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RESEARCH TO DETERMINE THE CONTRIBUTION OF SYSTEM FACTORS IN THE OCCURRENCE OF UNDERGROUND INJURY ACCIDENTS

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7. Author(s)
Mark S. Sanders, Ph.D. and Brian E. Shaw

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Essex Corporation
741 Lakefield Road, Suite B
Westlake Village, CA 91361

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16. Abstract (Limit: 200 words)

A systems approach to accident investigation was applied to 338 underground mining accidents. A taxonomic model of contributing factors in accident causation was developed, and expert raters assessed the degree to which each factor played a role in each accident case. The model contained the following 10 factors: management, physical environment, work task, equipment, social environment, perceptual-cognitive-motor (PCM) error of the injured employee and co-workers, worker characteristics of the injured employee and co-workers, and other/miscellaneous factors. The report contains a literature review on the analysis and classification of human error, including the role of human error in accidents. Results indicated that 88% of the cases involved more than one causal factor. Injured employee PCM error was involved, to some degree, in 93% of the cases and when involved, averaged about 33 (of 100) points of causality. The factor was considered a primary causal factor in almost 50% of the cases and a secondary causal factor in another 24%. Management was the second most important causal factor. It was considered a primary factor in 22% of the cases and a secondary factor in another 12%. Recommendations are presented and discussed.

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Accident Investigation	Countermeasures	Rating Methodology
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FOREWORD

This report was prepared by Essex Corporation, 741 Lakefield Road, Suite B, Westlake Village, CA 91361, under USBM Contract number J0348042. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Pittsburgh Research Center with Mr. James M. Peay acting as Technical Project Officer. Mr. Joseph A. Gilchrist was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period 1984 to 1988. This report was submitted by the authors in September 1988.

Research of this type and magnitude requires the cooperation of many people. The authors would like to acknowledge the following and express sincere thanks for their help and cooperation:

- The corporate management of the mining companies who participated in the study and opened their doors, adits, and shafts to us for data collection, as well as providing us with almost unlimited access to their workers and existing safety data;
- The safety managers at the individual mines who coordinated the interviews and data collection, provided underground escort services, and helped us to assure complete collection of accident data; and
- The individual mine workers who discussed, in graphic detail, their accidents and injuries, often after "punching out" for the day.

Special acknowledgement and thanks are expressed to Mrs. Joan Funk who provided administrative continuity, editorial and production services, and morale support throughout the project.

Without the cooperation of all these individuals, this project could not have been successful.

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EXECUTIVE SUMMARY

This report was produced under Bureau of Mines Contract No. J0348042 entitled "Research to Determine the Frequency and Causes of Human Error Accidents in Underground Mining." The contract was awarded to Essex Corporation on August 15, 1984. This section was written as a stand-alone summary of the methodology and results of this project. As such, it is redundant with later sections of this report. The organization of this summary follows the general organization of the report, highlighting the salient findings and conclusions.

Purpose

The objective of this project was to perform a comprehensive analysis of underground mining accidents to determine the relative contribution of various causal factors, including human error. In addition, the following subsidiary objectives were accomplished: (1) comprehensive review of the human error literature; (2) development of a systems model of accident causation; (3) development of methodology for assessing the relative contribution of various factors to accident causation.

Project Activities

This project was carried out in three phases. The first phase involved the development of the methodology for assessing the causes of underground mining accidents. A pilot test was conducted on a sample of 92 accidents from nine mines. Phase II was the full-scale execution of the study. Modifications were made to the methodology and a total of 338 accidents (including the 92 from Phase I) were investigated and analyzed. Phase III involved the writing of this report.

Literature Review

The literature review focused on the analysis and classification of human error, including definitions of human error, the role of human error in accidents, and descriptive human error classification schemes and causal models of human error. The following are the main findings from the literature review:

1. The field of human error is still very much in a formative state.

2. No single classification scheme or model seems to account for the diversity and complexity of human error.

3. There is surprisingly little empirical data on human error.

4. Most definitions of human error involve some notion that a human's behavior deviates from an established standard, and that standard is often defined after the fact. Some definitions stress the effect or potential effect of the error.

5. Human errors may be a natural consequence of learning and are necessary for the development of skilled performance.

6. The contribution of human error to accidents depends upon such considerations as which humans' errors are included and the other factors examined as possible causes.

7. It is virtually meaningless to synthesize the studies that have attempted to determine the proportion of accidents/incidents due to human error.

8. Fifteen studies attempted to determine the proportion of accidents/incidents attributable to human error. The percentages attributed to human error ranged from 4.2% to 90%, with a median of 35%.

9. Four broad categories of human error classification schemes were identified: system-oriented schemes, innate dimension-based schemes, overt behavior-based schemes, and cognitive model-based schemes.

10. Cognitive model-based and overt behavior-based schemes are the most popular and probably will endure the longest. System-oriented schemes and innate dimension-based schemes offer little explanation as to how or why the errors occurred.

11. Causal models of human error are either broad theoretical models that bring together the myriad of factors that influence human behavior, or they are empirical models that identify the contributing factors in a specific domain of accidents. Usually, the factors identified in the empirical models are more specific than those included in the theoretical models.

12. A general model of contributing factors in accident causation (CFAC) was developed for this project. The model includes the following six major categories of causal factors: management, physical environment, equipment design, work itself, social/psychological environment, and worker/co-worker characteristics and perceptual-cognitive-motor error.

Data Collection Methodology

Goals of the data collection methodology were to secure the cooperation of a sample of mines that would provide a broad, typical range of accidents for investigation, and to collect relevant information that would allow assessments to be made of the contributing causes involved in those accidents. The highlights of the data collection methodology included:

1. The sample of mines used in this study should not be considered truly representative of the underground mining industry; however, the sample does represent a wide range of typical medium-to-large mining operations.

2. A total of 20 mines, operated by five companies were included in the sample, 17 of which were coal mines.

3. The sample included approximately 2,000 underground miners working approximately 3.5 million labor hours.

4. All non-fatal, MSHA-reportable injuries occurring at the participating mines were investigated.

5. A total of 338 accidents were investigated over a 29-month period at the participating mines.

6. A trained accident investigator visited each mine every 4 to 6 weeks and investigated all injuries occurring since the last visit. The injured worker was interviewed; mine safety representatives were questioned; when appropriate, witnesses and supervisors were interviewed; and, if possible, the accident site and equipment involved were inspected. On average, each case involved approximately 1.5 hours of interviewing.

7. When the investigation was completed, the investigator developed a narrative summary of the facts and circumstances behind the accident. These reports formed the basis by which experts rated the contributions of various factors in the incident.

8. Four attributes of the methodology contributed to maximizing validity and reliability of the data collected: (1) the use of investigators that were trained in both human factors and the systems approach to accident investigation; (2) the use of independent investigators to collect data rather than relying on government- or mine-supplied data; (3) focusing on causality rather than culpability; and (4) the use of a semi-structured interview technique rather than a rigid structured approach to data collection.

Methodology for Assessing Causes of Accidents

By its very nature, assessing the causes or contributing factors to an accident is a judgmental process. The approach taken here, therefore, was to use experts to assess the relative contribution of 10 factors to the occurrence of accidents in a systematic and reliable manner. Highlights of the methodology included:

1. Seven (7) experts were selected with expertise in one or more of the following areas: human factors, mining, accident investigation, and human error. The rating team included a mining engineer and a mine safety director.

2. Based on the accident causation model (CFAC) developed for this project, the following 10 causal factors were defined: management, physical environment, equipment, work task, social climate, injured employee characteristics, co-worker characteristics, injured employee perceptual-cognitive-motor (PCM) error, co-worker PCM error, and other/miscellaneous.

3. Raters were trained to apply the 10 factors to a sample of accident cases.

4. Refinements were made to the definitions and conventions used in Phase I. All Phase I cases were rerated using the refined methodology in Phase II.

5. The raters, independently, assigned 100 points among the 10 factors for each case, justified their ratings, and provided countermeasures for reducing the probability or severity of the injury/accident.

6. For each case, the matrix of interrater correlations was computed across the 10 factors. Those raters' ratings that did not correlate with those of other raters (i.e., low reliability raters) were dropped before the average ratings for a case were determined.

7. Spearman-Brown reliability coefficients were computed for each case. If the reliability coefficient was below 0.70, raters were removed until the coefficient exceeded 0.70. In all but two cases, only one or two raters had to be removed to achieve the 0.70 criterion. If the criterion could not be reached, the case was rerated by the entire rating team. Only 11 cases required rerating.

8. The following factors insured that the final average ratings for each case would be valid and reliable: use of a multi-disciplinary team of raters, use of a rating scale based on a comprehensive model of accident causation, flexible rules and guidelines for rating, and the removal of unreliable raters for a case.

Description of Accident Data Base

The accident data base was described according to who was injured, what the injury was, when it occurred, where it occurred, and how it occurred. The following are some of the highlights of the contents of the accident data base:

1. The injured worker tended to be male and under 40 years of age.

2. A total of 33 different job classifications were represented.

3. About 50% of the injuries occurred to workers with 3 or less years of experience in their job classification.

4. A wide variety of injuries were represented, with the majority being sprain/strains, contusions, and lacerations.

5. The injuries were relatively minor, with only eight resulting in disability.

6. More injuries occurred during the first 4 hours of a shift than in the last 4 hours.

7. The most common type of accident was being struck by an object, with almost all of the struck-by accidents being caused by falling objects.

Results of Assessing Contributing Factors to Accidents

The Spearman-Brown reliability coefficient for the ratings given each case ranged from 0.70 to 1.00, with a mean of 0.90, thus indicating that the ratings were highly reliable. The following are some of the highlights of the analysis of the causal ratings:

1. The 10 causal factors were relatively independent and because of the ipsitive nature of the data (all ratings added to 100 for each case), as one factor increased in importance, other factors tended to decrease in importance.

2. Accidents were caused by more than one factor; 88% of the cases involved some combination of multiple primary factors, or primary and secondary factors. The number of factors significantly involved in a case tended to be small; rarely more than three primary and/or secondary factors were identified.

3. Injured employee PCM error was involved, to some degree, in 93% of the cases. When involved, the average rating was about 33 points. Injured employee PCM error was considered a primary causal factor in almost 50% of the cases and a secondary causal factor in another 24% of the cases. PCM errors included acceptance of a high level of risk, misinterpretation of the risks involved, failure to perceive a perceivable hazard, forgetting to do something the worker knew should have been done, and general inattention or carelessness.

4. Work task was involved, to some degree, in 76% of the cases. When involved, the average rating was about 21 points. Work task was considered a primary causal factor in 22% of the cases and a secondary causal factor in another 19% of the cases. Work task involved exposure to inherently hazardous situations such as roof bolting and scaling of loose back/roof, or exposure to inherently hazardous tasks such as heavy, repetitive lifting.

5. Management was involved, to some degree, in 73% of the cases. When involved, the average rating was about 21 points. Management was considered a primary causal factor in 22% of the cases and a secondary causal factor in another 12% of the cases. Management was implicated for failure to establish, maintain, and/or enforce formalized safe work procedures and practices, inadequate or improper selection of safety equipment, failure to support an adequate equipment maintenance system, failure to identify and/or supply proper equipment, and inadequate solutions applied to safety problems.

6. Physical environment was involved, to some degree, in 52% of the cases. When involved, the average rating was about 13 points. Physical environment was considered a primary causal factor in 7% of the cases and a secondary causal factor in another 9% of the cases. Physical environment was implicated for bad roof/back conditions resulting from geological instability or anomalies, low roof height conditions, and/or irregular bottom/floor conditions.

