$R(t) = \left\{ R_{k \in E} E_j(t) \right\}$$

where $R_{k \in E} E_j(t)$ is a response which carries $E_i$ to $E_j$ and $M_k$ to $M_k$ at time $t$. $R_{k \in E} E_j(t)$ essentially brings about a change in elements of the sets $M$ and $E$. Note that $E_i = E_j$ and $K = \ell$ is possible. This is a status quo response.

The decision rule through utility assignment of the sampled information evolves a decision to 1) make a specific response to change $E_i$ and $M_k$, and 2) set the time interval for the next sampling, $r$. Let $Z_{E_i}$ be the set of all possible time intervals $r$ from $S_{E_i}(t)$ and $S_{M_k}(t)$ until the next sampling. $Z_{E_i}(t + r)$ indicates that $S_{E_i}(t)$ and $S_{M_k}(t)$ are followed by a second sample $r$ periods later, $S_{E_i}(t + r), S_{M_k}(t + r)$.

Let $U_{E_i}$ be the utility assigned to $S_{E_i}(t)$ and $S_{M_k}(t)$ at time $t$ for $T$ time intervals where $U_{E_i}^{(T)} = \sum_{E_j} U_{E_i}^{(T+1)}$. It is assumed $U_{E_i}$ includes $R_{k \in E} E_j(t + T)$ is a function of $S_{E_i}(t), S_{M_k}(t)$ and $U_{E_i}^{(T+1)}$. Here $R_{k \in E} E_j(t + T)$ is a response to be evoked at $t + T$ to change $E_i$ to $E_j$ and $M_k$ to $M_k$.

$D_{T,\mathcal{E}_j} \mathcal{E}_k(t)$ is a decision at time $t$ which decides:

1. $T$, the time for the next response
2. $r$, the time for the next sample
3. $E_j$, the new event to be obtained by the response
4. $\mathcal{L}$, the new transition matrix to be obtained by the response given that $M$ and $E_i$ exist at $t$.

Items 1, 3, and 4 are incorporated in $R_{k \in E} E_j(t + T)$. Thus

$D_{T,\mathcal{E}_j} \mathcal{E}_k(t)$ is a transformation which carries $S_{E_i}(t)$ and $S_{M_k}(t)$ into $U_{E_i}^{(T)}$ for various $T$ and carries $U_{E_i}^{(T)}$ into $R_{k \in E} E_j(t + T + T_{E_i} E_j)$.
and $S_{E_k} (t + r)$ and $S_{M_k} (t + r)$ where $T_{E_i E_j}^t = \text{response time in changing from event } E_i \text{ to } E_j$. If the operator acts to maximize utility then the selection of $r$, $T$, $E_j$, and $M_j$ would be those variables which provide the maximum utility over $T$. Note that we can also use this structure to consider the normative aspects of operator decisions (i.e., $K_{E_i}^t$ instead of $K_{E_i}^t$).

To illustrate the formal statement of the problem presented above, consider the following simple example. There are three events possible to the job, 1, 2, and 3. Number 3 represents an accident event. There are two transitional matrices, $M_a$ and $M_b$. $M_a$ results with $R_1 2$; $M_b$ results with $R_2 1$. $R_1 2$ is a response which obtains event 1 from 2. $R_2 1$ is a response which obtains event 2 from 1. Assume each sampling obtains correct identification of $E_i$ and $M_k$.

$$
\begin{array}{ccc}
& 1 & 2 & 3 \\
1 & .3 & .1 & .1 \\
M_a = 2 & .3 & .2 & .5 \\
3 & 0 & 0 & 1.00 \\
\end{array}
\quad
\begin{array}{ccc}
& 1 & 2 & 3 \\
1 & .1 & .1 & .8 \\
M_b = 2 & .4 & .5 & .1 \\
3 & 0 & 0 & 1.00 \\
\end{array}
$$

Assume the process begins with a sample which is a correct identification of $E_i$ and $M_k$. Assume that the operator acts to minimize

Let 1) $L_i$ be the same for all $E_i$, = $1000

2) $\gamma = 0$

3) each unit time interval is one minute
At \( t = 0 \), the time of sample, the event equals \( E_2 \) and the transition matrix is \( M_a \).

Consider the period under study is three minutes, \( T = 3 \).

Assume each transition occurs at the end of one minute.

<table>
<thead>
<tr>
<th>Decision</th>
<th>Response</th>
<th>( H_{E_i}^T )</th>
</tr>
</thead>
<tbody>
<tr>
<td>No responses in T (No change in M)</td>
<td>---</td>
<td>$659$</td>
</tr>
<tr>
<td>( R_{21} ) at ( T = 0 )</td>
<td>( R_{21} )</td>
<td>903</td>
</tr>
<tr>
<td>( R_{21} ) at ( T = 1 )</td>
<td>( R_{21} )</td>
<td>1390</td>
</tr>
<tr>
<td>( R_{21} ) at ( T = 2 )</td>
<td>( R_{21} )</td>
<td>1430</td>
</tr>
<tr>
<td>( R_{21} ) at ( T = 3 )</td>
<td>( R_{21} )</td>
<td>659</td>
</tr>
</tbody>
</table>

Over the three minute interval the decision to make no response changes minimizes the expected loss due to accidents.
Chapter 6.

GENERAL INTERPRETATIONS FROM THE MODEL

One of the problems that has plagued industrial safety is accident definition. In a field which lies between the precision of engineering terminology and the broad connotative descriptions of human behavior, considerable difficulty arises in the specification of accidents, the mechanism behind them, and measures of safety performance. One of the terms which causes confusion is the subject of this paper, namely, accidents. No one definition of accidents is necessarily perfect. We generally characterize an accident by its consequences, which usually are:

A disruption of production

A personal injury

Questions of the magnitude of the above makes this distinction difficult. How long must the disruption be? How serious must the injury be? Are both necessary for an accident? What about no injury accidents, or events which disrupt production and yet fail to incur injury? Are fire and occupational diseases considered accidents? Simonds and Grimaldi (60) define a traumatic accident as "an unplanned event which disrupts production and could or did incur injury." One way to answer the problem of magnitude is to let the above definition apply generally and classify accidents by
their magnitude of production disruption and injury. Hence, we find terms as first aid cases, lost-time accidents, permanent partial injuries, etc. Simonds and Grimaldi also use time and dollars to distinguish accidents. First aid cases result in a loss of less than 8 man-hours and damage less than $20.00. The injured operator reports back to work at least by the next scheduled shift. If the attention of a physician is required, the accident is termed a doctor’s case instead of a first aid case.

Additional problems develop when one attempts to use accident frequency as a measure of safety. Is a no-injury accident an accident? Does "unplanned" suggest unexpected? Is a man with a chronic back problem charged with 15 accidents as a result of 15 recurrences of an old injury, or is this simply one accident? Should accidents be charged to the one hurt or the one responsible for the injury? A paradox results when the known safe operator is unfortunate enough to be injured in an accident, while the operator who constantly takes chances luckily incurs no accidents. Human engineers like to make use of the term error in human behavior. Error usually implies a departure from standard or desired behavior. Operators misread displays, select wrong controls, make responses incompatible with their own observations, etc. Thus, it might be asked if accidents are not merely human errors, or at least in part the result of human error.

The above questions have pretty well been left to the discretion of those concerned with the problem at the plant level. For this
reason published figures of industry-wide accident rates are justly viewed with suspicion. Those studies on accident proneness must be examined carefully to separate blame from victimization. Finally, there is the general problem of occupational diseases which are treated like traumatic accidents in terms of workmen's compensation laws, but require special distinction in accident prevention programs. Since an occupational disease is rarely the result of a single unplanned event, it is difficult to explain under the general causal model mentioned earlier. Is an unsafe act associated with an occupational disease? Does an occupational disease fall into the same classification as traumatic accidents, even though there is little disruption of production as a result of it? Moreover, what part does individual susceptibility to certain conditions (e.g., cutting oils and dermatosis) have in stipulating operator liability? It is the intent of the suggested theoretical framework of the accident phenomena to provide a more consistent set of definitions and resolve some of the problems presented above.

Perhaps the greatest single value of the feedback model in its present state of development is its ability to tie together the ramifications of the accident phenomena into a single structure, and to re-interpret presently held truths in industrial safety. The model can be used to explain any kind of accident, and in so doing suggests the proper remedial action. The following are some of the accident stereotypes that can be explained in terms of the model.

Accidents of commission are interpreted as those which result
from the operator's election to work at high hazard events. This is the safety gambler, the person who is overconfident about his ability to protect himself. His disdain for hazards is traced back to his utility structure and the high utility that he places on certain risky events. This same disdain may be reflected in a loose sampling plan, which results in unnecessary exposure to undetected hazards.

The so-called unconscious operator who literally "didn't know what hit him" is interpreted as either:

1. the victim of rapid shifts in environmental events to high hazard levels and subsequent exposure because of either a) failure to detect the hazard event even though a sample closely followed the shift, or b) inadequate sampling plan such that excessive exposure results until a sample is taken;

2. one whose comparator is jammed by internal stimuli—daydreams, etc. Existing events are identified but no use is made of this information.

Similar to this kind of accident is the operator who makes unintended responses which result in accidents. Interpreted by the model, internal stimuli linked directly into the response network bring about unelicited responses.

The "erratic operator" has an unstable decision rule and thus he persists in making unpredictable and inconsistent responses, because of an unstable utility structure. His safety performance varies perceptibly from day to day, and perhaps hour to hour. At one time he
is particularly conservative about risk-taking, and the next moment he elects exposure to high hazard events when presented with the same situation.

There are, of course, many accidents which result when the operator is not able to make responses in time to lower expected loss. These would be traced to sudden and unexpected environmental shifts to very high hazard events. On the other extreme, there are accidents which occur when the job has been made practically accident-free. Here the hazardous event results from the state of operator behavior. Certain responses of themselves promote high expected losses. Running down hallways, driving at excessive speeds, horseplay, etc., are indicative of this type of accident.

A no-injury accident results from hazardous exposure which succeeds in disrupting production but not causing personal injury. The distinction of a no-injury accident presents little difficulty in terms of the model, since there is a loss of production associated with no-injury accidents as well as disabling-injury accidents. The operation of the system remains the same, the difference arising in the consequences of the accident. The important consideration here is not the existence of what we term an accident event, but the condition leading to it. Since operating at high expected loss will mean in the long run a high frequency of accidents, we can use exposure to hazard (expected loss) and not actual accident frequency as the measure of safety. This has several advantages. Safe operators can be rated safety-wise in terms of hazard exposure. The accident
prone then becomes not merely the result of a statistic, but one who
unduly exposes himself to high hazard, whether or not an accident
occurs. Two-party accidents, involving the perpetrator and victim
of the accident, have always been difficult to interpret in accident
frequency terms. Such situations can now be given an objective dis­
tinction. The victim, by virtue of his failure to detect a change
to a high hazard event in time to effect a response to a low hazard
event (if he had the opportunity to detect it), may have permitted
exposure to a high hazard event brought on by the perpetrator. The
latter, by his response or lack of it, has permitted the existence
of a high hazard event. This in effect says that the expected loss
of an event need not apply to the operator responsible for the event,
i.e., the one who has the ability to lessen it. In the case of a
victim who either had no recourse to detection of the event or in­
sufficient time to effect a response, it cannot be said that he per­
mitted exposure. Hence, he did not contribute to the accident, other
than serving as the injured party. This does not exclude those persons
who set up such situations. A man who moves under a loaded crane has
already exposed himself to a high hazard. The change in event results
from the crane operator dropping his load. In terms of the model, we
might say that the transitional probability associated with this change
and the very large hazard associated with it should have dictated a
high frequency sampling plan for the victim, i.e., constant alertness
to the possibility of a change.