7. Equipment was involved, to some degree, in 50% of the cases. When involved, the average rating was about 19 points. Equipment was considered a primary causal factor in almost 11% of the cases and a secondary causal factor in another 10% of the cases. Equipment was implicated for poor original design or inadequate redesign, equipment malfunction, inadequate ingress/egress design, exposed sharp surfaces or pinch points, and/or restricted visibility.

8. Injured employee characteristics were involved, to some degree, in 40% of the cases. When involved, the average rating was about 21 points. Injured employee characteristics were considered a primary causal factor in 11% of the cases and a secondary causal factor in another 7% of the cases. Injured employee characteristics implicated in an accident included predisposition to back injury, chronic health problems such as being overweight, and/or chronic inappropriate judgement or behavior patterns.

9. Co-worker PCM error was involved, to some degree, in 32% of the cases. When involved, the average rating was about 22 points. Co-worker PCM error was considered a primary causal factor in 10% of the cases and a secondary causal factor in another 7% of the cases. Co-worker PCM errors were the same types as found for the injured employee PCM errors.

10. Co-worker characteristics were involved, to some degree, in only 4% of the cases. When involved, the average rating was only about 5 points. Co-worker characteristics were not considered a primary causal factor in any of the cases and were considered a secondary causal factor in less than 1% of the cases.

11. Social climate was involved, to some degree, in only 14% of the cases. When involved, the average rating was only about 4 points. Social climate was considered a primary causal factor in less than 1% of the cases and a secondary causal factor in almost 2% of the cases.

12. Other/miscellaneous factors were involved, to some degree, in 38% of the cases. When involved, the average rating was about 16 points. Other/miscellaneous factors were considered a primary causal factor in almost 5% of the cases and a secondary causal factor in another 4% of the cases. Other/miscellaneous factors included an unsafe condition that existed but was undetectable, but most cases represented accidents for which causes could not be determined.

13. Physical environment and work task causal factors tended to be more heavily implicated in low-seam mine accidents. Management was rated as a lower source of causation in low-seam accidents than in high-seam accidents.

14. Management tended to be more heavily implicated when accidents occurred in fixed facilities (maintenance areas and haulageways) than in more transient areas (working sections).

15. Physical environment was implicated more heavily in transient areas where conditions are less controlled than in fixed areas.

16. Roof fall accidents showed a consistent pattern of causal factor involvement, with high ratings given to physical environment and work task. Back injuries also showed a consistent pattern, with high ratings on work task and injured employee characteristics.

17. None of the causal factor ratings were significantly correlated with age or injured employee experience.

Results of Analysis of Countermeasures

Raters supplied countermeasures for each case in which they thought a countermeasure would reduce the probability or severity of the accident or injury. These countermeasures were consolidated and content analyzed. The following are some of the highlights of that analysis:

1. A total of 2,198 countermeasures were provided for the 338 cases. After duplicates were consolidated into single countermeasures for a case, 743 countermeasures remained.

2. Countermeasures were grouped into the following categories: management, job assignment/scheduling, new or revised standard operating procedures (SOPs), equipment design, employee training, maintenance/housekeeping, supplies, environment, and "other."

3. The main category of management-related countermeasures was to provide proper equipment to do the job or task (88 cases), with the largest single category of equipment being lifting aids. Enforcement of SOPs was another management-related countermeasure mentioned in several cases (52), with SOPs related to roof control mentioned most often.

4. Need for new or revised SOPs was mentioned as a countermeasure in 23 cases.

5. In 126 cases, equipment design modifications were mentioned as a way to reduce the probability or severity of the accident or injury. Several equipment design countermeasures dealt with reducing the amount of buffeting experienced by operators of mobile equipment. Need to modify the egress features on equipment was also mentioned, as was designing for maintainability.

6. Improved job performance training was mentioned in 90 cases.

Discussion and Recommendations

Recommendations gleaned from development of the causal model, exercising the project's methodology, analyses of the projects data, and observations made of industry trends are presented and discussed. The following are the specific recommendations made:

1. Develop technology transfer seminars for dissemination of the systems approach to accident investigation and analysis.

2. Assemble project data into a unified data base to serve as a source for future researchers.

3. Develop a training system which focuses on risk identification and assessment in dynamic situations.

4. Investigate alternative methods of reducing high-incidence, low-cost accident/injury incidents.

5. Continue efforts toward development of lightweight roofbolter canopies to supplement ATRS systems.

6. Develop "recommended practices" for OEM designers on human factors considerations in crewstation design and design-for-maintainability issues.

7. Continue research directed at accident reduction of back injuries associated with manual materials handling.

INTRODUCTION

This report was produced under Bureau of Mines Contract No. J0348042 entitled "Research to Determine the Frequency and Causes of Human Error Accidents in Underground Mining." The contract was awarded to Essex Corporation on August 15, 1984.

Purpose

The objective of this project as stated in the contract was as follows: "to empirically determine through field research the number of underground mining accidents that occur as a result of human error and ascertain those factors which permit such error to occur." This objective was operationalized to include a comprehensive analysis of underground accidents to determine the relative contribution of various causal factors, including human error. In addition to the main objective, several subsidiary objectives were included in the project: (1) provide a comprehensive review of the human error literature, including the definition of human error, human error classification schemes, causal models of human error, and the relationship of human error to accidents; (2) develop a systems model of accident causation to serve as a basis for analyzing the causes of underground mining accidents; and (3) develop a methodology for assessing the relative contribution of various factors to accident causation.

Philosophy and Assumptions

The philosophy behind the methodology developed during this project involved the following assumptions: (1) accident reports generated by mine personnel to meet government or company reporting requirements would not contain adequate information upon which to assess causation; (2) on-site investigations by individuals trained in the systems approach to accident investigation and knowledgeable about human factors would be required to collect adequate data; (3) accidents are caused by multiple factors interacting in a given situation; (4) knowledgeable individuals can make reliable assessments of the relative contribution of various factors to the causation of an accident; and (5) accidents are not totally random events, but rather are due to various patterns of contributing factors that can be assessed with an adequate data base of accidents.

Project Activities

The project was divided into three phases. Phase I involved the development of a methodology for assessing the causes of underground mining accidents and pilot testing the methodology on a sample of accidents. Phase II involved the refinement of the Phase I methodology and the analysis of a larger sample of accidents. Phase III involved the writing of this report and communication of the results to the participating mines.

During Phase I, 92 accidents from 9 mines were investigated and the relative contributions of various causal factors were assessed by a panel of human factors, safety, and mining experts. Based on the results of that phase, modifications were made to the definitions of the causal factors and to the composition of the expert panel. Using the refined methodology, the panel rerated the 92 accidents from Phase

I. During Phase II, an additional 246 accidents were investigated and rated by the panel. Phases I and II covered a time period of 29 months of investigating accidents at underground mines. A comprehensive literature review citing over 70 references was also prepared during Phase II.

Overview of Methodology

All non-fatal, MSHA-reportable accidents occurring during the data collection period at a sample of 20 mines (17 coal and 3 metal/nonmetal) were investigated by a trained accident investigator. The sample included approximately 2,000 underground miners, working approximately 3.5 million labor hours during the data collection period. Each mine was visited every 4 to 6 weeks, and all injury accidents occurring during that time were investigated. Interviews were conducted and site visits to the injury scene were made. Each accident was written up in a narrative report.

Seven experts in human factors, accident causation, and mining were trained to assess the relative contribution of 10 causal factors in the production of accidents. The following 10 factors were assessed: management, physical environment, equipment, work task, social climate, injured employee characteristics, co-worker characteristics, perceptual-cognitive-motor (PCM) errors of the injured employee, PCM errors of co-workers, and other/miscellaneous factors. The panel members independently assigned 100 points of causation among the 10 factors. Interrater reliability was assessed and the ratings averaged for reliable raters. The average factor ratings for each case were used as the measure of the underlying causal factors involved in each accident.

In addition to making the causal assessments, each rater suggested countermeasures to reduce the probability and/or likelihood of the accident. The countermeasures were content analyzed and grouped. A total of 743 unique countermeasures were suggested by the rating panel.

Data analysis included a tabulation of the relative contribution of the various causal factors to underground accidents, both in terms of average contribution and percentage of cases in which the factor was considered to be a primary or secondary causal factor. Factor analysis and cluster analysis were performed to uncover causal pattern among the accidents.

Organization of the Report

The first section presents the literature review of human error. The emphasis of the review is on the analysis and classification of human error, including causal models and the role of human errors in accidents.

The next two sections discuss the methodology used to collect the accident data and the methodology used to assess the contribution of the causal factors. The following three sections present the results of the study. The first describes the accidents in the data base in terms of who was injured, what the injury was, when it occurred, where it occurred, and how it occurred; the second presents the results of the relative contribution of the various causal factors and explores in more depth what specific factors contributed to the accidents; and the third presents the results of the analysis of countermeasures suggested by the rating panel. The next section contains conclusions and recommendations, and the final section is the bibliography of references cited in the report.

LITERATURE REVIEW

Scope of Literature Review

The following literature review focuses on human error and its contribution to accidents. Rouse and Rouse (52)[1] distinguish two major approaches to characterizing human error: probabilistic and causal. The probabilistic approach is typically pursued by those who are interested in the human reliability aspects of risk analysis. (See, for example, 1, 29, 32, 67.) In these analyses, human errors are treated like hardware failures. Human failure rates for particular tasks are determined and used to analyze the overall reliability of a system.

In contrast, the causal approach to human error is based on the premise that errors are seldom random and, in fact, can be traced to causes and contributing factors which, once identified, can perhaps be reduced or eliminated. The emphasis is on analysis and classification of human error. This review will concentrate on the causal approach. The review will present and discuss: definitions of human error, the role of human error in accidents, descriptive human error classification schemes, and causal models of human error.

The field of human error is still very much in the formative stage. Even the definition of "human error" is still being debated. No single classification scheme or model seems to account for the diversity and complexity of human error. Different investigators adopt very different perspectives, and come to divergent conclusions. Some authors take a microscopic approach, while others take a more macroscopic perspective. Unfortunately, the relationship between these differing approaches is not always evident. Despite the volume of material written on human error, there is surprisingly little empirical data on the topic; and what there is, is hard to apply to the schemes and models proposed. It would be premature, in this review, to integrate the various theories and models, or even to order them in terms of relative merit or worth.

Definition of Human Error

Most definitions of human error involve some notion that a human's behavior deviates from an established standard. In addition, some definitions also incorporate the idea that the behavior results in an undesirable consequence. The following are typical examples:

> Human error is an inappropriate or undesirable human decision or behavior that reduces, or has the potential for reducing, effectiveness, safety, or system performance (54).

> Human error is any action of the human element of a system that is inconsistent with a predetermined behavioral pattern established in the system specifications, and in the resulting system design (4).

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[1]Underlined numbers in parenthesis refer to items in the list of references at the end of this report.

Human error consists of any significant deviation from a previously established, required, or expected standard of human performance, that results in unwanted or undesirable time delay, difficulty, problem, trouble, incident, malfunction, or failure (38).

Human error is the specified deviation of a human activity or decision from an operationally defined norm (6).

Human error is any member of a set of human actions that exceeds some limit of acceptability (49).

Human error is any human action revealing a deviation from the action that would have averted the event or reduced its seriousness (16).

The term "deviation" is common to most of the above definitions. Kjellen (27) identifies four types of norms against which deviance is often judged: (1) a standard, rule, or regulation; (2) adequate or acceptable; (3) normal or usual; and (4) planned or intended. Norms that involve judgments, such as what is adequate or what is usual, involve problems of reliability and differences of opinion between those performing the action and those judging whether it is deviant or not.

Definitions that stress the effect, or potential effect, of the error focus attention only on deviant behaviors that are important in the context of some system. Deviant behaviors that would lead to no undesirable effects in the system are acceptable and can be ignored.

If a human error is considered to be a deviation from a norm, how the norm is established is important to the understanding of human errors. Rasmussen (42) points out that such norms are often set by someone conducting a rational, careful evaluation of the behavior after-the-fact. In essence, what is considered to be a human error is somewhat arbitrary because the norm may not have been established until the human error was identified. Rasmussen (44) goes further and states that the identification of an event as a human error depends entirely upon the stop-rule applied during the explanatory search. If system performance is judged to be lower than the accepted standard, someone will typically try to backtrack the causal chain to find the causes. How far back to go is an open question. One could stop at the operator's actions and call the event a human error, or one could investigate what caused the human to act as he or she did. The cause may then be traced to other factors such as faulty equipment, poor management practices, inaccurate or incomplete procedures, etc. Rasmussen (43) makes a provocative point that an action might become an error only because the action is performed in an unkind environment that does not permit detection and reversal of the behavior before an unacceptable consequence occurs.

Senders (57) and Rasmussen (44) make an interesting point with respect to eliminating human error. They point out that humans are servomechanisms and must experiment with their environment to learn and acquire skill. They maintain that errors are a natural consequence of this experimentation and trial-and-error learning. Errors, they contend, are necessary for the development of skilled performance. Their emphasis would be on how to provide "safe" opportunities for making errors (e.g., in training) or how to structure the environment to improve error detection and correction.

Relationship of Human Error to Accidents

Before reviewing the relationship of human error to accidents, the concept of "accident" will be discussed.

Dictionaries use such terms as "without apparent cause," "unexpected," "unintentional act," "mishap," and "chance" to define an accident. In some cultures, accidents are attributed to "acts of God" with no further attempts to determine the causation. The idea that an accident is totally without cause, or is due solely to chance or an act of God, however, is a serious impediment to further scientific inquiry. Suchman (65-66) discussed the problem of definition at length and concluded that "it is doubtful that any single definition will cover all types of events of interest to the student of accidents." He went on to produce a list of indicators of the accidental nature of an event. The more indicators that are present, the more likely the event is to be called an accident. The indicators are: (1) low degree of expectedness; (2) low degree of avoidability; and (3) low degree of intention.

Most definitions of the term "accident" also include reference to the consequence of the event. Meister (33), for example, defines an accident as "an unanticipated event which damages the system and/or the individual or affects the accomplishment of the system mission or the individual's task." This covers a broad spectrum of possible outcomes. In many practical settings, the term "accident" is synonymous with injury. For the most part, this is true in the mining industry. Injuries are reported to government agencies and thus serve as a ready measure of accidents. In the literature relating human error to accidents, however, some studies are based on non-injury producing events.

In the wider perspective, accidents should not be considered synonymous with injury. Human error can lead to an accident without injury, as well as it can lead to an accident with injury. The difference is often a matter of chance and the presence or absence of an injury-producing hazard.

Investigators have attempted to determine the proportion of accidents that are caused by human error. Several factors influence the results that are obtained. The first factor is which humans will be included in human error. Traditionally, human error has been used to describe operator error, or errors of the injured employee. This is a very narrow view of human error. Other humans whose errors can contribute to an accident are managers, system designers, maintainers, and co-workers. When this broader perspective is considered, it is no wonder that Petersen (40) concluded that "human error is the basic cause behind ALL accidents" (emphasis added). Rarely is the broader perspective of human error adopted when assessing its role in accident causation.

The second factor that influences the proportion of accidents attributed to human error is what other factors, besides human error, are considered in making the determination. In the simplest model, accidents are categorized as caused by either unsafe acts of persons (read operator error) or by unsafe conditions (21). The consequence of using this dichotomy is to blame the individual who was injured or who was in charge of the machine that was involved in the accident. This occurs because of the tendency to first direct our attention to the fault of the person, and then to the unsafe act of that person; rarely do we consider the unsafe condition. Shealy (58) suggests four reasons why this tends to happen. (1) It is just human nature to blame what appears to be the active operator when something goes wrong. (2) Our legal system is geared toward the determination of responsibility, fault, and blame. (3) It is easier for management to blame the worker than to accept the fact that the workplace, procedure, or environment might need improving. (4) The very forms that we use when we investigate accidents are modeled after the "unsafe act-unsafe condition" dichotomy. The major emphasis tends to be on describing the person who was injured and the injury-producing events, rather than finding the aspects of the job that contributed to causing the accident, or of the environment that disposed the individual to have the accident.

Given the differences in philosophy regarding the role of human error in accidents and the differences in the scope of accident investigations, it is virtually meaningless to synthesize the studies that have attempted to determine the proportion of accidents/incidents due to human error. In fact, it is probably meaningless to even ask what proportion of accidents/incidents were due to human error. A more meaningful question to ask would be how much does human error contribute to accidents/incidents relative to other contributing factors? Despite the difficulties inherent in specifying the percentage of accidents/incidents attributable to human error, numerous investigators have done so. Table 1 presents a summary of many such attempts. The percentages range from 4.2% to 90%. The median percentage from table 1 of accidents/incidents attributable to "human error" is 35% (broadly defined).

Descriptive Taxonomies of Human Error

Taxonomies of human error can be of value as a basis for organizing data, for setting priorities, and for designing and implementing countermeasures. Over the years, there have been numerous attempts to develop a practical taxonomy of human errors. The various taxonomies which have been proposed are difficult to group; some are global, some specific, some unidimensional, some multidimensional, some deal with the internal processing of information, and some deal with the overt manifestation of the error. In general, the various schemes were developed logically or were derived from a theoretical framework. Rarely, if ever, have the schemes been empirically validated. The notion of validation, however, is a bit fuzzy. To validate a taxonomic scheme would, in part, require an independent means to verify that the error events were indeed correctly classified, and that the classifications covered the universe of events under consideration. If such an independent verification were possible, there would be no use for additional taxonomic schemes. In most cases, even interrater reliability for classifying events has not been assessed.

In an effort to bring a semblance of order to the array of classification schemes, the various taxonomies will be grouped under four broad categories: system-oriented schemes, innate dimension-based schemes, overt behavior-based schemes, and cognitive model-based schemes. System-oriented schemes classify errors based on the system development cycle or by the individual committing the error. Innate dimension-based schemes classify errors based on inherent dimensions of errors, such as the consequence of the error or its reversibility. Overt behavior-based schemes categorize errors based on the observable action involved, some general, some specific. Cognitive model-based schemes are the most numerous and varied. Some base the classification of errors on the information-processing function that failed, others classify errors based on the level of processing involved. Although it is not possible to say which of the above approaches is best, it appears that the cognitive model-based and overt behavior-based schemes are the most popular and probably will endure the longest.

TABLE 1. - Summary of studies investigating the incidence of human errors in accidents

Source	Type of incidences	% human error
Finnegan, Rettig, & Rau (13).	Fossil fuel power plant generation failures.	20-25%
Grondstrom, Jarl, & Thorson (17).	Swedish occupational injury and fatalities.	33% worker negligence. 36% management negligence.
Hayashi (20).	Japanese chemical plant.	24% of actual accidents. 50% of potential accidents.
U.S. General Accounting Office (69).	Military weapon system and support failures.	50%
Sabri (53).	Nuclear power plant event reports.	4.3%
Maritime Transportation Research Board (30).	Insurance company casualty claims.	85%
Beatson (3).	British nuclear power plant incidences and accidents.	50%
Ramsey, Burford, & Beshir (41).	Worker behaviors, industrial plants.	10% unsafe.
Ricketson, Brown, & Graham (48).	Army aircraft accidents 1969-1971.	84%
Rigby (49).	Discrete industrial work-related acts.	.006% to .00004% errors, undetected & cause significant effect.
Rook (51).	Production defects in nuclear weapons production.	82%
Simpson & Sims (60).	British coal mine transport near-misses.	34%
Sims, Graves, & Simpson (61).	British coal mine transport near-misses.	50%
Griffon-Fouco & Ghertman (16).	French nuclear power plant reactor trips.	33%
Kinney, Spahn, & Amato (26).	Air traffic control system errors.	90%

System-Oriented Schemes

One approach to the classification of human error is to categorize the error by the system development phase in which it occurred or could be traced. Altman (2) lists the following six phases of system development and the subcategories under each which he suggests would be the basis for a human error classification scheme:

Planning: Definition of objectives; identification of capabilities; definition of constraints; evaluation of tradeoffs; establishment of requirements; scheduling.

Designing and Developing: Analysis and simulation; general, functional, or conceptual design; detailing, mockup, and prototype fabrication; developmental testing.

Producing: Fabricating; handling and transporting; inspecting and checking.

Distributing: Selling; packaging; transporting; installing; installation inspection and checking.

Operating: Information processing; decision making.

Maintaining: Direct support; preventive; corrective; recycle and overhaul.

Joos, Sabri, and Husseiny (24) classified 401 human errors occurring in nuclear power plants over a 25-month period into four categories based on the perpetrator of the error: Operator, maintenance, installation, and administrative. The report presents the number of each type of error for each phase of system operation (e.g., during actual operation, surveillance testing during actual operation, start-up and shut-down, etc.). Table 2 summarizes the number of errors of each specific type.

Innate Dimensions of Errors

Altman (2) suggested that three dimensions are innate to all error. These dimensions are determined after-the-fact, in that they relate to characteristics that only come into being when an error has been committed. The three dimensions are:

Detectability: Includes both the probability that an error will be detected and the time-space remoteness of detection from the error occurrence.

Error detection by perpetrator.
Detection by quality control or executive loop.
No detection within work context.

Revocability: Concerned with the extent to which the possible consequences of the error can be alleviated if it is detected at specific points in time.

Immediate correction.
Correction only after intervening steps.
No correction within a given mission.
Irrevocable consequences.

TABLE 2. - Number of human errors reported by nuclear power plants over a 25-month period

Operator errors:			
Improper or inadvertent equipment manipulation	57		
Failure to return equipment to service	16		
Misunderstanding or misinterpretation of requirements	6		
Failure to correct out of specification conditions	21		
Calibration errors	1		
Incorrect chemical analysis or test results	4		
Analysis or test not performed on schedule	10		
Ignorance of plant or requirement	1		
Others	18		
Total operator errors		134	
Maintenance errors:			
Improper or inadvertent equipment manipulation	11		
Failure to return equipment to service	21		
Failure to test equipment following maintenance	1		
Improper servicing or reassembly	19		
Improper adjusting	15		
Inadvertent servicing wrong component	3		
Misunderstanding or misinterpretation of requirements	3		
Others	1		
Total maintenance errors		74	
Installation errors:		39	
Administrative errors:			
Test, calibration, or analysis performance failure	24		
Operation procedure error or deficiencies	45		
Maintenance procedure error or deficiencies	9		
Calibration procedure error or deficiencies	10		
Test procedure error or deficiencies	15		
Calculational errors	12		
Judgement errors	4		
Inadequate administrative control over plan	23		
Worker exposure due to inadequate control	5		
Errors by other workers	5		
Others	2		
Total administrative errors		154	
Total human errors			401

Source: Joos, Sabri, & Husseiny (24).