Problems of how much injury or how much disruption of production
is necessary to have an accident are not critical under this new criterion of safety. The exposure to the hazard is the criterion of safety, not the actual results of this exposure which is subject to chance. The chronic back case is reinterpreted with this criterion. After the first injury, successive exposure to events overtaxing the back muscles mean that the hazard level of an event increases. With each recurrence of the back injury, a given exposure means higher expected loss since the risk has increased with each exposure. This exposure criterion can also distinguish between the "lucky unsafe operator" and the "unlucky safe operator." The former works under high expected loss but by chance avoids the accident, while the other works under low expected loss and by chance suffers an accident. The comparison of the two operators is in terms of the expected loss, not the frequency of accidents.

Human error often used to describe accidents can be defined more explicitly in the framework of the model. This error could result from:

1. failure to take sufficient samples of the environment
2. selection of an $E_i$ in preference to $E_j$ ($j \neq i$) when $H_i^t > H_j^t$
3. failure to obtain sufficient information about the environment when a sample is taken
4. inability to achieve the desired response, e.g., control selection error
Judgment error implies cognizant action. This could be interpreted in terms of the model to mean the number of time high hazard events were selected over lower hazard events. The term error is actually of little value in explaining accidents. Like carelessness, it connotes the placement of blame. Any accident can be thought to result from some error. It is the source of the error that provides an explanation of the accident. The model clearly indicates the different types of error sources and illustrates the fact that remedial efforts vary considerably with the source involved.

The whole host of psychologically disturbed operators, the hypomanic, the paranoid, etc., in terms of the model would have one thing in common, - a distorted utility structure and decision rule. The basis for the distorted utility structure may be excessive fear, depression, joy, guilt, etc. The outgrowth of these descriptions of mental states may be the breakdown of the receptor-comparator-effector circuit. Such mental states can encourage internal stimuli action and disengage the utility structure from the effector mechanism.

Fisher (22), in his study of mental accidents, listed the types of mental causes of accidents, some of which include:

1. the tired and fatigued mind
2. the unguarded mind (ignorance)
3. the stubborn mind (unwilling to accept instruction)
4. the diverted mind
5. the misguided mind (receives incorrect information about the job)

These mental situations can be interpreted in terms of the model. Types
1, 2 and 4 are situations of system dominance by internal stimuli. Type 3 results from a distortion in the utility structure. Type 5 may have a sound utility structure and decision rule, but is presented with improper data from the receptor mechanism. Improper data here refers to either false or incomplete identification of the existing event, or failure to make note of changes in events.

With the flexibility of the model we can tie occupational diseases into the same structure as traumatic accidents. The notion of loss must be reinterpreted in this case. With occupational diseases, loss is directly proportional to exposure time under the disease producing event. Thus, we first must distinguish between occupational disease events and non-occupational disease events. In the latter case, there is no expected occupational disease loss from exposure. In consideration of occupational disease events, loss, exposure, and susceptibility are related. This relation might be expressed as follows:

The expected occupational disease loss = \( f(a^t_i L_i) \)

where \( t_i \) = exposure time to \( E_i \)

\( L_i \) = expected loss per unit of exposure to \( E_i \)

\( a^t_i \) = index of individual susceptibility to exposure of \( t \) units to the toxins in \( E_i \)

\( (a^t_i = 0 \) for those not susceptible to the occupational disease hazard

Note that \( a^t_i \) is equivalent to \( p^t_i \). In this case \( a^t_i \) varies with the individual physical characteristics of the operator, while \( p^t_i \) depends upon the event and operator behavior. In the occupational disease
situation there is no probability of loss other than the probability of the occurrence of a specific event. An interesting facet of this inclusion of occupational disease into the model is the ability to express the hazard of events in terms of published maximum allowable concentrations which are maximum exposure rates to certain concentrations of toxic substances. For each concentration $C_i$, which would correspond to a certain event $E_i$, there is a maximum allowable exposure $G_i$ based upon minimum human susceptibility. Loss in terms of dollars or time is then proportional to the amount that $t_i$ exceeds $G_i$ for a given $C_i$. This loss would be summed over all $i$ which are relevant to some group of toxins, e.g., solvents, metals, silica, etc. The functional relationship of $L_i$ and $t_i - G_i$ would probably not be linear. For dermatosis it might approach linearity, but for solvent and metallic poisoning, the relationship might be exponential with large $t_i - G_i$ resulting in death. If the occupational disease loss could be attributed to exposure to a given event, then accident loss and occupational disease loss could be combined in the basic model. In avoiding accidents, the operator must make selective responses to change events. In avoiding occupational disease hazards that exist on the job, the operator must make use of protective equipment or retreat from the environment. The major difficulty in occupational disease is that the operator often does not realize the dangers involved since the effects of exposure are disguised and may not be recognized until after exposure has long terminated.

The feedback model may also be used to incorporate and explain
the basic elements of the causal model described earlier, and provide more specificity to the accident causes usually reported. In addition, it will be shown that interpretations from the model challenge some of these causes. Unsafe conditions in terms of the feedback model are simply those job states which constitute high hazard events. The seriousness of the unsafe condition depends upon the expected loss involved under usual operator response, and how abruptly the job states are introduced to the operator. The unsafe condition may involve improperly designed information displays and machine controls. Unsafe acts are the states of operator behavior, as either a single response or a set of responses. An important distinction brought out by the model is that certain responses are not necessarily unsafe of themselves. A response is unsafe only if it coincides with certain job states where the combination of both has a high expected loss associated with it. Moreover, the duration of an unsafe act determines the risk associated with it. Short durations of excessive speed, for example, do not necessarily constitute a hazard and, in fact, are desirable under specific job states. Once a decision has been made to pass a car on a two-lane highway approaching a hill, excessive speed is desirable to shift from a high hazard to a less hazardous event.

The behavioral subcauses, attitude, ignorance, lack of attention, and physical or mental disability can be interpreted in terms of the model. Ignorance may be reflected in an inaccurate value structure, underestimates of $\beta^t_{\lambda}$ and $U^e_\lambda(s)$, and overestimates of $U^t_\lambda(p)$. 
Ignorance of changing job states may also be evidenced by poor sampling plans. Insufficient job knowledge may result in operator failure to identify the event when sampled. The utility structure may be incomplete rather than inaccurate because ignorance of the environment prohibits the provision for utility assignment and adaptive responses for certain events. Vigilance or job attention as causes of unsafe acts suggests:

1. failure to sample as a result of a lax sampling plan, or because the conscious system is influenced by dominance of internal stimuli;

2. inability to get the right kind of information to the comparator. The identification process may be inefficient or internal stimuli may mix unnecessary information into the sample.

Mental and physical disabilities are explained by defective components in the system. An inefficient effector or receptor mechanism might result from some physical disability. In fact, by virtue of physical handicaps, the operator may not be able to perform certain responses, or read certain information displays. Physical disability may result in a general slowdown of the receptor-comparator-effector circuit action and consequently, excessively long reaction time. An important distinction required here is to separate human engineering aspects of measurement and control from physical defects. Failure to properly read a gauge or operate a control may be either the result of an operator's physical defect or simply a poorly designed gauge or control. Some of the physical defects that might be mentioned at this point would be those temporary breakdowns of the motor system as a result of fatigue or work decrement. Less typical are functional
motor disorders, such as ataxia and flaccidity, which are lesions in afferent and efferent pathways. Mental disabilities are reflected in distorted or pathological value schemes and subsequent decision rules. Although the true distinction of mental defects is not clear, they probably result in greater dominance of the system by internal stimuli. Job ignorance might just be one aspect of mental deficiency. Rather than attempting to make verbal distinctions of mental disability, we might hypothesize that it is affected by the amount of dominance by internal stimuli, variance in response patterns under identical conditions, as measured by expected loss incurred resulting from unelicited conditions.

Worker attitude, which is commonly used to explain unsafe acts, takes on a rather different significance in terms of the model. It is not intended to go into a detailed discussion of attitude, but some mention is useful here. Attitude as interpreted by the model is not a cause of accidents, but rather a consequence of other conditions with which accidents are associated. The utility structure is affected by information about existing and past events and by the knowledge possessed by the operator of the risk associated with various events. But how does attitude affect the utility structure? It would appear that attitude might re-enforce knowledge of the job, but it would more likely be a consequence of job knowledge. A "devil may care" attitude toward a hazardous job would seem unlikely if the true hazards of the job were known. Regardless of his attitude, no rational operator would expose himself to injury unless he hoped to gain more than he
might lose. Attitude, therefore, will be considered the position taken by the operator toward safety as a result of his best available information of the job and his own personal estimates of his performance ability. Attitude serves a purpose since we can relate attitude with job knowledge. Social pressure in terms of attitude of fellow workers is reflected in personal estimates of $U(P)U(S)$ and $p_i^t$. In absence of precise information about the states of the job, attitude might function to influence subjective estimates of $U(S)$ and $p_i^t$. An attitude affects risk estimates, which in turn affect responses which result in performance on the job, and this performance affects attitude. Therefore, it would appear that attitude lacks the necessary specificity that the model demands. Attitude might best be thought of as a weighting function attached to estimates of $U(P)$, $U(S)$ and $\alpha^c$.

The model also provides a framework to relate the efforts of the various disciplines in industrial safety. Sociologists and psychologists are concerned with the utility structure and resulting decision rule. They are concerned with descriptive decision-making and the effects on these decisions of stress, the health of the operator, social influence, foreman pressure, etc. The experimental psychologist, the human engineer, and the industrial engineer are concerned with the receptor and effector mechanism. Stipulation of what is to be identified and how it is to be identified is required, together with design of the job to maximize the efficiency of this identification. Job conditions must also be controlled to minimize affects of psychological and physiological stress on effector and receptor performance.
The industrial physician is concerned with detecting physical and mental defects, either at time of employment or during periodic checkups. The toxicologists must relate exposure, concentration, and susceptibility to industrial poisons so that hazard for an event can be estimated. Industrial, mechanical, chemical, and electrical engineers play key roles in the establishment of safe job states. Past efforts by engineers have, by and large, removed extremely high hazard events from industry, but the task of reducing the contribution of job states to accidents is a continual one. In the model the safety engineer would serve to integrate the information from the various disciplines, and incorporate it into an appropriate accident prevention program. The complex interaction of job and behavioral states emphasizes the importance of team research on the safety problem. Emphasis should be given to those jobs which indicate that ideal behavior can do little to reduce the over-all expected loss, and to those responses which result in high hazard events. The statistician can assist in describing event changes in statistical terms, prescribing with the industrial engineer the optimum sampling scheme which minimizes undetected exposure to high hazard events.

Another potential value of the model is its ability to indicate the direction of effort in accident prevention programs. Effort should be expended to reduce high hazard events through modification of the states which make up these events. Accidents should be classified with respect to responsible components of the model, and appropriate action taken to optimize the operation of those components. The model can
indicate areas of the safety problem where economical gains are possible. Since we can express expected loss in dollars (to the company), then the reduction in expected loss minus the expenditure necessary for the reduction is a measure of the return on investment. Since loss is a function of exposure, the accident prevention program should be pitched to reduce the exposure to these high hazard events on the job. The significant aspect of the approach here is not to spend safety dollars on jobs which report accidents, but on those jobs that involve extended exposure to high hazard events, regardless of past accident record.

Use of the feedback analogy offers help to other areas of safety research. A problem which has concerned psychologists and statisticians for the past 50 years is the concept of accident proneness. In the past, researchers have always used accident frequency as the criterion for distinguishing the accident prone from the safety prone. Yet if accident occurrence is probabilistic, then the fact that a worker had three accidents in one year could happen by chance. A measure of safety behavior would be the total elected expected loss accrued over a specified time period. As suggested in a later chapter, the model provides a measure of safety behavior which can be used to compare safe behavior on dissimilar jobs. Theoretically, the model would provide the answers to the two problems facing the psychologist in trying to purport an accident prone theory in light of empirical data.

1. The hazard level of dissimilar jobs must be the same.

2. The rankings of safety offenders must remain constant in time. (The accident prone for period 1 cannot be the safety prone for period 2.)
With expected loss as a measure of risk acceptance, one could plot monthly expected loss for the individual operator on a quality control chart to note any changes in safe behavior over time. This expected loss would be based on elected exposure to high hazard events. This measure might also be used as a yardstick for comparing the results of psychological tests intent on discovering the accident prone upon hiring.

The wide interpretive function of the model depends primarily on the level of approach taken in using it. Certainly measurement problems and experiments are much easier to verify in looking at the macroscopic rather than the microscopic view of the accident. Still, where better understanding is required the microscopic view provides a necessary role. As will be pointed out in the section of suggested experiments, the macroscopic approach depends on individual data collection and analysis. If we divorce the operator from the accident phenomena by assuming ideal behavior, it suggests ways of comparing jobs per se in terms of their inherent hazards. On the other hand, by differentiating operator elected exposure from total exposure to events, safe behavior can be evaluated. In terms of hopefully applying the consequences of the model to real accident problems, the best approach would seem to be macroscopic so that behavior and conditions for the entire job can be specified. Only those few isolated cases where repeated accidents have defied solution would the microscopic approach be justified, and even here lack of sample would limit the extension of results.
Chapter 7.
CONSIDERATIONS OF JOB HAZARD

In the preceding discussion we were concerned with describing the mechanism of accidents in terms of expected loss (hazard) with exposure to certain environmental events. The term event hazard embraces both the probability of an accident in time $t$ (risk), given event $E_i$, and the expected loss (in dollars or time) of the accident arising out of this event. No distinction was made to determine what part of the expected loss was attributable to operator performance and what part was inherent in the design of the job. One of the advantages of the present treatment of the accident phenomena is that we can separate the cause of the exposure to high risk events. If, by the use of simplifying assumptions regarding the nature of event changes, the hazard of a job independent of operator performance could be estimated, then the practical implications of comparing jobs safety-wise would be possible. This requires the notion of the safe operator, one with ideal safety characteristics, i.e., sampling scheme, reaction time, and utility structure which minimize expected loss. It is apparent that there are many levels of safe performance and hence our measure of job hazard is a relative one, predicated on the specification of safe operator behavior.

Generally speaking, the emphasis given to hazards in present
day industrial safety is limited to accident frequency rate and accident severity rate calculations for a given industry or type of job. Hazard for a particular job is often evaluated by reference to the number of past accidents or the total number of days lost due to accidents on the specific job. Job hazard of itself has never been measured adequately because there is no procedure for separating the human element in accidents. If there are enough operators on a given job, the usual procedure is to assume these operators represent average safe behavior. Under identical periods of exposure, two jobs could then be compared in terms of their accident frequency. A more realistic measure of job hazard is the premium rate set for different classes of jobs by workmen's compensation bureaus and private insurance carriers. These rates are based on the amount of past accident claims awarded to a particular class of jobs. There is no way of determining the variance of "operator safety behavior" among the reported job classes, but with a large number of workers in several job classes, these rates would provide an approximate ranking of job hazard. Another difficulty here is that the expected losses quoted are in terms of $100 of payroll and not exposure time to the job hazards, although approximations of time to payroll are possible.

Some of the practical advantages of measuring job hazard (independent of operator behavior) include:

1. A more realistic basis for workmen's compensation premiums for individual job types.

2. The optimum allocation of engineering effort to those
jobs with high hazard levels and to those events within the job with high hazard levels. In particular, such a measure would dictate fail-safe devices and automatic warning mechanisms for particular jobs and events within such jobs.

3. The optimum placement of operators. If a measure of operator safety performance could be derived, then accident loss would be minimized by the selection of the "safest" operators for the high hazard level jobs. Even without a reliable measure of operator safety performance, practical advantages would result from assigning those operators with special physical qualifications, such as fast reaction time, to jobs of high hazard. It has been hypothesized that response time is an important factor in job hazard.

4. A general guide for direction of accident prevention programs. Those jobs with known high hazard levels would receive more emphasis both with respect to maintenance, inspection, and engineering, and in maintaining general safety alertness in the operators of these jobs through safety propaganda, training, contests, etc.

5. The ability to predict the minimum accident cost of a department or plant under maximum safety performance.
In the following treatment of job hazard, it should be recognized that this is merely one approach to the issue. At this point we can make no claim to acquaintance with reality. In fact, the model conditions must be assumed into a trivial case before any generalizations are possible. A simplified approach, however, does have the advantage of further exploring the implications of the model, and permits some insight to the characteristics of job hazard. This is the justification for the treatment that follows.

The following factors contribute to accident loss:

1. the probability of an accident under exposure to any event $E_j$, $p_{j}^{t}$ ($t =$ duration of exposure)

2. the average time lag from detection of $E_j$ before the operator can complete a response to change to an event with lower risk (operator response time)

3. the average time lag between the change from $E_j$ to $E_i$ to the detection of this change (where $p_{j}^{t} < p_{i}^{t}$)

4. the frequency of shifts from $E_j$ to $E_i$ ($E_j$ refers to any event except $E_i$) which result from changes in job states

5. the voluntary exposure to $E_i$ elected by the operator

6. the expected loss due to an accident resulting from $E_i = L_i$

Items 2 and 4 essentially represent exposure to $E_i$ which is beyond the control of the operator. Item 3 is dependent upon the operator's sampling plan. Item 1 represents the risk associated
with this \( E_i \). The total exposure to \( E_i \) is then the sum of items 2, 3, 4, and 5.

If a job consists of a set of \( n \) possible events \( E_i \), each of which has an associated \( p_i^t \), the probability of an accident during \( t \) exposure to \( E_i \), and \( L_i \), the average loss (in days or dollars) due to the accident resulting from \( E_i \), then the expected loss from \( t \) exposure to an event \( E_i \) is \( H_i^t \) defined as

\[
H_i^t = L_i p_i^t
\]

Since \( t \) includes the operator's election to work under a certain \( E_i \), the equation above does not represent the minimum expected loss for a given \( E_i \), independent of the operator's choice. We assume the "safe" operator would not elect to work under high risk if lower risk events were available. This in effect suggests that \( H_i^t \) is not simply the minimum expected loss associated with \( E_i \), but the loss associated with the event and an individual operator's behavior over time \( t \). The claim rates published by insurance carriers represent the actual expected loss for a given job per $100 of payroll. Since payroll is a function of time, this rate in effect is the expected loss over a specified time. If the equation above were summed over all periods of exposure to all \( E_i \), for all operators, the resulting value would be comparable to the published claim rates, i.e., expected loss with exposure to all events of the job.

The critical question here refers to the exposure to \( E_i \) that the operator elects. Before a job hazard can be evaluated, this personal element must be removed. This in effect suggests that the
hazard associated with the job must be determined under maximum safe behavior on the part of the operator and constitute minimum loss that can be expected. If we assume that certain events have little or no probability of accidents (i.e., $p_j^t$ is small), then the safe operator has the ability to minimize accidents by the selection of such events. The hazard of any event $E_i$ then is a function of the minimum hazard possible, $p_j^t L_j$ and that exposure to $E$ which is beyond operator control ($p_i^t > p_j^t$).

Job hazard may then be measured by the minimum hazard level under which the operator must work to perform the job, and the involuntary exposure to higher hazard levels which result from changes in non-behavioral states. If we use as our basis of job hazard the notion of a safe operator, we could assume that he detects event changes immediately. Unelicited exposure would then be the response time necessary to return the environment to the minimum risk event. We would also assume that when samples were taken they would yield accurate identification of the event. It becomes apparent that our measure of job hazard depends upon the requirements we place on the safe operator.

For purposes of specifying the characteristics of a safe operator, consider the following:

Let $\overline{D}_i$ = average undetected exposure to $E_i$ (the time from the shift to $E_i$ until the next sample is taken)

$r_{ij}$ = the average response time, the time necessary to identify $E_i$ and complete a change to $E_j$
(safe state) with the appropriate response

\[(j \neq i ; L_i p_i^t > p_j t_j)\]

\[b_i = \text{the elected exposure to } E_i \text{ once it has been detected}\]

\[t_i = \text{the sum of } b_i, r_{ij}, \text{ and } b_i\]

\[L_i = \text{the expected loss of an accident resulting from } E_i\]

\[p_i^t = \text{the probability of an accident with exposure to } E_i \text{ for time } t_i\]

\[f_{ji} = \text{frequency of shifts from } E_j \text{ to } E_i \text{ in time } T\]

It is assumed that there is a desired event \(E_j\) and all shifts in events from \(E_j\) to \(E_i\) are undesirable. It is further assumed that the frequency of shifts is regular. This suggests shifts to \(E_i\) occur every \(\frac{T}{f_{ji}}\). With this nomenclature, the kinds of safe operators might be tabulated below.