Consequences: Concerned with the effect of the error on the performance or cost of the system of which the worker's performance is a part.

No significant consequence.
Time loss.
Degraded output quality.
Equipment damage or material loss.
Personnel injury.

Singleton (62) suggested two bipolar dimensions that are also innate to errors. The two dimensions are:

Systematic vs. Random Errors: A systematic error is essentially a predictable bias, and it is only necessary to determine the bias in order to make a compensating correction, such as a gun that aims too high. Random errors are just that, random, and increase the variance in performance. (Singleton points out that human errors are often neither entirely systematic nor random.)

Formal vs. Substantive Errors: A formal error is one in which the rules have been broken. A substantive error occurs when the problem was inadequately defined. (This dichotomy comes close to the slips vs. mistakes dichotomy to be discussed under cognitive model-based schemes.)

Classification schemes based on system development phases or innate dimensions of errors offer little explanation from a psychological perspective. Such schemes do not greatly enhance the direct association of error specifics with the general body of psychological knowledge concerning the causes and prevention of different kinds of errors. To make this association, it is necessary to infer something about the generic characteristics of the behavior represented by the particular error. Schemes based on overt behaviors and/or cognitive models move closer to providing that association.

Overt Behavior-Based Schemes

Probably the most widely cited error classification scheme is that proposed by Swain and Guttmann (67). Their scheme uses rather broad behavioral categories to classify errors. The focus is on the manifested behavior (or lack of it), rather than on the internal processing functions that caused the error. The following are the categories suggested by Swain and Guttmann:

Errors of Omission: A person fails to perform the task or part of the task (i.e., step).

Errors of Commission: A person performs the task or step incorrectly.

Extraneous Act: A person introduces some task or step that should not have been performed.

Sequential Errors: A person performs some task or step out of sequence.

Time Errors: A person fails to perform the task or step within the allotted time, either too early, too late, too fast, or too slow.

A classification scheme similar to that of Swain and Guttmann has been proposed by Senders (57). Senders proposes the following categories:

Errors of Omission: Not doing what should have been done.

Errors of Repetition: Doing something that has already been done.

Errors of Insertion: Doing something when nothing should have been done.

Errors of Substitution: Doing the wrong thing, including doing the wrong action; or the right action to the wrong thing; or the right action to the right thing, but at the wrong place or time.

Senders' errors of insertion are similar to Swain and Guttmann's extraneous acts. Senders' errors of substitution appear to include Swain and Guttmann's errors of commission; and, to some extent, time errors. Senders' errors of repetition do not seem to have an obvious parallel in the Swain and Guttmann scheme. Swain and Guttmann's sequential errors do not have an obvious parallel in Senders' scheme.

Another approach to classifying errors based on overt behaviors has been to collect incidents of errors within a specific situational context. These are then sorted and clustered. In some cases, the clustering is done empirically with factor analysis or statistical clustering programs. There have been several such research efforts over the years; their value, however, diminishes as one tries to apply the classification scheme beyond the context in which it was developed. Three examples will be summarized to provide the flavor of this approach.

Ramsey, Burford, and Beshir (41) compiled a list of unsafe behaviors related to manual material handling applicable to industrial settings. Although not equivalent to errors, unsafe behaviors are often indicative of them. Table 3 presents the classification taxonomy suggested by Ramsey et al. Included in table 3 are the percentages of the various unsafe behavior categories observed over a 14-month period. A total of 17,841 observations were made. A comparison of this taxonomy of unsafe behaviors to some of the cognitive model-based error classifications to be discussed later will illustrate the relative difficulty of applying cognitive model-based classifications to actual incidents of unsafe behavior.

Roberts, Golder, and Chick (50) cluster analyzed 60 P-3 aircraft errors. They identified three broad clusters of errors: judgment, oversight, and skill errors. Table 4 presents the clusters, subclusters, and a few specific examples of the behaviors in each cluster. In a similar study, Gerbert and Kemmler (15) factor analyzed critical flying incidents from the German Air Force. They identified the following four types of errors:

Vigilance Errors: Missing or fragmentary uptake of objectively presented information due to inattention, channelized, or shifted attention. For example:

Failed to check and maintain aircraft attitude.
Delayed in taking necessary actions.
Poorly scanned instruments.

TABLE 3. - Taxonomy of unsafe worker behaviors

(Percents show percentage of 17,841 observations.)

Related to worker (72.8%)

Improper use of body (6.4%)

Used hand, not tool (to feed, clean, adjust, grip, hammer).
Insecure grip (oily, pinch, grasp, too many objects).
Inappropriate lifting (with back, not legs, extended, torsional).
Should use mechanical lift or get help (crane, hoist, two-person load).
Not elsewhere classified.

Unsafe position or posture (20.2%)

Cramped, awkward or unsafe position (bend, stoop, work in small quarters).
Working too close together (gang too close to each other, tripods in assembly, materials handling).
Exposed under suspended load (under hoist or fork).
Unnecessary exposure (to heat, cold, fumes, paint, electricity, sand, dust).
Riding in unsafe position (on forks of lift, on hook or crane).
Unnecessary exposure to moving material or equipment (work in aisle or travelway).
Not elsewhere classified.

Unsafe body movements (23.2%)

Operating too fast (movement of body members, material handling).
Moving whole body too fast (walking, running).
Feeding too fast (supplying, pushing, drilling, sawing, grinding too fast, motor bogs down).
Throwing not handling (warehouse, handling parts/pumps).
Descending, ascending unsafely (jumping off, down, two steps at a time, truck/storage platforms).
Inattention to footing, seat, or surroundings (tripping over curb, platform edges).
Distracted from task (person walking by, watching horseplay, radio too loud).
Failure to follow regulations/policy (horseplay, smoking in non-smoking area).
Not elsewhere classified.

Failure to use protective clothing (19.6%)

Goggles, glasses (protective eyewear, side shields).
Foot/toe protection (shoe and toe devices).
Gloves (special to fit job done, hand protection).
Face/respiratory protection (dust mask, shield, ear plugs, welding masks, respiratory protection).
Trunk/leg protection (chain saw, firefighting foundry).
Hardhat/bump cap.
Not elsewhere classified.

Source: Ramsey, Burford, & Beshir (41).

TABLE 3. - Taxonomy of unsafe worker behaviors--Continued

(Percents show percentage of 17,841 observations.)

Related to worker--Continued

Failure to dress properly (3.4%)

- Loose or inappropriate clothing (sleeves improper length, long trousers, belts).
- Unrestrained long hair (should use band, net, hat).
- Adornments (rings, watches, necklace, neckties, pocket chains).
- Not elsewhere classified.

Related to tools, equipment, or materials (22.1%)

Tools, equipment, or materials errors (5.0%)

- Wrong tool, equipment, or material for job done (wrench as hammer or cheater, screw driver to clean).
- Unsafe use of tools, equipment or materials (correct equipment used unsafely, spray paint outside).
- Cleaning, oiling, adjusting, moving equipment (changing bits while drill is moving, under poser).
- Not elsewhere classified.

Unsafe placing of tools, equipment, or materials (14.7%)

- Unsafe placing of material moving/handling equipment (parking, stopping, or leaving carts, elevators).
- Unsafe placement of tools, materials, scrap (tripping, bumping, slipping hazards, poor housekeeping).
- Inattention to tool, material placement (placement on table, unstable, precarious).
- Not elsewhere classified.

Failure to shut down potential energy (1.6%)

- Power circuit or flame not secured (maintenance on electric motors, high voltage lines, open flame).
- Machine device not shut off, unattended (motors and engines, auto feed, welding gases, saws).
- Failure to lock, block, or secure against unexpected motion (gas bottles, shafts unblocked, tubing).
- Not elsewhere classified.

Making safety device or equipment inoperative (0.8%)

- Making device inoperative or failure to use (welding shields, barriers, rails, switches, guards).
- Not elsewhere classified.

Source: Ramsey, Burford, & Beshir (41).

TABLE 3. - Taxonomy of unsafe worker behaviors--Continued

(Percents show percentage of 17,841 observations.)

Related to materials handling equipment (5.1%)

Relating to crane, hoist, or fork truck (3.2%)

Failure to warn (starting, stopping, backing, turning, signals, releasing loads, move load above people).
Driving or moving too fast.
Misjudged clearance, lane, or position (cross over line, between boxes, aisles, pass on wrong side).
Overloaded, load insecure (beyond capacity, load too high).
Dropping, not placing carefully.
Suspended load unattended.
Not elsewhere classified.

Relating only to crane and hoist (0.3%)

Hook in passageway or in motion.
Not elsewhere classified.

Relating only to fork truck (1.6%)

Improperly parked or positioned (no parking zone including aisle, unauthorized parking space).
Passenger without seats (operator allows standing or sitting on vehicle).
Fork truck unattended, engine running.
Not elsewhere classified.

Source: Ramsey, Burford, & Beshir (41)

TABLE 4. - Results of cluster analysis of 60 P-3 aircraft errors

Judgement:

Decision:

Fly into a known thunderstorm area.
Continue flight with hail-damaged aircraft.
Allow crew entry into load center during flight.
Injury results to crewman from pilot-induced aircraft maneuvers.
Salvage a landing from a poor approach that should have been a wave-off.
Accomplish an unauthorized overweight landing.

Judgment:

Failure to use all available navaids to determine position.
Let aircraft descend below safe altitude at night.
Declare a low fuel state due to headwinds.
Go IFR on a VFR clearance.
Misread altimeter.

Oversight:

Preflight procedure:

Take off with flaps not set at "take-off and approach."
Checklist not completed.
Unable to raise gear due to gear pins being left in.
Ingest engine intake cover during night start.
Fueling/access panel not properly secured for flight.

Normal and emergency procedures:

Allow improper fuel transfer procedures.
Improper use of de-icing equipment.
Not recognizing a pitchlock condition.
Call for wrong engine to be feathered.
Attempt to start a decoupled engine.

Skill:

Awareness:

Raise the landing gear prematurely.
Taxi off the taxiway at night.
Turn off runway too fast, blow tire.
Allow prop wash to cause damage to other aircraft.
Fail to maintain safe flying speed, enter uncontrolled flight.

Technique:

Applying too much brake on landing rollout.
Flare too high.
Over rotate on takeoff.
Make a hard landing, "G" meter exceeds 5.2 "Gs."
Retract gear before flaps during a wave-off.
Raising gear before brakes cool, blowing thermal plugs.

Source: Roberts, Golder, & Chick (50)

Information Processing Errors: Faulty or erroneous judgement, miscalculations, wrong decisions, or faulty action plan. For example:

Penetration into IMC under VFR.
Misjudgment of weather conditions.
Navigational error.

Perception Errors: False utilization of probabilistic information. For example:

Misjudgment of altitude and clearance.
Spatial disorientation.
Failure to see obstacles.

Sensorimotor/Handling Errors: Deficiencies in timing and adjustment of simple-discrete and/or complex-continuous motor activities, as well as perceptual-motor confusion. For example:

Omission of necessary non-procedural actions.
Exceeding design stress limits of aircraft.
Poor coordination of controls.

There are some similarities between the categories outlined by Gilbert and Kemmler and those found by Roberts et al. The generalizability and utility of the above specific overt behavior-based classification schemes are questionable. It would be difficult or impossible to apply these schemes to the mining industry and expect to cover the spectrum of errors occurring there. At best, these schemes are suggestive, but are of limited usefulness outside the context in which they were developed.

Cognitive Model-Based Schemes

Cognitive model-based classification schemes encompass the widest range of approaches to human error. Four broad types of schemes can be discriminated. The first is based on a component model of information processing. The second type of scheme is based on a process model of information processing. The third deals with levels of behavior or skill. Finally, the fourth deals with a cognitive model based on the use of strategies or heuristics of behavior. Each of these types will be discussed in turn.

An example of a component-based cognitive model scheme is that proposed by Reason (46). In actuality, the scheme embraces the concepts of behavioral strategies and heuristics, as well as a component model of information processing. Reason postulates a set of basic error tendencies and a set of cognitive domains (components). Human errors are generated from the points of interaction between these two sets.

The five basic error tendencies are: ecological constraints, change-enhancing biases, resource limitations, schema properties, and the use of particular strategies or heuristics. Ecological constraints are the genetic and biological limitations on our senses and information-processing capabilities. Change-enhancing biases refers to the principle that our nervous system is essentially a change-detector and attenuates the values assigned to steady states. Resource limitations recognize that people have a finite amount of information resources that can be brought to bear in a situation, and that only a restricted number of cognitive structures will be maximally active at any one time. Schema properties take into account the fact that much of what we do is routine, and we have built up largely automatic ways of processing information. These automatic programs are called schema. Often information processing is really just the selection, stringing, and execution of a series of schema. One result of this is that perceptions, memories, thoughts, and actions have a tendency to err in the direction of the familiar and the expected. Strategies and heuristics are the rules that govern and direct the limited processing resources to the various schema available. Heuristics are well-tried rules of thumb, i.e., automatic strategies.

Orthogonal to the basic error tendencies discussed above, Reason (46) postulated the following cognitive "domains" (really components of information processing):

Sensory Registration	Recognition Processes
Input Selection	Judgmental Processes
Volatile Memory	Inferential Processes
Long-Term Memory	Action Control

The intersection of these two sets (basic error tendencies and cognitive domains) yields the following primary error groupings:

False Sensations - Intersection of sensory registration with ecological constraints and change enhancement: Human errors can be due to a lack of correspondence between our subjective experience of the world and the objective reality. When this lack of correspondence is caused by the distortion or misrepresentation of the physical world by our sensory apparatus, it is called a false sensation.

Attentional Failures - Intersection of input selection with resource limitations, schema properties, and/or strategies and heuristics: Attentional failure errors are due to inadequate or improper control of the limited cognitive resources at the stimulus input phase of information processing. Such errors tend to occur when coping with distraction, processing simultaneous inputs, or dividing attention between the performance of concurrent tasks.

Memory Lapses - Intersection of volatile memory with resource limitations, schema properties, and/or strategies and heuristics: Memory lapses include forgetting to do things, forgetting list items, forgetting intentions, and losing track of previous actions.

Inaccurate and Blocked Recall - Intersection of long-term recall with resource limitations, schema properties, and/or strategies and heuristics: All the errors in this group involve faulty recollections (misremembered stories, names, faces, events, etc.).

Misperceptions (also called Recognition Failures) - Intersection of recognition processes with all five basic error tendencies: These are errors that result from erroneous cognitive interpretation being placed on veridical sensory data. They occur when the sensory evidence is either incomplete or impoverished, and when there is a strong schema-based expectation to perceive either the presence or the absence of a particular stimulus configuration.

Errors of Judgment - Intersection of judgmental processes with all basic error tendencies except ecological constraints: Errors of judgment include psychophysical misjudgments, temporal misjudgments, misconceptions of chance, misconceptions of covariation, misjudgments of risk, and misdiagnoses.

Reasoning Errors - Intersection of inferential processes with resource limitations, schema properties, and/or strategies and heuristics: Reasoning errors include errors in deductive reasoning, errors in concept formation, and errors in hypothesis testing.

Unintended Words/Actions - Intersection of action control with resource limitations, schema properties, and/or strategies and heuristics: This error group comprises all the absent-minded deviations of words, signs, and actions from their intended path. They arise from failures of execution rather than from inadequate plans. These types of errors are also called "slips" (34-35).

Reason's (46) categorization scheme is somewhat esoteric and would be difficult to apply to complex behaviors such as one finds in industrial situations. A classification scheme that is similar, but less esoteric is that proposed by McFarland (31). Five types of errors are identified:

Failure to detect signal.
Incorrect identification of signal.
Incorrect value weighting or assignment of priority.
Error in action selection.
Error of commission.

A good example of a cognitive model-based classification scheme that is organized around the processes involved in information processing is the scheme developed by Rouse and Rouse (52). The model is based on a simplified view of the tasks performed by human operators in systems such as aircraft, ships, and power plants; that is, system control tasks. With a little effort, however, the model can be applied to other types of human behavior. For example, Johnson and Rouse (23) used an earlier form of the model to analyze human errors in maintenance troubleshooting tasks. Table 5 presents the general category and specific subcategories of error proposed by Rouse and Rouse (52).

Probably one of the most microscopic analyses of human errors was presented by Dubrovsky (9) in his analysis of errors involved in a simple action such as activating a control. Dubrovsky identifies 11 stages of action and typical errors associated with each stage. Table 6 presents the scheme.

Rasmussen (43) presents a flow diagram to aid in the determination of an internal human malfunction. The diagram is presented in figure 1. By stepping through the flow, seven types of errors are identified: detection missing, identification not correct, goal not acceptable, target state inappropriate, task inappropriate, procedure is incorrect, and execution is erroneous.

Another approach to classifying errors is to categorize errors by the level of behavior and learning involved. One such approach is that proposed by Altman (2). Altman proposes five levels of behavior which he ties to Gagne's (14) types of learning. The following is Altman's classification scheme organized by behavioral level:

Sensing, detecting, identifying, coding, and classifying (Gagne's Type 1 signal learning or classical conditioning, Type 2 instrumental conditioning, Type 5 multiple discrimination, and Type 6 concept learning):

TABLE 5. - Human error classification scheme proposed by Rouse and Rouse (52)

General category	Specific category
1. Observation of system state:	a. Improper rechecking of correct readings of appropriate state variables. b. Erroneous interpretation of correct readings of appropriate state variables. c. Incorrect readings of appropriate state variables. d. Failure to observe sufficient number of appropriate state variables. e. Observation of inappropriate state variables. f. Failure to observe any state variables.
2. Choice of hypothesis:	a. Could not cause particular values of state variables observed. b. Could cause values observed but much more likely causes should be considered first. c. Could cause values observed but very costly (in time of money) place to start. d. Does not functionally relate to state variables observed.
3. Testing of hypothesis:	a. Stopped before reaching a conclusion. b. Reached wrong conclusion. c. Considered and discarded correct conclusion. d. Hypothesis not tested.
4. Choice of goal:	a. Insufficient specification of goal. b. Choice of counter-productive goal. c. Choice of non-productive goal. d. Goal not chosen.
5. Choice of procedure:	a. Choice would not fully achieve goal. b. Choice would achieve incorrect goal. c. Choice unnecessary for achieving goal. d. Procedure not chosen.
6. Execution of procedure:	a. Required stop omitted. b. Unnecessary repetition of required step. c. Unnecessary step added. d. Required steps executed in wrong order. e. Step executed too early or too late. f. Discrete control in wrong position. g. Continuous control in unacceptable range. h. Stopped before procedure complete. i. Unrelated inappropriate step executed.

TABLE 6. - Error classification scheme for simple actions

Stage of action	Typical error
Deciding	Wrong goal set.
Intending	Wrong operation intended.
Triggering	Wrong time of beginning (too early or too late).
Approaching for contacting	Wrong object activated (one control instead of the other).
Contacting for activating	Wrong contact with object (incorrect grasping).
Activating	Wrong commission (reverse direction).
Internal checking	Failure to correctly determine final position of a control.
Halting	Wrong moment of termination (too early or too late).
External checking	Failure to check the results correctly by comparison of the goal and the outcome.
Discontacting	Incorrect release of the object (unintended change of the position of the control while releasing it).
Disapproaching	Incorrect departure (unintended activating of a control during departure from the just used control).

Source: Dubrovsky (9).

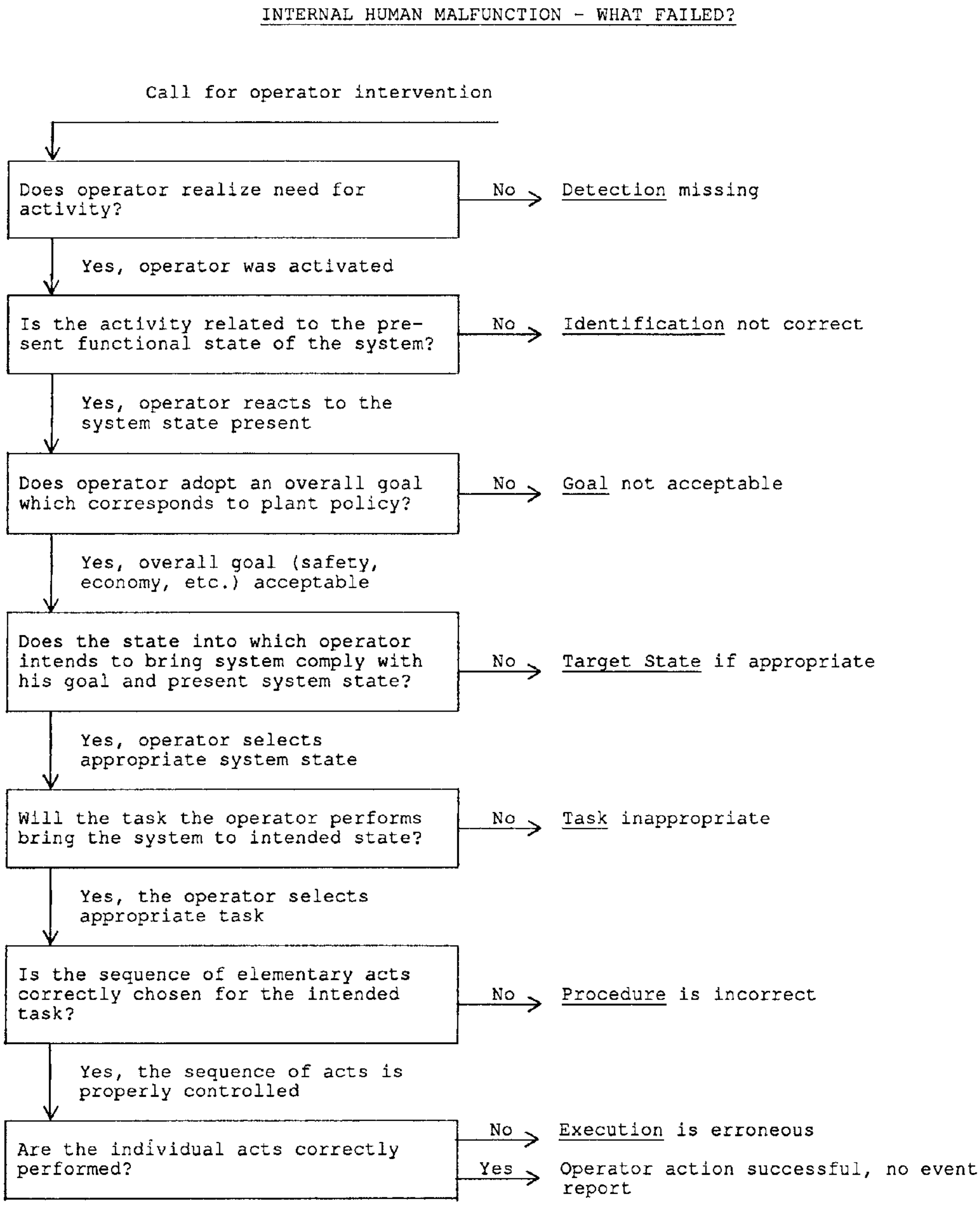

FIGURE 1. - Guide to identify the internal human malfunction from an event analysis of a human error (43).