<table>
<thead>
<tr>
<th>Case</th>
<th>Requirements of the Safe Operator</th>
<th>(t_i)</th>
<th>(H_i)</th>
<th>(H_i^T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>(\bar{b}<em>i = 0), (r</em>{ij} = 0)</td>
<td>(t_i = 0)</td>
<td>(L_i p_i^t)</td>
<td>(\sum H_i^T = 0)</td>
</tr>
<tr>
<td></td>
<td>(b_i = 0)</td>
<td></td>
<td>(H_i = 0)</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>(b_i = 0)</td>
<td>(t_i = r_{ij})</td>
<td>(L_i p_i^t)</td>
<td>(f_{ji} L_i p_i^t)</td>
</tr>
<tr>
<td></td>
<td>(\bar{D} = 0)</td>
<td></td>
<td>(H_i = 0)</td>
<td>(\sum H_i^T)</td>
</tr>
<tr>
<td>3.</td>
<td>(b_i = 0)</td>
<td>(t_i = \bar{b}<em>i + r</em>{ij})</td>
<td>(L_i p_i^t)</td>
<td>(f_{ji} L_i p_i^t)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(H_i = 0)</td>
<td>(\sum H_i^T)</td>
</tr>
</tbody>
</table>

\(H_i^T\) is the expected loss associated with \(f_{ji}\) shifts to \(E_i\) for \(t_i\) in
time $T$. $H_i$ is the expected loss associated with the single occurrence of $E_i$. $H^T$ is the total expected loss in $T$ for shifts to all $E_i$ for duration $t_i$. It is assumed that the remaining time, $T - \sum t_i j i t_i$, is composed of a series of discrete time intervals in which $E_j$ exists. The sum of all these periods of operation at $E_j$ constitutes the minimum expected loss during "safe" operation.

Let $t_j = \text{average exposure to } E_j$

then $H_j = L_j p_j t_j$ is the expected loss for a single exposure to $E_j$

$H_j^T = f_j j_i H_j$ is the total expected loss in $T$ from operation at $E_j$

With this approach the expected loss for any job over $T$ is then $H^T + H_j^T$

Case 1 represents the operator with zero response time and a sampling scheme which immediately detects any shift from $E_j$, the desired state. He also refuses to operate in any event except $E_j$. Case 2 is identical to Case 1, except the response time is included as involuntary exposure. Case 3 is identical to Case 2, except the time to detect the shift from $E_j$ to $E_i$ is included. The magnitude of $D_j$ depends upon the operator's sampling plan and the time pattern of the shifts to $E_i$. Cases 1 and 2 are obviously unrealistic assumptions of safe behavior. Case 3 provides a more reasonable picture of the safe operator, but presents several problems. What is the distribution of $D_j$, and how can the temporal distribution of shifts be related to the sampling pattern? This will
discussed in a later chapter.

It is interesting to note that if the assumptions behind the formal structure proposed in Chapter 5 are used, the hazard or expected loss of a given event has little significance if an operator fails to make a response over an extended period of time. For large time intervals the initial event becomes insignificant, and hazard is a function of the transition matrix and the duration it is in effect. The above treatment of job hazard is oversimplified because even with the most realistic basis it assumes a regularity to shifts in events. What makes a job hazardous is the random character of shifts to events of high hazard. In some cases one can predict precisely these shifts; in other jobs, the introduction of an event shift is stochastic, which makes early detection of such shifts extremely difficult. In addition, a hazardous job is characterized by large expected loss when an accident occurs, (e.g., for jet test pilots an accident often means the loss of life and ship). A hazardous job is further characterized by the minimum time between event shifts caused by changes in job states. If this time is less than the minimum permissible time between samples, serious difficulties can arise. In addition, excessive time to carry out responses is conducive to high job hazard, since the operator must be exposed to the high hazard event until a response can evoke an event change. Considering job design from a human engineering aspect, we might modify $r_{ij}$ by

$$r_{ij} = \frac{a_i}{2 - (a_i + b_j)}$$

where $a_i$ is the probability of accurate detection and $b_j$ is the probability of accurate response.

These characteristics of hazardous jobs focus attention on
the actions which can be taken to minimize this hazard. Human engineering data can be used to effectively reduce response time and suggest information displays that provide immediate detection of existing events. In many cases, special fast-acting control systems may be necessary to account for the rapid nature of event shifts. In jet aircraft where events change with high rapidity, hydraulic booster systems for control actuation are provided to minimize the response exposure to high hazard events. In those cases where $r_{ij}$ has an extremely high value, one would propose that the operator might best be replaced in the system by a machine of some type. This would also apply where event shifts are so rapid that human detection is not possible. Recognition of the safety problems that exist in job design might well be a criterion for decisions regarding the selection of jobs for automation. Short of such action, the installation of machine guards and fail-safe devices would minimize the severity of injury.

The above proposed characteristics of job hazard are not particularly novel ones. Intuitively, one would agree with most of them. The framework of the model provides a more explicit basis for comparing job hazards, and emphasizes several points that are often overlooked in assessing hazard to jobs. With the use of the model, each event shift that is detected requires a decision to either change responses or maintain the existing response pattern. The more shifts in events, the more the operator must sample, make decisions, and respond. Practically speaking, these are all potential sources of error. Hence, jobs with frequent and unpredictable changes in events
make excessive demands on operator behavior and constitute a significant aspect of job hazard.

If event shifts are assumed to be stochastic in nature with unknown statistical properties, then on pragmatic grounds, the only way to arrive at a scale for comparing hazard for different jobs would be to assume:

1. an average response time and average probability of proper detection and response (based on human engineering considerations in the job design)

2. an expected duration (based on a "reasonable sampling plan") between the event shift and the time of identification

Using Case 3, we would then be able to compare hazard for different jobs on a rather gross basis.
Chapter 8.

EVALUATION OF INDICES OF SAFETY PERFORMANCE

It was pointed out in Chapter 7 that the structure of the model as presently conceived theoretically allows the separation of environmental hazard into that part arising from the nature of the job itself, and that part resulting from the behavior of the operator. The extreme complexity of the accident phenomena makes this separation difficult. The model has been an instrument to explore this complexity and to offer different approaches to the accident problem. Any discussion of job hazard and safety performance based on the model must necessarily involve the assumptions and abstraction of its framework. The purpose of this chapter is to further explore some of the potentially useful implications from the model. This exploration must be recognized as not meeting completely the quantitative requirements of a formal structure, nor the requirements of practical reality. This discussion will point out some of the problems associated with the derivation of a scale of comparison of safe behavior and mention a few of the possible approaches to these problems. The criterion of safety performance presented requires extensive oversimplification of the problem. Hopefully, these restrictions can be relaxed with better understanding of the problem and increased formal development of the model.
Human behavior has long been considered the key factor in accidents. This is supported by examination of accident reports which generally specify some facet of human behavior as the cause of the accident. Unsafe behavior, however, is difficult to measure objectively. What is unsafe action for one operator may be safe for another. Certain jobs may necessitate some risky behavior on the part of the operator. In light of our present understanding of accidents, it is impossible to compare the seriousness of various unsafe acts, since this seriousness depends upon the job conditions, the operator, and the probability of an accident. Presently used measures of safe behavior (accident frequency or accident severity) do not account for the probabilistic aspects of accidents, and have no basis for comparing performance on dissimilar jobs. The prospect of developing a performance index of safe behavior along some scale of comparison holds widespread significance. Such measurement could

1. provide a sound basis for testing accident prone theories

2. establish an important criterion in the selection of operators for various jobs

3. serve as a basis for performance in safety contests

4. with better understanding of what factors make up unsafe behavior, develop methods of modifying such factors to increase safe behavior

5. allow prediction of safe behavior resulting from job conditions, past accident experience, and efforts to change safety behavior in accident prevention programs

To be effective, this criterion or criteria of safe behavior must be capable of application across both similar and dissimilar jobs.
In terms of the model, description of safe behavior involves the extent of exposure to high hazard events. It is assumed that in the long run exposure to high hazard levels leads to accidents. With the notion of risk, the probability of an accident under a given exposure to an event, and severity incorporated in the term hazard, we can suggest the following measures of safe behavior in terms of the model:

1. the amount of exposure to certain high hazard events
2. the total expected loss from exposure to all events which are attributed to operator performance
3. the difference in expected loss for a given operator as compared to some standard of operator performance (ideal or average)
4. maximum hazard accepted by the operator

The above measures create the following problems:

1. the ability to describe the temporal changes in job states independent of operator responses
2. the ability to estimate the hazard or expected loss from exposure of a specified time to a given event
3. some basis of performance for purposes of comparison

Exposure time to any event which is subject to operator control is made up of three components: the elapsed time from the shift occurrence until it is detected by a sample, the time required to identify the event and evoke a response to change the event, and the time the operator elects (consciously or unconsciously) to operate in an event. The first component is a function of the operator's sampling scheme, the second is a function of the operator's physical
characteristics and the nature of the identification and response required. The third is a function of the utility structure of the operator and the extent of influence by internal stimuli. This suggests that we might compare the safe behavior of various operators by comparing their reaction times, the goodness of their sampling schemes (goodness here refers to the exposure of undetected event shifts), and the appropriateness of their utility structures.

Several difficulties are evident in this approach. We cannot compare different jobs if the requirements for identification and response vary. In addition, the nature of some jobs increases the probability of operating under undetected events. Some jobs have frequent and erratic event changes, while others have few event changes and these changes are completely determined. Since response time is a function of the job and the physical characteristics of the operator, it is proposed to omit this exposure time from the present discussion of safe behavior, since the individual operator has little control over it. This does not mean that this factor is not important in the safe operation of a job. Training programs might be used to bring the receptor-comparator-effector circuit time to a minimum. Employment physical examinations would serve to select those operators with the physical characteristics which would best suit the individual requirements of the job.

In terms of the model, any measure of safe behavior must include specification of operator sampling characteristics. With a given job we could make comparisons about the appropriateness of
different operator sampling schemes. One measure of appropriateness would be the amount of exposure to undetected high hazard event shifts. We could then compare the various sampling schemes against some ideal scheme (one which detects a shift in minimum time). This assumes that for the given job the event shifts are independent of the operator's sampling plan. Since in most instances operator responses will affect subsequent shifts, the sampling scheme effectiveness cannot be divorced from the decision rule dictated by the goal setting mechanism. In this case, we can only compare the total observed hazard exposure for various operators. Safe behavior, then, is a function of the operator's sampling plan and his elected exposure.

It becomes evident in exploring indices of safety performance that the many ramifications of the accident phenomena make formal specifications of behavior impossible at this time. This complexity necessitates examination of the problem under restricted conditions. One approach to the problem of safety behavior would be to construct a hypothetical job situation, enumerate the factors contributing to safe performance, and suggest some possible measures of this performance.

Assume that for a given time period, the duration of exposure to each event can be specified and that the minimum hazard to which the operator must be subjected is known. At this point we make no distinction concerning the reasons for the operator's exposure to certain events. On a gross basis then, one measure of safe performance might simply be the difference between the expected loss
incurred with exposure to all events, $H_{act}$, and the minimum expected loss that must be incurred to satisfactorily perform the job, $H_{min}$. This difference, $H_{act} - H_{min}$, will be termed the additional expected loss (A.E.L.) and is simply a comparison of observed to ideal behavior. $H_{min}$ is the hazard inherent in the job, and as was pointed out in Chapter 7, may be based upon various requirements for the ideal operator. Although theoretically the A.E.L. would allow comparison of operator performance over dissimilar jobs, several difficulties arise here. Identical A.E.L. for low hazard and high hazard jobs does not reflect the true consequences of safety performance. A small exposure to a high hazard event is not equivalent to a long exposure to a low hazard event. Hence, the A.E.L. would require modification for use as a yardstick of safety performance between dissimilar jobs.

If a job exists which changes states independent of operator response (e.g., automatic screw machines), or if a job could be devised which would possess this quality, then the sampling aspect of exposure could be divorced from the utility structure and decision rule and the A.E.L. could be evaluated for both. This would then allow comparisons of sampling schemes and experimentation into the mechanism behind them.

With the notion of expected loss we might discuss other related measures of safe performance. Exposure time to a high hazard event might be used to compare safe performance, although this is not too useful as an index because safety depends upon not
only the exposure but the risk exposed to. We might designate
operator performance by the maximum hazard and the minimum hazard
under which he would elect to operate. The above are analogous to
the maximum risk acceptance reported by Cohen, et al. (14), in their
study on bus drivers.

The logical extension of a measure of safe performance would be
to specify the mechanism behind safe performance and methods of re­
ducing the A.E.L. Previously, it was pointed out that hazard was
influenced by the sampling plan used, and the utility structure and
resulting decision rule. Various aspects of sampling schemes under
different operating conditions are discussed in a later section.
Attention here will be given to the elected A.E.L. which results
from the decision rule. The elected A.E.L. involves both the
decision rule and the effect of internal stimuli. Just why an
operator elects to operate under a given $E_i$ is dependent upon:

1. his utility structure—he places more utility
   on operation in this event than any other

2. internal stimuli—the operator's decision might
   dictate a change to less hazardous events, but
   the comparator is jammed by internal stimuli which
   in effect provides a period of no decision

The special condition of unintended responses (triggered by
internal stimuli) which evoke high hazard events is not considered
here to be an elected exposure. It does constitute a valid part
of operator hazard exposure, but does not result from his decision
rule. It is considered undetected exposure until a sample is taken.
If the operator fails to respond to change the event once detected,
then the resulting exposure is said to be elected. For purposes of comparing operator behavior, this condition of unelected response is considered to be similar to changes in job states. Of themselves, unintended responses might constitute a measure of safe performance, but unless modified by the duration of subsequent exposure, it would be of limited value.

An inviting prospect of the feedback analogy is the separation of risk-taking caused by the decision rule and that caused by internal stimuli. The first requirement would be to isolate or at least fix conditions which establish a given utility structure and decision rule. Operator performance could then be observed under controlled conditions, and that exposure not dictated by the decision rule could be noted. We might view this action by internal stimuli as the separation of the decision rule and goal setting mechanism from the system for a certain period of time. This would be analogous to power failure in the controller circuit of a feedback system. In this case, the duration of system control by internal stimuli at any one time would be some random probability density function. Of importance here is not only the frequency of internal stimuli action, but the duration of its action. What would be desired is the probability of a goal setting mechanism shutdown at some time (t) for a duration (d). This assumes a dichotomous situation in which internal stimuli either block or do not block the receptor-comparator-effector circuit. Practically speaking, we would expect internal stimuli to be graded in amount and in some cases only partially affect the goal setting
mechanism. This would be the case for those operators who work in a daze, alive to only part of the job around them. Some laboratory experimentation might be undertaken to evaluate the occurrence and duration of internal stimuli, if certain restrictive assumptions could be made, such as:

1. The operator follows a prescribed decision rule.
2. The time from event detection to elected response minus reaction time is time during which the system is under control of internal stimuli.
3. Responses not dictated by the decision rule result from a system dominated by internal stimuli.
4. Distortion of a prescribed sampling plan result from internal stimuli.
5. If present, the effect of internal stimuli is complete and total.

In general, with a specified decision rule and sampling plan, any deviation from predicted behavior could be ascribed to internal stimuli. This might be an unusual measure of operator alertness on the job. More interesting would be the probability distributions and timing of these goal setting mechanism shutdowns. If we could predict with any degree of accuracy when internal stimuli would dominate the system, we could devise procedures which would induce cognisant behavior at times which would minimize internal stimuli effect.

It is not the intent of this paper to go into the psychological and physiological ramifications and implications of internal stimuli controlled behavior. Although experimentation would be extremely
difficult because of all the variables involved such as mental
make-up, past emotional experiences and their measurement,
knowledge of when to expect these stimuli and their duration
from a gross standpoint would be a giant step forward in under­
standing accidents. Many recent studies seem to bear on this
problem. Howland (30) found better monitoring performance when
subjects were forced to maintain constant record of meter displays.
Homogeneity of response is known to be more susceptible to work
decrement than heterogeneous response patterns. Perhaps an overly
simple decision rule (one which dictates little response) and a job
whose states seldom change (or if they do, the changes are repe­
titious) lead to monotony and subsequent dominance by internal
stimuli. This last statement is rather paradoxical. On the one
hand, absence of changes in job states encourage dominance of the
system by internal stimuli which can in turn lead to unelected
responses and failure to take action when job state changes do
occur. Conversely, frequent changes in job states require detection,
decision, and response. Since we can associate a probability of
error to each function, then frequent job state changes would appear
to promote unsafe behavior. This suggests that perhaps there is a
certain amount of activity (changes in events) which optimizes over­
all safety performance. This is just one of many hypotheses that might
be tested to find the factors relating event changes, internal stimuli,
and safe behavior. The complex interrelationship of event changes,
physical characteristics of the operator, and internal stimuli domi­
nance would seem to be a really worthwhile research effort. The
contribution of the feedback model is to place a value (or loss) on this dominance by internal stimuli and show the temporal consequences of its action.

Using the framework of the model and neglecting the influence of internal stimuli on safety performance, the three factors that contribute to event exposure were reported as:

1. elected exposure
2. exposure during identification and response
3. exposure resulting from undetected shifts

Item 2 depends upon the nature of the events, human engineering considerations regarding information displays and controls, and the physical characteristics of the operator. In general, this exposure is not a significant factor in safe performance, because the operator has little control over this exposure and because its magnitude is usually small compared to items 1 and 3. It was pointed out that in the general case, item 3 cannot be distinguished from item 1 unless the operator is following a prescribed sampling procedure. In that case, knowledge of the statistical properties of event changes would enable prediction of undetected exposure to events. The conditions regarding normative sampling plans will be discussed later.

Item 3 cannot be divorced from the job because the efficacy of an individual sampling plan depends upon job conditions. Before this aspect of exposure could be included in an index of safety performance, a standard or normative sampling plan would have to be specified as a basis for the evaluation of all other plans. At present, sampling
theory has not progressed sufficiently to stipulate the best possible sampling plan for the type of process that would be encountered here.

Item 1 is the outgrowth of the goal setting mechanism and reflects the utility structure and decision rule of the operator. Elected exposure to high hazard events is characteristic of the safety gambler, the operator who willingly takes chances on the job.

The bases for an operator's election to operate under a given event is his utility structure and decision rule. To each event we hypothesize that the operator establishes some utility. His decision to respond is based upon the utility assigned to the event detected (correctly or incorrectly) and his decision rule resulting from a principle of choice. These are, of course, contingent on the assumption that the operator does place utility on exposure to certain events and acts in some way to achieve or maintain utility. Depending upon our selection of his principle of choice and decision rule, we could hypothesize several different frameworks for the goal setting mechanism and its effect on elected exposure.

One might make use of laboratory experiments to delve into the descriptive decision processes of the operator to infer his method of assigning value to certain events. In absence of such knowledge, we might assume for purposes of discussion that the operator:

1. uses maximization of utility as his principle of choice

2. derives expected utility from the difference between expected gain (the utility of gain times the probability of success) and the expected loss (the utility of loss times the probability of loss)
uses a decision rule which dictates the selection of the response which maximizes expected utility

Here the probability of success = 1 - probability of loss. Under these assumptions, the observation of operator behavior will yield information about his utility structure. We would hypothesize that elected exposure to high hazards results from any or all of the following: an underestimate of the utility of loss, an overestimate of his utility of gain, and an underestimate of the probability of loss. Interestingly enough, many of our intuitive notions about risky behavior can be explained in this context. Foreman pressure, incentive pressure, and the desire for admiration from fellow workers would account for over-evaluation of gain. Disdain for personal injury and ignorance of the consequences of an accident would account for under-evaluation of loss. Past accident experience on the existing job and other similar jobs would influence the subjective estimate of the probability of loss. It should be recognized that under this framework of the goal setting mechanism, accidents and their consequences may only be one aspect of expected loss. Ideally, from the safety standpoint we would prefer a minimax principle of choice, wherein expected loss was a function of accidents only.

The minimax principle of choice suggests some interesting experiments. If the magnitude of accident loss in an experiment was fixed at a given level, then the operator's decision would depend upon his estimate of the probability of an accident. If the actual risk were known, then a comparison of actual versus subjective estimates of risk would be possible. Cohen, Hansel, and Dearnaley
have used similar techniques on bus driver performance. Two facets of risk analysis are worthy of note. First, we could determine the maximum and minimum estimates of risk under which the operator would be willing to operate. In other words, how big a chance would an operator take? This could be expressed as maximum acceptable risk or maximum acceptable hazard (expected loss), and minimum acceptable risk or loss. The latter situation is the rare instance of an operator who feels some risk is desirable in a job, e.g., to provide some thrill. The former situation has implications pertinent to job selection. High risk-taking operators or ones willing to accept high risk might make good firemen, but poor steeple jacks. Second, the study of risk estimation would prove interesting if the per cent of time an operator would take chances at various risk levels could be determined. In both of these situations, the subjective estimates or risk and the true risk could be compared to find the magnitude and direction of error estimates. Finally, the variability of operator risk estimates over time would be a fruitful area of research. With constant error in risk estimate, procedures could be devised to minimize its consequence. Large variable error, on the other hand, would make prediction of response difficult.

The preceding discussion has merely indicated some of the exploratory approaches that could be used to explain and predict elected exposure to events. Much of the work in descriptive decision-making under uncertainty would be applicable here. Experiments could be devised to estimate how much past event information is used by the
operator in making decisions. Game theory studies would appear to be applicable to studies of risk acceptance under uncertainty. No attempt here is made to explain the mechanism behind human behavior. The salient point in this discussion is to show how far afield the accident phenomena extends, the tremendous complexity involved, and some of the problems that arise when using this framework to study accidents.