Failure to monitor the field;
Failure to record or report a signal change;
Recording or reporting a signal change when none has occurred;
Recording or reporting a signal change in the wrong direction;
Failure to record or report the appearance of a target;
Recording or reporting a target when none is in the field;
Assignment of a target to the wrong class.

Chaining or rote sequencing (Gagne's Type 3 chaining and Type 4 verbal association learning):

Making a below-standard response;
Omitting a procedural step;
Inserting an unnecessary procedural step;
Mis-ordering procedural steps.

Estimating with discrete responding and estimating with continuous responding (Fitts' (12) discrete case and Briggs' (5) continuous case of perceptual motor skill learning):

Failure to respond to a super-threshold target change;
Responding to a sub-threshold target change;
Premature response to a target change;
Late response to a target change;
Inadequate magnitude of control action;
Excessive magnitude of control action;
Inadequate continuance of control action;
Excessive continuance of control action;
Wrong direction of control action.

Logical manipulation, rule using, and decision making (Gagne's Type 7 principle learning and Estes' (10) probability learning):

Incorrect value weighting of responses to a contingency;
Failure to apply an available rule;
Application of a correct, but inappropriate, rule;
Application of a fallacious rule;
Failure to obtain or apply all relevant decision information;
Failure to identify all reasonable alternatives;
Making an unnecessary or premature decision;
Delaying a decision beyond the time it is required.

Problem solving (Gagne's Type 8 problem solving learning):

Formulating erroneous rules or guiding principles;
Failure to use available information to derive needed solution;
Acceptance of inadequate solution as final.

As can be seen, the specific error categories are rather microscopic and probably do not represent a complete listing of all possible errors. In addition, it is very difficult to apply such microscopic analysis to actual errors committed in the real world. Usually, an investigator has only a description of the end result of the error upon which to base classification. To apply the above scheme would require more information than is usually available, and would often require the investigator to "get inside the head" of the person making the error. For example, a person moves a control in the wrong direction. Did the person record a signal change in the wrong direction, perform a wrong direction of control action, fail to apply an available rule, apply a fallacious rule, or fail to use available information to derive the needed solution? Each of these are separate error types representing different behavioral levels, yet all yield the same objective error, i.e., moving a control in the wrong direction. A somewhat different approach to error classification based on behavioral level is taken by Rasmussen (43). He distinguishes three levels of behavior or performance: skill-, rule-, and knowledge-based performance. To quote Rasmussen:

> . . . In the skill-based domain, including automated, more or less subconscious routines, performance is controlled by stored patterns of behavior in a time-space domain. Errors are related to variability of force, space, or time coordination. The rule-based domain includes performance in familiar situations controlled by stored rules for coordination of subroutines, and errors are typically related to mechanisms like wrong classification or recognition of situations, erroneous associations to tasks, or to memory slips in recall of procedures. Since rule-based behavior is used to control skill-based subroutines, the error mechanisms related to skill-based routines are always active. Rule-based behavior is not directly goal-controlled, but goal-oriented, and the immediate criteria for errors deal with whether the relevant rules are recalled and followed correctly or not.
>
> . . . [The knowledge-based domain] . . . is called upon in case of unique, unfamiliar situations for which actions must be planned from analysis and decision based on knowledge of the functional, physical properties of the system and the priority of the various goals . . .. In general, errors in this domain can only be defined in relation to the goal of the task and generic error mechanisms can only be defined from very detailed studies based on verbal protocols which can supply data on the actual data process.

Rasmussen further states that data collection and prediction of errors in the knowledge-based domain are only possible for very tightly controlled experimental situations, not for real-life task settings. The level of behavior being evoked in a specific situation depends strongly upon the degree of training of the person making the error.

Based on an analysis of 200 nuclear power plant events, Rasmussen (43) identified 13 mechanisms of human error. Rasmussen points out that this list is not complete, and would have to be modified for other situations. The 13 mechanisms, organized by phase of information processing in which the error occurs, are as follows:

Errors of Discrimination:

Stereotype fixation
Familiar association short-cut
Stereotype takeover
Familiar pattern not recognized

Errors of Input Information Processing:

Information not seen or sought
Information assumed and not observed
Information misinterpreted

Errors of Recall:

Forgets isolated act
Mistakes alternatives
Other slip of memory

Errors of Inference:

Side effects or conditions not adequately considered

Errors of Physical Coordination:

Manual variability
Topographic (spatial) misorientation

One of the unique and positive aspects of Rasmussen's work is a flowchart guide for analyzing events to isolate the specific error type. No other classification systems reviewed provides such an aid. Figure 2 presents the flow diagram.

Other cognitive model-based error classifications have attempted to classify human errors within a more artificial intelligence framework, evoking concepts such as schema and subroutines (35, 45). Two distinct classes of errors are defined: slips, which are failures of execution; and mistakes, which are failures of planning. Simply, a person establishes an intention to act. If the intention is not appropriate, this is a mistake. If the action is not what was intended (regardless of whether the intention was correct), it is a slip. Classifications of slips appear to have progressed further than the development of mistake classifications. Table 7 presents a classification of slips based on their presumed source (35). Reason (47) presents a preliminary classification of mistakes. He distinguishes four types:

Mistakes of Bounded Rationality: Only a small aspect of the total problem space is considered or processed; characterized by oversimplification.

Mistakes of Imperfect Rationality: Arise from the contextually inappropriate application of judgmental and inferential heuristics; characterized by being too rule-bound, too rigid, and too conservative.

Mistakes of Reluctant Rationality: Excessive reliance on what appears to be familiar cues, and to the over-ready application of well-tried problem solutions.

Irrational Mistakes: Purposeful actions directed toward some undesirable goal or which thwart the achievement of desirable ends.

As with other cognitive model-based classification schemes, it is often difficult to classify complex real-world events. Most of the cognitive model schemes were developed within the context of tasks where the goal is to control the system (e.g., automobile driving, nuclear power plant operation, or aircraft operation). The schemes

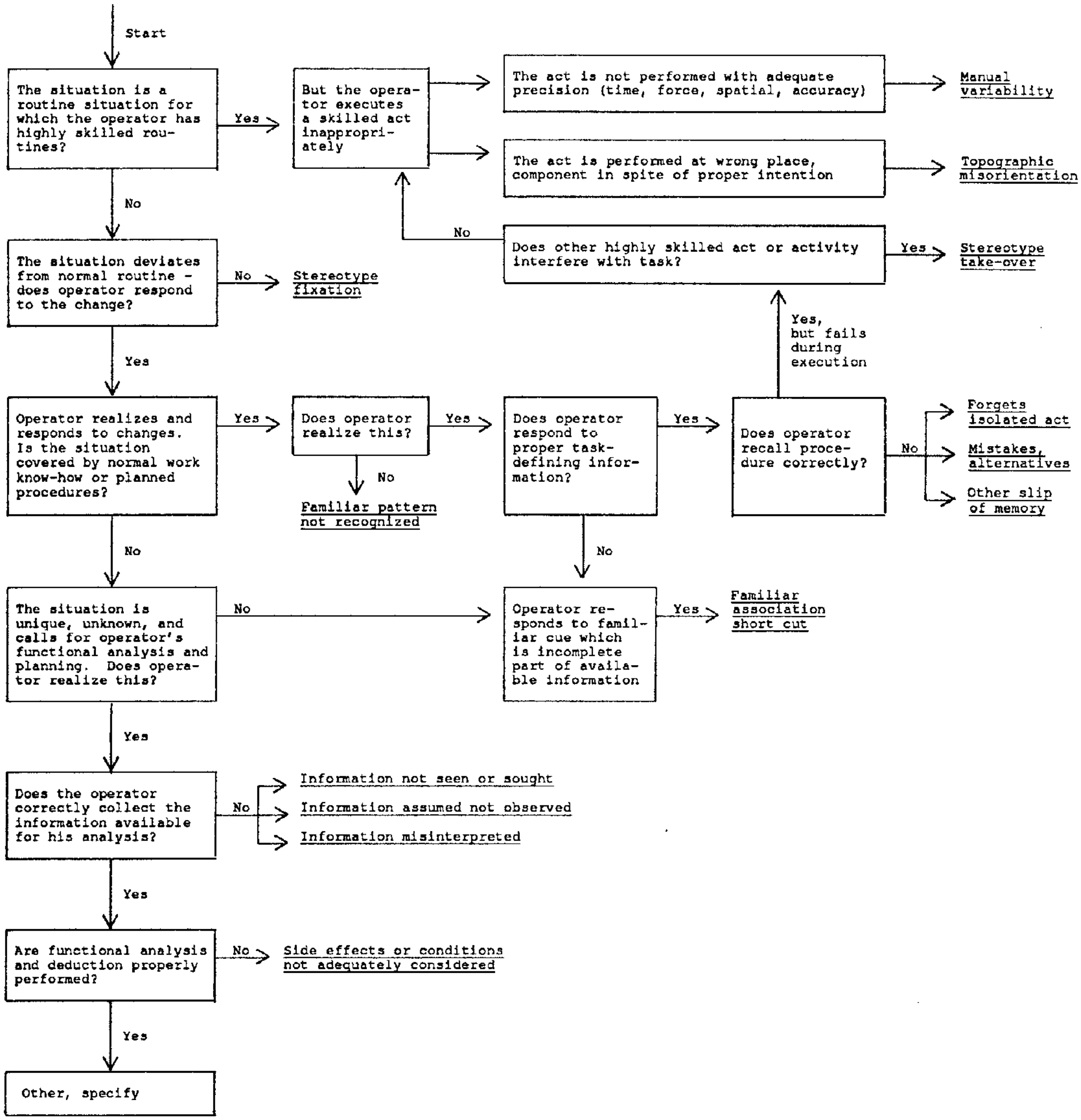

FIGURE 2. - Flow decision guide for analyzing an event into one of the 12 error types identified by Rasmussen (43).

TABLE 7. - A classification of slips based on their presumed sources

Slips that result from errors in the formation of the intention:
<u>Errors that are not classified as slips</u>: errors in the determination of goals, in decision making and problem solving, and other related aspects of the determination of an intention.
<u>Mode errors</u>: erroneous classification of the situation.
<u>Description errors</u>: ambiguous or incomplete specification of the intention.
Slips that result from faulty activation of schemas:
<u>Unintentional activation</u>: when schemas not part of a current action sequence become activated for extraneous reasons, then become triggered and lead to slips.
Capture errors: when a sequence being performed is similar to another more frequent or better learned sequence, the latter may capture control.
Data-driven activation: external events cause activation of schemas.
Associative activation: currently active schemas activate others with which they are associated.
<u>Loss of activation</u>: when schemas that have been activated lose activation, thereby losing effectiveness to control behavior.
Forgetting an intention (but continuing with the action sequence).
Misordering the components of an action sequence.
Skipping steps in an action sequence.
Repeating steps in an action sequence.
Slips that result from faulty triggering of active schemas:
<u>False triggering</u>: a properly activated schema is triggered at an inappropriate time.
Spoonerisms: reversal of event components.
Blends: combinations of components from two competing schemas.
Thoughts leading to actions: triggering of schemas meant only to be thought, not to govern action.
Premature triggering.
<u>Failure to trigger</u>: when an active schema never gets invoked because:
The action was preempted by competing schemas.
There was insufficient activation, either as a result of forgetting or because the initial level was too low.
There was a failure of the trigger condition to match, either because the triggering conditions were badly specified or the match between occurring conditions and the required conditions was never sufficiently close.