Without further formal development and experimental data, we cannot evaluate the various indices of safety performance suggested. Whether exposure, expected loss (hazard), maximum risk acceptance, or maximum hazard acceptance are adequate criteria of safe behavior depends primarily upon the ability to describe the statistical properties of the event changes and their relation to the operator's sampling scheme, and to adopt procedures which measure action of internal stimuli. An index of safety performance requires the specification of a standard or norm of safe behavior, and a measure of job hazard. Once these requirements could be fulfilled, an index of safety performance holds considerable promise in the areas of job matching, accident prevention programs, and job design.

**Sampling Aspects of the Model**

It was hypothesized in the section on the basic feedback model of the accident phenomena that the operator functions as a sampling servo. At periodic intervals he makes certain observations regarding the existing environmental event. This information is fed back to the comparator and the decision is made to continue with that event.
or to effect a change in events through appropriate responses. The frequency of inspections is a function of the alertness of the operator and plays a significant role in the nature of accidents. The basis for the inspection frequency is a mechanism we might call the operator's time sharing controller. This simply means that the operator must share or apportion his attention to the various aspects of the job, only one of which is the safety environment. Attention to production details, foreman instruction, and distractions compete with safety cognizance. In addition, his conscious attention to the job is in competition with internal stimuli, the outgrowth of which is revery, emotional preoccupation, etc. The factors which dictate the time apportioned to safety estimation are of interest if we wish to dictate the optimum sampling plan for the operator. The sample made on the job is considered to be a determination of the existing $E_j$. This information may be combined with inspections for other purposes, e.g., production rate or quality. As was pointed out earlier, the frequency of inspections will determine the amount of exposure to certain high hazard level environmental events.

One of the predominant factors influencing the time sharing decision rule is the nature of environmental events. The environmental event of a job can be altered by a change in any one of its states. For practical purposes, only operator behavior and the immediate job conditions affect the nature of the event. The job conditions may be either:

1) deterministic
2) probabilistic
3) operator controlled and deterministic

4) operator controlled and probabilistic

If the conditions are deterministic, we know at any time t the exact state of job conditions. Operator response has no effect on the job states. This does not mean constant job conditions. The conditions may be cyclical or irregular, but at any time in the future the states can be predicted with complete accuracy. There are few occupations which fit this type. Trouble-free automated equipment which is simply monitored by an operator could be classified as deterministic. Certain machining operations follow prescribed cycles of operation independent of operator response. This type of job requires a prescribed behavior on the part of the operator—a standard operating procedure which guarantees job exposure to minimum hazards. The operator need only to make infrequent samples to locate the existing point in the job cycle. His behavior in subsequent periods can be spelled out since future job conditions are predetermined.

The change in job conditions may also be probabilistic. This suggests that the various factors which make up the condition of a job are subject to the laws of chance. Equipment may fail. Material may shatter. Machines may jam. If the job consists in driving a fork lift truck, persons may step into the path of the truck at undetermined intervals. Neither the precise time of job condition changes, nor the new states can be predicted with certainty. Any job whose conditions are subject to change by behavior of other
operators might be classified as probabilistic. A further restriction on this class of jobs is that the changes in the job states are independent of operator behavior states. As in 1), this essentially means that the operator must match the job state with a behavioral state which minimizes the expected loss of the resultant event. In terms of the Markov process discussed earlier, 2) means that a single transition matrix exists. The probabilities associated with the occurrence of any event need not be constant in time. This introduces serious estimation problems, since we are dealing with probabilities of "probabilities."

A third situation exists when the job states are deterministic but are affected by operator response. The states follow a specified sequence until an operator response returns the job to a certain state from which all future states are predetermined, until another response is made. Machine cycles may be placed out of phase by operator response. The determination of future job states is therefore a function of:

1. the cycle of job states, and
2. the point on the cycle which results from a particular operator response.

It is assumed that the job state can be defined for any operator response.

The fourth and most realistic situation results when the job states change with certain probabilities and are affected by operator responses. It is known what states result from various operator responses, but the future states after this response can only be estimated by the transitional probabilities which govern the changes in environmental events.
This is the case where operator response can evoke a new transitional matrix. As in case 2), the transitional probabilities may vary in time. In terms of the formal development described earlier, this means that at any time with a given operator behavioral state, events may change and the transitional probability matrix which governs these changes may also take on different values. This in effect describes a process in which event changes are stochastic.

The operator's sample of the existing environment serves two basic functions. First, the sample provides information on the existing event for immediate use by the comparator. Hence, it serves as the basis for decision to make or not make particular responses. Second, with each sample the operator gets more information on which to base his subjective estimate of the transitional probabilities of event changes, i.e., \( P_{ij} \), the probability of \( E_i \) given \( E_j \) \( (j \neq i) \).

In addition, he also improves on his estimate of \( t_{ij} \), the duration of the \( E_j \) preceding the shift to \( E_i \). As will be shown later, these two estimates influence the elected sampling scheme. It is not the intent of this section to delve into the mechanism behind the evolution of these estimates. The operator might simply take the last sampled information and use this as the best estimate of \( t_{ij} \) and assign \( P_{ij} = 1 \). More likely \( P_{ij} \) and \( t_{ij} \) are based on the last \( n \) samples committed to memory. A basic problem here is one of learning. The stochastic learning model proposed by Bush and Mosteller (9) may have application here. A stochastic process is one in which the probabilities of a set of events keep changing with time. This is probably the case with
the transitional probabilities among the various environmental events. With each event shift the transitional probabilities undergo a mathematical operation (a linear one in the case of the stochastic process involved in this learning model). Successive transformations of $P_{ij}$ occur with each outcome or shift in events. The learning aspects of sampling play an important role in training new operators. It is an accepted fact that a higher proportion of accidents occurs to the new men on the job as compared to more experienced hands. If the new worker’s learning process could be made more efficient, it might reflect in better estimates of $P_{ij}$ and $t_{ij}$, and less exposure to high hazard events. The operator’s sample might also be a simple evaluation of the error (if any) involved in describing a deterministic process. There is also a probability of accurate identification for a given sample. To simplify further discussion, however, we will assume each sampling provides accurate detection of event changes.

The factors which affect the sampling plan chosen by the operator can now be discussed in terms of the model.

1) $P_{ij}$ = the transitional probabilities of shifts from $E_j$ to $E_i$.

2) $t_{ij}$ = the duration of a given $E_j$ prior to a shift to $E_i$.

3) The hazard level of the changed event $E_i$, i.e., $H_i$ (in terms of expected loss)

4) The difference between $H_i$ and $H_{\text{min}}$. The latter refers to $\text{min. } P_i L_i$ event

5) The number of shifts in events per unit of time = $f$
6) The cost to the operator of making an inspection decision and response

7) The reaction time or time required to effect a change in $E_i$

It should be noted that the sample might include only partial identification of $E_i$ (i.e., selected job states). For purposes of this discussion we will assume the sample to completely and accurately describe the event.

An unsafe operator in terms of the model described earlier either elects to work in high hazard events or uses sampling schemes which allow considerable exposure to high hazard events when shifts to these events occur (by failure to detect these changes quickly). This latter situation can result in accidents regardless of how sound the individual's value scheme is (that is, his ability to change to low hazard events when high hazard events are detected).

Whenever a shift in $E_i$ occurs, the resulting exposure before a response can be elicited depends upon the reaction time of the receptor-effector circuit and the undetected exposure to the new $E_i$. Items 2) and 5) reflect the exposure to the shifted $E_i$. Items 1), 3), and 4) determine the seriousness of the hazard exposed to as a result of the shift. In a sense, these factors influence the cost of exposure to a shifted $E_i$. Item 6) represents the cost to the operator in making a sample and subsequent response.

The chief characteristic of this sampling plan is the time between samples. This time may be either regular or irregular.
The latter might result from knowledge of the existing event. Transitional probability values might dictate a shift to a high hazard event. This would call for frequent samples over the next time period to minimize exposure to this event. An example of this would be in driving an automobile. At 10 miles per hour we do not expect our environment to change to a high hazard event, and we consequently sample the road or environment less frequently than if we are driving 80 miles per hour. A change in road conditions in the latter case, e.g., to icy conditions, would expose us to high hazard. Hence, if this change occurs, we would want to change our environment with a rapid reduction in driving speed.

The nature of the inspections or samples consists essentially of identifying the event $E_i$. Since 90% of our information about the real world would come from visual receptors, we could expect the identification to be visual. Some jobs might provide auditory or kinesthetic cues to existing events, but this in no way interferes with the notion of inspection.

In discussing appropriate sampling plans which will provide early detection of shifts to high hazard events, we find ourselves with a problem that lies beyond the present domain of sampling theory. What is required is a sampling scheme to detect shifts in a stochastic process. This is further complicated by the fact that the nature of event changes is dependent upon the operator's response. Moreover, the sampling plan must be based on hazard associated with event. If the probabilities for job state changes were stationary in time, then
some of the work by Wald (66) in statistical decision functions might be appropriate. In this case we would attach a loss to each possible sampling interval, and use a minimax principle of choice to arrive at the optimum sampling scheme. Although this method is not applicable to the stochastic situation, it does suggest the direction of effort to be taken to arrive at some "dynamic statistical decision function" needed for the model.

In discussing the general problem of sampling, we might first describe the types of sampling schemes that could be employed. Sampling plans can be classified by the selection of the time interval between samples. With fixed time intervals, the time period may be equal or unequal. The latter would appear to be more appropriate in terms of the safety problem. The detection of certain events which have a high probability of accident would suggest that a high sampling rate be used in subsequent periods. On the other hand, other event detections would dictate a relatively low sampling rate. This type of sampling would be desirable if one knew exactly when the process should be sampled. It would provide a method of checking the forecast accuracy of a deterministic process. If the process were known to be deterministic, then no samples would be required at all. One would simply specify the responses required to minimize expected loss. Another type of sampling scheme would be one in which the sampling interval was randomly selected by some probability device. If the job states had stationary (in time) probabilities, then a random sample would minimize bias. One might develop a scheme to investigate
sampling plans for various types of event changes, making use of traditional game theory. If one restricted the situation by specifying that only one sample could be taken over a unit time interval, and that the process would shift to a high hazard event during this time interval, then one could analyze the situation in game theoretic terms with nature being the opponent. The unit time period could be broken down into n subperiods, and the sampler would be required to choose which period to take the sample against nature's strategy to select the subperiod for the shift. The payoff in each cell would be the hazard (expected loss) associated with exposure to that event. In this case, since each row and column possesses the same hazard, the sampler's best strategy would be to select each subperiod with equal probability. The game might be further enriched by including the different event shifts that might be possible. This approach would not permit analysis of stochastic processes. The main contribution of such an approach would be to provide a better understanding of the mechanism behind the sampling characteristics of the model.

Similarly sequential sampling schemes might be relevant to a simplified situation. In this case, sampling frequency might be increased upon the detection of certain events and decreased with other events. With a sequential decision function, the decision for the time of the next sample depends upon the results of past events. We would intuitively feel that this is the manner in which the human operator would behave.

The above remarks were intended to indicate the kind of problem
that the sampling aspect of the model is concerned with. The foremost requirement of the sampling scheme is knowledge about the statistical properties of the event changes. Existing sampling theory does not provide for stochastic processes. Nevertheless, some oversimplified sampling situations will be of help in providing a better understanding of the problem. Two illustrations of this type follow.

Consider an oversimplified situation in which there is a standard event or group of events $E_j$ which the operator must maintain for maximum safe operation. At various times a change in non-behavioral states results in the occurrence of an event $E_i$ ($i \neq j$) for which $p_{ij} > p_{jL}$. The operator should detect these changes as soon as possible so that a response can be evoked which will return the environmental event to $E_j$. At any time $t$ with the event at $E_j$ there is a probability of a shift to $E_i$, $P_{ij}(t)$ with its attendant unit hazard $H_i$. Further, let $\bar{t}_j$ be the average duration of $E_j$ prior to a shift to $E_i$. If $H_{\text{min}}$ is the hazard associated with unit exposure to $E_j$ and $K_1$ is a constant of proportionality, then we would expect $t_{sji}$, the time to the next sample, to be a function of the expected $E_i$, $\bar{t}_j$, $H_{\text{min}}$, $H_i$, and $P_{ij}(t)$. This relationship might appear as

$$t_{sji} = f \left[ \frac{K_1 \bar{t}_j}{H_i - H_{\text{min}}} \right].$$

if a specific $E_i$ were known to be the next event. This suggests that $t_{sji}$ should be small if $(H_i - H_{\text{min}})$ is large and if $\bar{t}_j$ is small. In the absence of knowledge about a specific $E_i$, the above equation
could be modified as follows for the average case:

\[
t_s = f \left[ \frac{K_t \bar{t}_j}{\bar{H} - H_{\text{min}}} \right]
\]

where \( \bar{H} = \frac{\sum H_i P_{ij}}{n - 1} \)

and \( n \) = the number of possible events

Here \( t_s \) is the average time between samples. Note that \( H_i, \bar{H}, \) and \( H_{\text{min}} \) are computed on the basis of unit exposure. The risk is assumed to be a linear function of time. The variance associated with \( t_j \) would have a serious effect on the sampling period selected. With a large variance, it would be possible for \( \bar{t}_j \) to be large and still have small value of \( t_j \). The above functional relation applies only in the average case. Moreover, we assume that sampling as often as possible is not necessarily ideal because of the demands it would impose on the operator.

The above is no attempt to lay out an optimum sampling plan. The primary purpose here is to relate some of the factors which dictate a desirable plan. The statistical characteristics of \( P_{ij} \) and \( t_j \) would be required for a more rigorous approach.

In traditional sampling plans, one method to determine the frequency of inspection is to weigh the costs of inspection against the cost of failure to inspect. In the case of the human servo system, the cost of failure to sample results in exposure to hazards with the attendant expected loss. Since accident severity is often expressed
in dollars, an expected loss for failure to inspect is possible. The cost of inspection is much more difficult to evaluate. Where the inspection would require time off from the job, e.g., to read a gauge, and where the job is a self-paced incentive operation, then the sample cost could be estimated in terms of production lost or lost operator incentive (dollar). It is possible that sampling, decision-making, and response involve some cost to the operator, but whether a dollar value could be attached to it is questionable. Since accidents can also be expressed in time lost from the job, it might be possible to compare time charges of inspection and those as a consequence of not inspecting.

Assuming for the moment that such a dollar or time charge can be given to a sample, a procedure could be developed to determine the time between inspections after those methods used in quality control, specifically that proposed by Wijvake (71). The following simplifying assumptions are required:

1) a shift cannot occur during a correcting response
2) a shift to an $E_i$ incurs an expected loss which is a function of the exposure to this $E_i$
3) the operator has zero reaction time
4) probability of a shift is independent of the sampling frequency
5) the probability of any shift is constant
6) there is an event $E_0$ to which all shifted events are returned
7) the time interval between inspections is constant

Basis - 1 hour of operation

Let $R =$ time interval between inspections

$f =$ number of event changes per hour

$\bar{H} =$ average expected loss (in dollars) per hour

of exposure to any $E_i$ ($i \neq 0$) $\bar{H} = \sum \frac{L_i p_i}{n-1}$

with $p_i =$ probability of an accident with exposure to one hour of $E_i$

$K =$ loss in dollars per inspection

$t =$ elapsed time from the last sample ($t \leq R$)

$Z = f R$

$P_R$ (of a shift in $dt$) = $f dt$

$P_R$ (of no shift after $t$) = $e^{-ft}$

$P_R$ ($R - t$ hours exposed to $E_i$) = $e^{-ft} f dt$

Integrating the last expression over $R$ and replacing $f R$ by $Z$, the total cost = $\Theta$

\[
\Theta = \left[\frac{Z + e^{-Z}}{Z} \right] \bar{H} + \frac{K f}{Z}
\]

Differentiating the total cost with respect to $Z$ and setting the result equal to zero yields:

\[1 - e^{-Z} (Z + 1) = \frac{K f}{\bar{H}}\]

if $Z$ is small

then $Z = \sqrt{2Kf/\bar{H}}$

and $R = \sqrt{2K/ f\bar{H}}$
This result is remarkably similar to the functional expression above. It again suggests that the sampling period should be short where high average loss is expected with exposure, or if the number of shifts per hour is large. If the sampling cost is high, then this would tend to lengthen the sampling period.
Very often theoretical treatment of real world phenomena creates more problems than it initially set out to answer. In fact, with almost any research effort, the original problem unfolds into a host of related problems. In suggesting a new framework for the study of accidents, this research did not intend to provide any immediate answers to the uncomparably complex problem of the accident phenomena. Instead, it proposed a radically different approach to accidents, primarily for the purpose of establishing relationships among the factors which make up accidents and to suggest further research to establish the validity and usefulness of this approach. The appropriateness of the feedback framework can be determined only by establishing the validity of the concepts derived from it. This involves measurement and testing of hypotheses. This does not suggest that the present development of the model is sufficiently advanced to permit testing. Additional research must proceed along both formal and empirical lines if desired results are to be realized. Often in dealing with complex phenomena in abstract or formal fashion, the relationship of various factors within the phenomena appear to be relatively simple. It is only when we try to apply such abstractions to the real world do we suddenly find ourselves
in a dilemma. Hypothetical constructs and intervening variables which nicely fit into the structure of the model resist empirical definition and measurement.

The model described above requires considerable future research effort, both to verify the hypotheses presented and to extend the formal treatment of the model into more explicit terms. In discussing formal and empirical research required, we cannot treat the one without consideration of the other. Results from experiments to verify the initial hypotheses will undoubtedly influence the formal structure of the model. The critical aspect of future research is one of measurement. The model has been developed primarily in a microscopic fashion with discussion centered about shifting events. Whether these events can be identified and described is the major criterion for the usefulness of the model from a pragmatic point of view. The model was originally posed as a unique interpretation of a complex problem. With its development, the model has suggested some specific measures of safe behavior and environmental hazard. These measures should be substantiated through analysis of empirical data, first to test the plausibility of the model, and second to test the plausibility of the indices of safety performance derived from the model.

It must be emphasized that any future research effort will not be simple in design or execution. In dealing with the many dimensions which make up the accident situation, complications arise both in formal development and the experimental design. The problem
is tremendously complicated by the fact that we are dealing with human behavior and thus subject to its ramifications and measurement difficulties. Our justification for inviting the Herculean problems of future research in this field is the recognition of the importance of safety in our society and the pressing need for intensive research to shed some light on the problem.

We might classify future research into three activities:

1) formal development
2) controlled laboratory experiments
3) experiments in the industrial climate using both past plant accident data and generated plant data

The first and second activities might be considered as further study at the microscopic level. The third activity is considered here as a macroscopic approach. There is no strict ranking of the priority of these three activities. To some extent each will influence the other. Moreover, the classifications are not independent. Concurrent effort on mathematical development and laboratory experiments will be necessary in many cases. However, the formal structure of the model will often dictate required laboratory and industrial experiments. For this reason initial effort should be directed along the formal development of the model.

Considerable refinement and enrichment of the present model is required to establish more explicit relationships among the system parameters. In its present stage the model lacks specificity which necessarily limits the precision of subsequent experimentation. It
is certainly possible that other general classes of mathematical models are equally appropriate in describing the accident phenomena. For example, game theoretic models could describe certain aspects of the accident situation, such as risk acceptance. In terms of the proposed model, the first requirement would be to further develop the mathematical structure introduced in Chapter 5. Studies could be initiated to determine the type of stochastic processes involved in the changes of job states, and to evaluate steady state probabilities for given processes. Investigation is needed to determine the causes of event shifts. The formal structure should be revised to allow tests by critical observations, aspects of the structure which would yield empirical verification. Some insight into the psychological aspects of the model, such as the factors which make up internal stimuli, might be gleaned by factor analysis.

Considerable effort is needed in developing normative decision rules for the safe operator. The formal relationships of utility, decision rules, principles of choice, and responses are necessary in tying together the various aspects of the goal setting mechanism. Should the model be developed to the point of providing quantitative estimates of the basic parameters, then computational procedures would be required to solve for the values of those parameters which maximize safe operator performance. Another interesting facet of the model which would be amenable to formal treatment is the relationship between operator sampling schemes and the stochastic nature of event changes. Given the type of stochastic process
exhibited by changes in job states, optimum sampling plans which minimize undetected exposure to high hazard events would be a very worthwhile research endeavor.

Laboratory experiments to verify the structure of the model under controlled conditions are necessary adjuncts of the formal aspects of the research. The task for the experimenter is not an easy one. Simulation of the accident situation in the laboratory is extremely difficult and few experiments along this line have been successfully conducted. Unfortunately, there are few volunteer subjects who will submit themselves to an accident. We could possibly simulate an accident by some artificial device such as a jet of air at the eyeball, high frequency and high intensity noise, or even actual dollar loss to the subject. None of these, however, appear to be acceptable substitutes for an actual accident. Moreover, we necessarily sacrifice validity when we attempt to fit the industrial climate into the laboratory. The initial problem which future laboratory research must undertake is primarily one of measurement. How does one describe and measure the "events" of the job? What constitutes measurable end points of these events? What are the various states of the job and how do they comprise events? How do these states change in time? Included in this measurement problem is the identification of event risk or hazard.