Source: Norman (35).

have less utility in the more physical activity types of industrial tasks such as those found in mining (e.g., roofbolting, manual materials handling, or scaling). It is for that reason that the simple schemes dealing with broad categories of human information processing seem most appropriate to the analysis of human error in accidents.

More fruitful than classification schemes are causal models of human error. The emphasis of such models is on identifying the contributing factors that increase the probability of human error. The next section reviews several promising models. Some of these models are based on, derived from, or inspired by some of the classification schemes discussed above.

Causal Models of Human Error

Singleton (63) provided a fair summation of the state of human error and causal models when he said: "There are many kinds of errors, many different causation factors, [and] many relevant models or theories." Patrick (37) believes that it is premature to formulate a theory of human error at our present state of knowledge. Nevertheless, there is a need to understand human error and what causes or contributes to it. It is possible, however, that some errors have no causes; they just happen (57).

Generally, for something to be considered a cause, it must precede the effect in time. An event, factor, or condition can be a necessary and/or sufficient condition for the effect; however, it is extremely rare that a cause is both the necessary and sufficient condition for an event. In most endeavors, we are satisfied if we can identify the events/factors/conditions that increase the probability of an effect. Shinar, McDonald, and Treat (59), in the context of automobile accidents, define a causal factor as a necessary condition for the occurrence of an accident. Shinar et al. also make the distinction between direct causes and indirect causes. They considered direct causes to be acts and failures to act in the moments immediately preceding an accident which increased the risk of a collision. Direct causes, therefore, are the specific human errors contributing to the accident. Indirect causes, or as Shinar et al. called them "conditions and states," were defined as causal factors which adversely affect the ability of the driver to perform the information processing functions necessary for safe performance of the driving task. It is these indirect causes, or contributing factors, that have been the focus of investigation by many researchers.

Investigations that have identified factors that contribute to human error have been of two classes. The first are broad theoretical models that bring together the myriad of factors that influence human behavior. Some are more elaborate than others. The second class of investigations are more empirical and attempt to identify the contributing factors in a specific domain, such as roof fall accidents, railroad accidents, or driving accidents. These empirical investigations often provide little more than a list of contributing factors and the proportion of accidents in which each factor was involved. Usually, the factors identified in the empirical studies are more specific than those included in the theoretical models.

Theoretical Models of Contributing Factors

A rather simple model is that proposed by Beek, Hayman, and Markisohn (4). The model divides human error into predictable and random error. Random error, by definition, has no systematic cause. Two classes of causal factors are postulated to be related to predictable error: (1) personnel characteristics; and (2) design. Personnel characteristics include both environmental conditions (weather, combat conditions, others) and personnel composition (training, staffing, selection, motivation). The design factor is comprised of equipment design and procedural problems (equipment availability, proper procedures). Thus, the model, although somewhat primitive, does encompass human, equipment, and environmental factors.

Another model that is somewhat more detailed, but nonetheless limited, is the model developed by Osuna (36) (as cited in 40) and shown in figure 3. The model uses a logic diagram to delineate the causes of an unsafe act. The model presents three immediate causes of an unsafe act: person does not know, is unable to do it, or refuses to do it. The contributing causes of each of these are displayed as a logic diagram. The model includes the following contributing factors: training; policy; safety analysis; lack of space, facilities, personnel, or equipment; mental and physical capabilities; selection; system interface; and job satisfaction.

An early model of accident causation was proposed by Hale and Hale (19) and is shown in figure 4. The model is built around a model of information processing. The contributing factors emphasize those internal to the individual (physical defects, innate ability, motivation) and those impinging directly on the individual (training, drugs, stress). Little or no mention is given to external factors such as environment and equipment design factors. Smillie and Ayoub (64), using Hale and Hale's model as a basis, produced a more complex model that included both equipment and environmental factors. The model is shown in figure 5.

Rasmussen (43) identifies the following three classes of factors contributing to the human error process:

Performance Shaping Factors

- Subjective goals and intentions
- Mental load, resources
- Affective factors

Situation Factors

- Task characteristics
- Physical environment
- Work time characteristics

Personnel Task

- Equipment design
- Procedure design
- Fabrication
- Installation
- Inspection
- Operation
- Test and calibration
- Maintenance, repair
- Logistics
- Administration
- Management

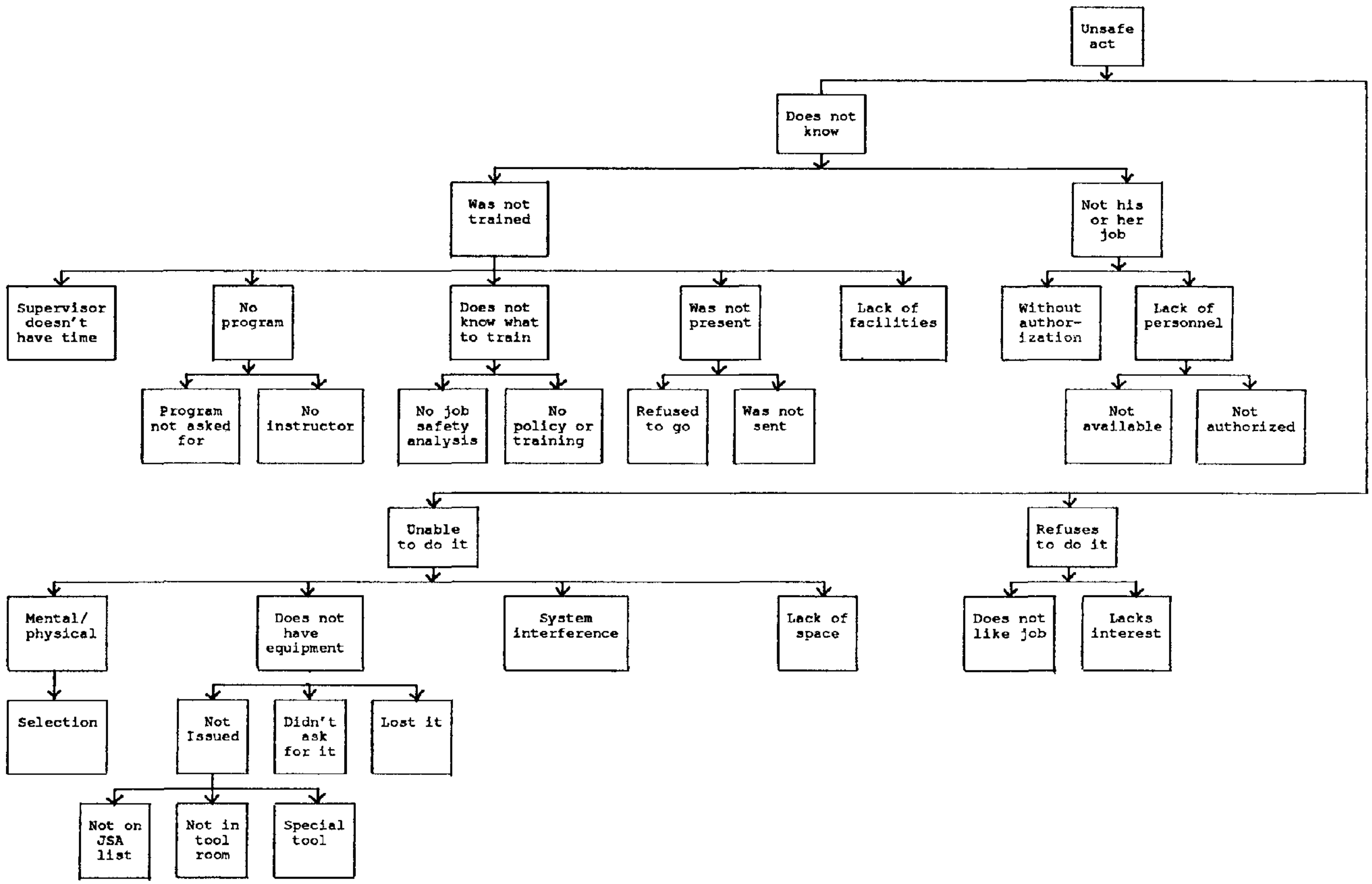

FIGURE 3. - Logic diagram of the causes of human error (36), as cited in (40).

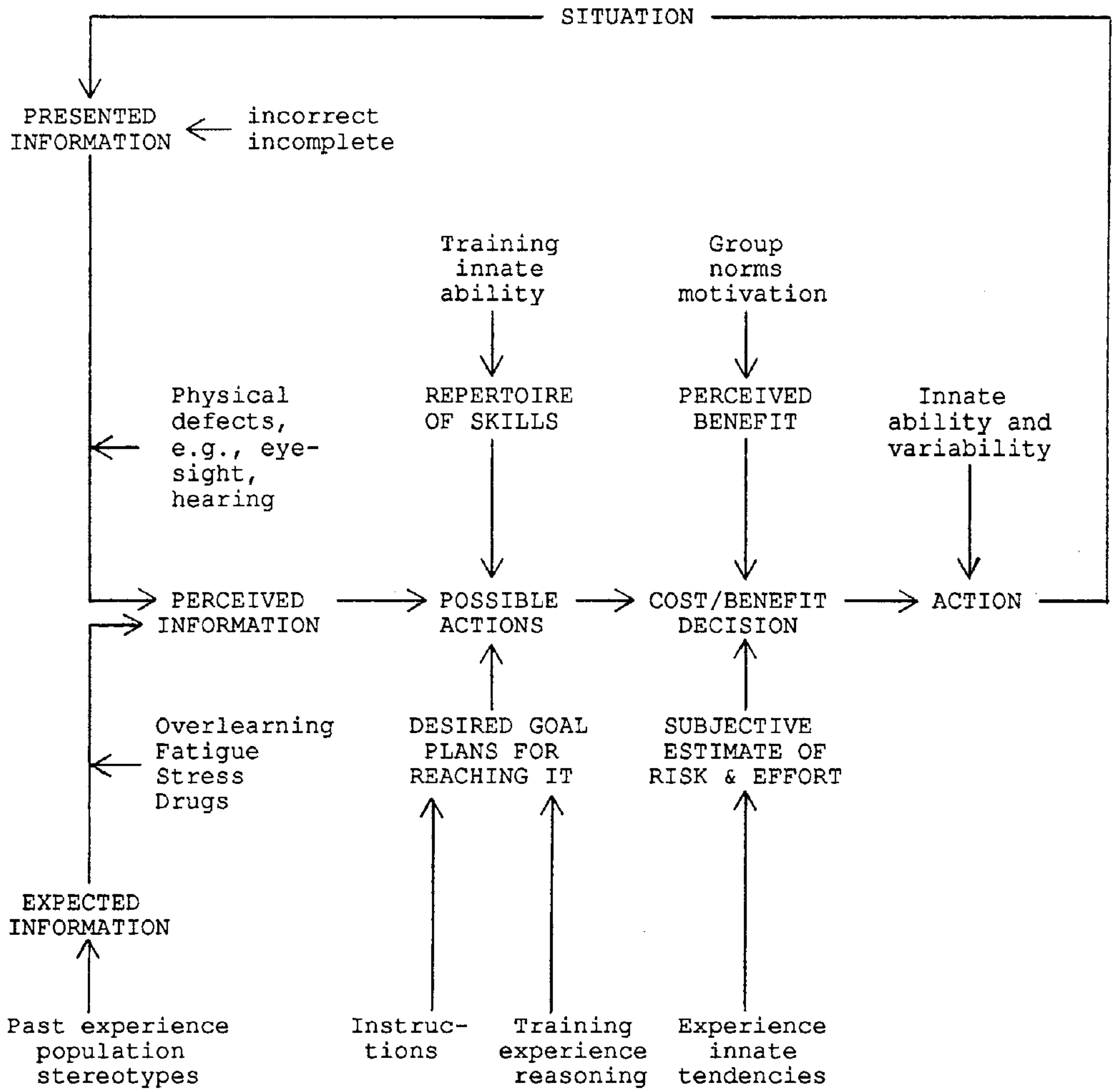

FIGURE 4. - Hale and Hale's (19) model of accident causation.