In order to functionally relate the states of the job, principles of choice, decision rules, reaction time, and sampling plans, a laboratory experiment would be required in which the various states
could be generated with a given set of transitional probabilities. The choice of operator behavioral states could be controlled at three or four levels. Hence, all possible events would be specified. A risk in terms of exposure could be arbitrarily assigned to each event. An accident could be the forfeiture of earnings from accident-free operation. The motivational scheme might also consist of an initial sum of money given to the subject. With each accident or exposure to high hazard levels, this initial sum would be reduced. Although this is by no means an adequate simulation of consequences of accidents, it might serve for the purposes of the experiment. A device to select the time and event which would result in an accident could be developed, based on the transitional probabilities of the various events. After a period of familiarization with the event hazard levels, operator behavior would be measured by how well he could detect event changes and minimize his hazard exposure. Motivation might also be accomplished by providing different payoff rates for various events. In this way various principles of choice and decision rules, e.g., maximize expected utility, minimize expected loss, etc., could be tested. Operator sampling of events could be simulated by requiring him to remove covers over displays to identify the job states. Since the time sharing characteristics of the operator are desired, a continuous tracking task or secondary function would be required to compete with the sampling function. With prolonged training on this simulated job, we might be able to estimate how well the operator could evaluate the transitional
probability of the job states and their expected duration. This experiment necessarily lacks the realism of the accident situation, but would begin to establish relationship of the basic components of the proposed model. Another interesting facet of this experiment would be to determine the relation between the actual risk of $E_i$ and the operator's subjective estimate of it. Some of the aspects of this type of study were discussed in Chapter 8. Essentially what is desired is how well the operator can predict the transitional probability matrix.

A potentially fruitful area of research on the industrial safety problem would be one which investigates the effect of environment (heat, light, noise, etc.) on job safety. If the laboratory situation closely simulates the accident situation, then controlled experiments could be conducted using these environmental factors as independent variables, and using expected loss from exposure to various events as the criterion measure. In addition, other variables such as the effect of training, prolonged work periods, and stimulants (drugs) could be introduced into the experimental design. With the same criterion measure, jobs involving displays and controls would allow verification of human engineering data regarding optimum design of equipment for human use. The interesting facet of these experiments would be the ability to measure the effect on the various factors which comprise exposure as suggested by the model, namely:

1) undetected exposure
2) detected exposure
3) exposure during response (this would be particularly pertinent to equipment design)

4) unconscious exposure (if dominance of the system by internal stimuli could be distinguished)

The problem of measuring the effect of internal stimuli on operator performance may be beyond our knowledge of human behavior. However, for purposes of the accident situation, certain simplifying assumptions might allow some investigation. Perhaps if internal stimuli system dominance could be redefined as "that part of exposure that the operator is unaware of," then the operator could log his exposure to various events and this could be compared with actual exposure recorded by films taken over the same period. Also, there may be physiological measures of emotional preoccupation, revery, etc. Alpha and delta wave activity between cognizant and revery states might be significantly different so that electroencephalographs would provide a measure of system dominance by internal stimuli. Another measurement might be the time required to respond to some action by the experimenter. We might hypothesize that response times would be longer if the command occurred during a period of emotional preoccupation.

Experiments on an industrial scale offer valuable information to the over-all development of the proposed approach. The validity attached to such experiments is often gained at the loss of control of independent variables. In addition, gross approximations to the model parameters are often necessary. Nevertheless, industry is the setting where the final determination of the model's utility will be
evaluated. If the notion of event hazard can be substantiated, then the indices of hazard associated with the job and with operator behavior offer significant contribution to accident prevention. The basic problem here as in the laboratory is the identification and definition of events and states, and their changes with time. There are several possible approaches. Motion pictures of particular jobs would allow classification of events. The difficulty here is whether the sample of activity filmed includes all possible events. Work sampling techniques using motion picture cameras might minimize this sampling bias. On the other hand, one might determine the possible events from operator descriptions of his changing environment. These events might also be evaluated indirectly by analysis of detailed accident reports for a given type of job. On the basis of the situation at the time of the accident, a description of an event might be developed. All non-accident exposure could be assumed as exposure to "safe events." Once an event and its states are defined, it would be necessary to evaluate the hazard (expected loss) with certain exposure to these events. Permitting gross approximations, one might estimate $p_i$ from past accident claims assigned to specific events, and (assuming the distribution of event occurrences and duration remain constant over time) evaluate the exposure to these events by work sampling methods. This would enable a crude comparison of hazard among jobs. One might also make use of multiple regression methods (using sampled exposures to events and existing claim experience for a large number of operators) to evaluate the risk associated with a specific event on a given job.
Even if risk cannot be established in the industrial setting, one can still evaluate through memomotion techniques the ability of the operator to detect changes in environmental events and the relationship between his sampling scheme and the nature of the changes in events.

A fruitful area of industrial research would be an evaluation of the bases for accident prevention programs as discussed in Chapter 3. Particularly important in this regard would be the determination of accident costs. Included here would be the assessment of value to the intangible costs of accidents, i.e., employee morale, public relations, etc. In addition to the evaluation of costs, there is considerable potential in statistical analysis of plant accident data. Some work has been done along this line, using quality control charts. Difference in reported accident data could be evaluated in terms of statistical significance.

In general, the opportunities for future research in industrial safety are unlimited. The model suggests several areas of research designed to bring about a better understanding of the mechanism behind accidents. Only a few of the other research possibilities were mentioned. The present deterministic approach to accidents suggests a field of research efforts, namely, the probabilistic interpretation of accidents. Sensitive measurement instruments are needed to describe the transient nature of the industrial environment. Decision rules for the allocation of effort in accident prevention programs are needed which will incorporate this probabilistic
concept of accidents. Objective bases for comparing safe behavior
and job hazards are needed to appraise management of those jobs
and persons to which accident prevention programs should be directed.
The multi-disciplinary aspect of safety offers research opportunities
not only to the individual disciplines concerned, but also to the
mixed-team approach.

Summary
The material presented in this study has attempted to bring
together the various facets of the safety problem, and to focus
them in the framework of a model of the accident phenomena. The
introductory material was presented to establish a foundation for
the model to follow. A brief sketch of the United States accident
record revealed the enormity of the accident problem today. The
overview of research in industrial safety brought out the salient
problems, namely, the diversified and fragmented efforts of psy­
chologists, statisticians, engineers, and industrial physicians
have failed to place emphasis on the "whole accident" and conse­
quently there are few studies on the fundamental aspects of the
problem. Chapter 3 proposed a model for decisions regarding the
amount and direction of effort in accident prevention programs,
and in so doing, accented the inadequacy of our basic understanding
of accidents. The model, essentially a cost equation, would provide
a sound basis for safety expenditures once the required data are
available. The criterion measure of accidents as suggested by the
model has immediate use in the cost equation.
The major emphasis in this study has been the exploration of a feedback model which relates the various aspects of the accident phenomena. The operator is considered analogous to a sampling servo mechanism, sampling his environment (defined as an event) at certain time periods, and deciding on the basis of his subjective utility of events whether to continue operation as before, or to change the event by action of appropriate responses. The operator's sampling scheme, his utility structure and resulting decision rule, and his receptor and effector mechanisms are functionally related in the model. An environmental event consists in both non-behavioral states and behavioral states. Each environmental event is considered to have some hazard associated with it. Exposure to an event results in expected loss which is a function of the duration of exposure to the event, the probability of an accident during the exposure, and the expected loss associated with the accident. This notion of expected loss with exposure to certain environmental events is the basis for comparing job and operator safety. It was proposed that expected loss for exposure to all events on the job is a more representative measure of safety than accident frequency.

The implications from the model suggested two useful measures in accident analysis. First, if one assumes ideal operator behavior, then various jobs can be compared on the basis of unavoidable exposure to certain events. The total expected loss of a job is a function of the number of shifts in events beyond control of the operator, the extent of loss associated with each event, and the duration of exposure necessitated by the time required to detect event changes and select appropriate
responses to minimize expected loss. In this fashion, the minimum expected loss of dissimilar jobs may be capable of comparison.

Second, using the same measure of expected loss with exposure to an event, a scale of comparison was proposed for measuring safe behavior of operators on similar or dissimilar jobs. The criterion here was the elected exposure to hazardous events, or the elected expected loss. This loss results from exposure which could be eliminated with optimum operator behavior. This elected exposure results from:

1) an inadequate sampling plan which permits exposure to events resulting from changing job states

2) decisions to operate at events that are more hazardous than those required for proper job performance

3) unnecessary exposure to high hazard events through dominance of the system by internal stimuli (an intervening variable introduced in the model to account for revery, daydreams, unconscious responses, and the like)

An interesting development from the model was the sampling aspect of the accident phenomena. The ability of the operator to identify the existing environmental event and to judiciously select the time of sampling to detect any shifts in job states plays an important part in minimizing expected loss during job operation.

Some of the determining factors of optimum sampling plans were proposed based upon the distribution of changing job states and their expected loss with exposure. This aspect of the model is extremely complicated, and is not amenable to analysis by present sampling theory.
The notion of expected loss with exposure to environmental events offers the additional advantage of combining accident hazard with occupational disease hazard. Heretofore, these two causes of occupational disability have been treated independently. Under the model, the effect of responses on both occupational disease and traumatic accidents can be related.

Another contribution of the model is that it permits explanation of any kind of accident stereotype and the part(s) of the feedback system involved. No-injury accidents, two-party accidents, accidents from judgment errors, accidents of omission, accidents from gambles can be explicated in the feedback system.

The model also serves to relate the various disciplines with the safety problem. The domains of the industrial physician, the psychologist, and the engineer are oriented in terms of the various components of the model. The contribution of human engineering studies, descriptive decision-making, employment physical examinations and the like can be effectively integrated in the framework of the model. In addition, in terms of future research the model can be used to balance research effort on all phases of the accident problem.

Throughout the development of the model, the need for further research was indicated. Formal development in particular will require a more rigorous analysis. The hypotheses derived from implications of the model will require empirical validation. The problem of measurement appears to be the major obstacle in further development. However, even if specific data are not available, the model will still prove
useful if it promotes a better understanding of the accident phenomena. This framework for the study of accidents has already pointed to the need of specific research to answer problems which have arisen in its development.

In exploring the accident phenomena, the tremendous complexity of the problem has been clearly demonstrated. Since accident behavior is just one of the myriad dimensions that constitute human action, the primary difficulty in formalizing the accident situation stems from the inherent obstacles in quantifying human behavior itself. This study does not attempt to solve a problem which has persistently evaded the genius of our time. The model has, however, opened up the problem of accidents, illustrating its relevancy to developments in the fields of mathematics, system analysis, psychology, and medicine, and emphasizing the need for greater understanding of what constitutes human behavior.

This study, then, must admit to creating more problems than it answers. The general intent has been to map out the various facets of the accident problem in a single structure. In its present stage, the model lacks specificity. However, its flexibility permits the inclusion of factors heretofore unrelated. It is believed that only through a "total" approach to the complicated problem of accidents can real progress in accident prevention be effected. It is hoped that this study will promote further research in this and other models, so that our general understanding of accidents can progress to meet the present demands of the safety problem.
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