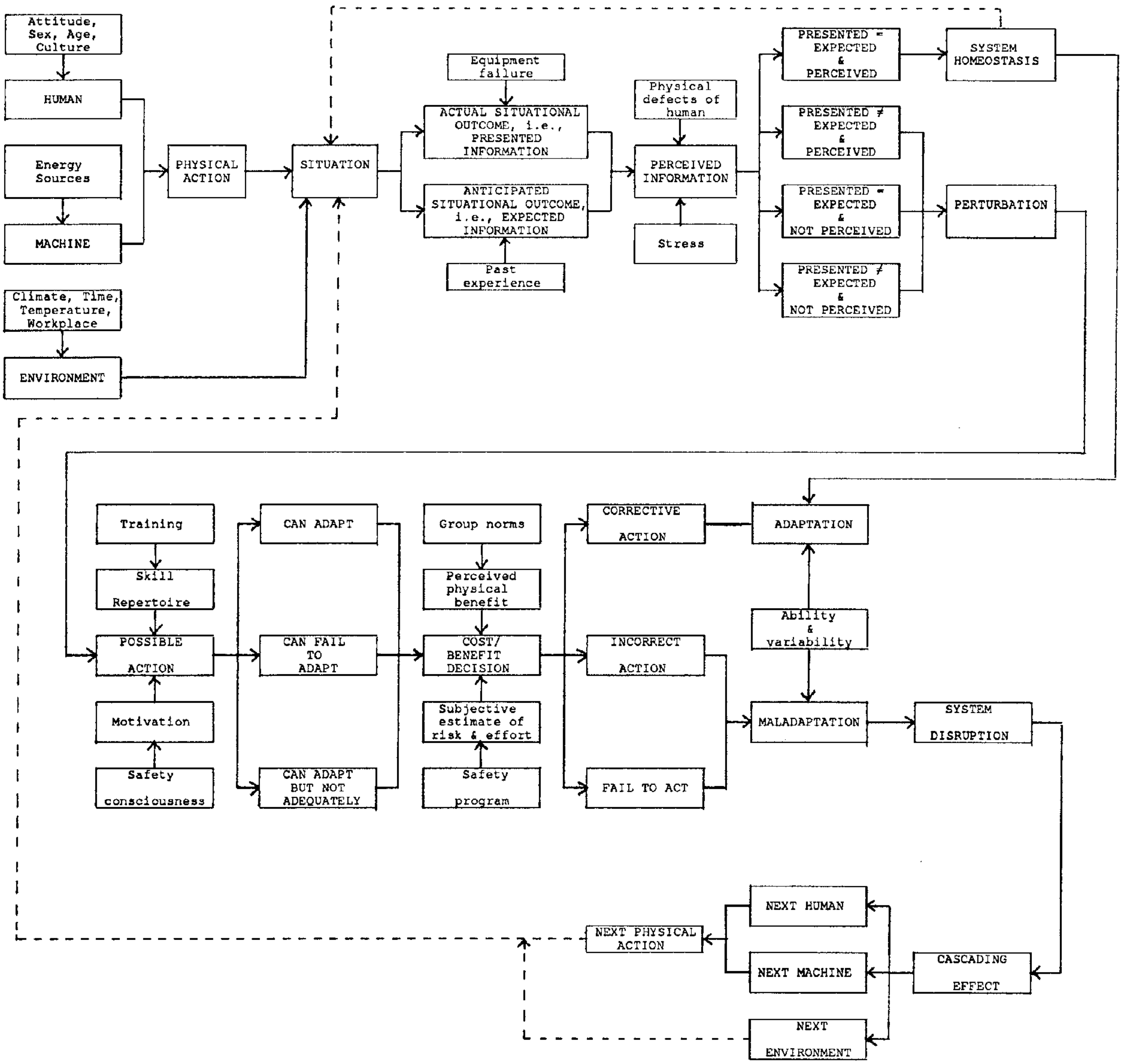

FIGURE 5. - Integrative model of the accident phenomenon based in part on figure 4.

As can be seen, the personnel task category seems to mix human factors considerations (equipment and procedure design) with the stage of system design in which the error occurred. To further complicate the situation, Rasmussen also includes a category of factors specifically called "causes of human malfunction." This category is comprised of:

External events (distraction, etc.);
Excessive task demand (force, time, knowledge, etc.);
Operator incapacitated (sickness, etc.);
Intrinsic human variability.

To Rasmussen's credit, however, he does supply a flowchart to aid in determining which of the above four causes was present in the human malfunction. The flowchart is presented in figure 6. The model and flowchart were developed within the context of system control tasks such as processing plant control. It would be difficult to apply the flowchart to other sorts of tasks such as those found in underground mining.

A widely known model is the Management Oversight Risk Tree (MORT) which is a human error fault tree (22). The entire MORT approach to accident investigation is quite complex. The portions of MORT that are relevant to human error causation are the "personnel performance discrepancy" and "human factors review" branches of the tree. As Petersen (40) indicates, MORT "seems somewhat simplistic -- it includes only four major causes of human error." Actually, if one includes human factors, it includes five. The five causes and their sub-causes are:

Personnel Selection LTA (less than adequate):

Criteria LTA
Testing LTA

Training LTA:

None
Criteria LTA
Professional skill LTA
Methods LTA
Verification LTA

Consideration of Deviations LTA:

Normal variability
Changes
Did not observe
Did not correct because:
did not reinstruct
did not enforce

Employee Motivation LTA:

Management concern, example, or vigor LTA
Schedule pressure
Non-performance is regarding
Performance is punishing

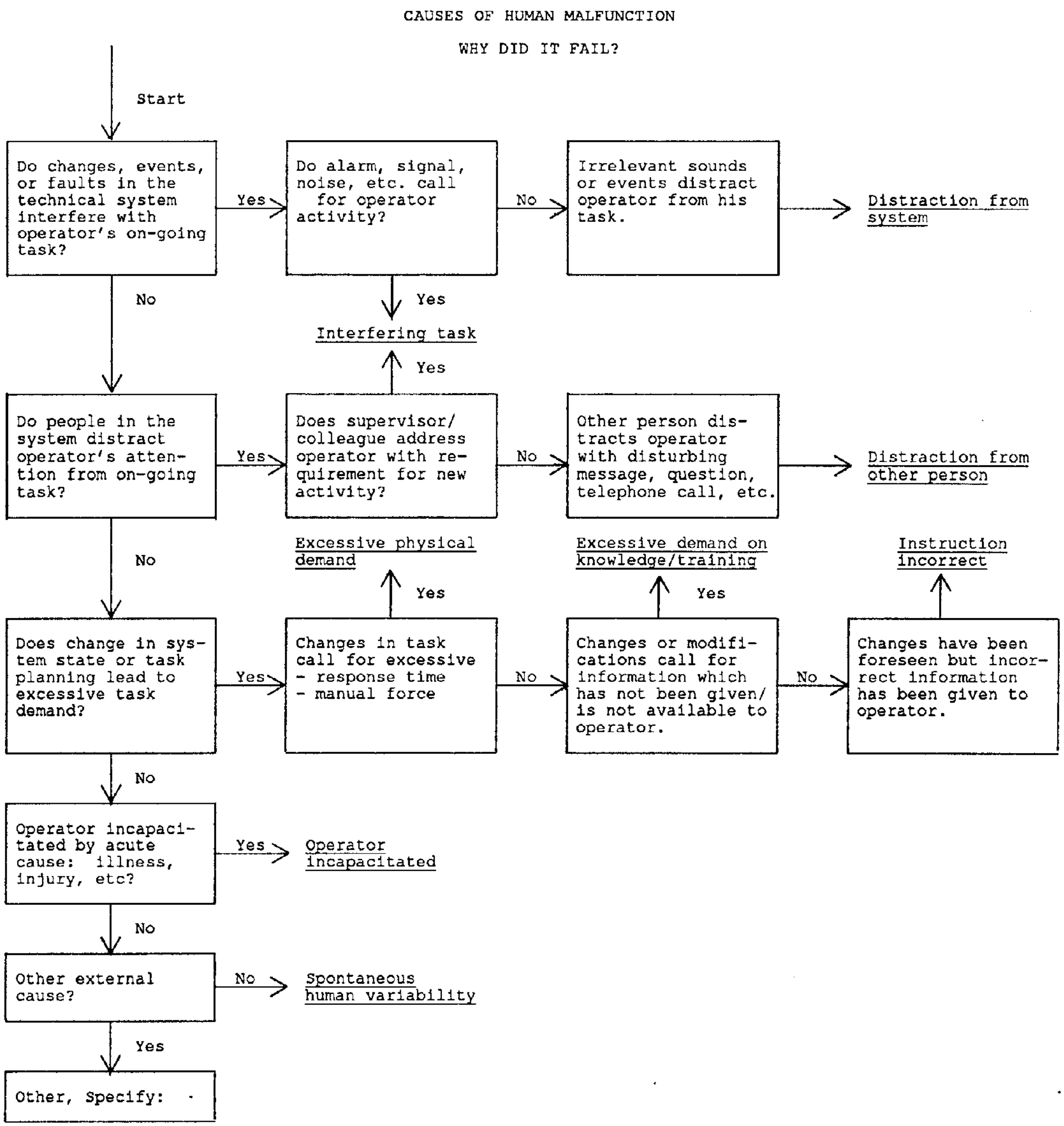

FIGURE 6. - Guide for determining the cause of human malfunctions according to Rasmussen's (43) model.

Job interest building LTA
Group norms conflict because:
  worker participation LTA
  innovation diffusion LTA
Obstacles prevent performance
Personal conflict:
  with supervisor
  with others
  due to being deviant
General motivational program LTA

Human Factors Review:

Professional skills LTA
Did not describe tasks
Allocation of man-machine tasks LTA
Did not establish man-task requirements because:
  Did not define users
  Use of stereotypes LTA
  Displays LTA
  Mediation LTA
  Controls LTA
Did not predict errors due to:
  Incorrect act
  Act out of sequence
  Failure to act
  Act not required
  Malevolence

An approach similar to MORT is the Technic of Operations Review (TOR) developed by D. A. Weaver Safety Associates (7) (Pueblo, CO 81001). TOR consists of a list of factors that contribute to human error. The list is divided into the following eight categories:

Training	Supervision	Personal Traits
Responsibility	Work Groups	Management
Decision & Direction	Control	

The list of factors for each of these categories is shown in table 8. As can be seen, the factors overlap the categories. For example, under Work Groups is the item "Lack of things needed," but under Control is "Equipment: Insufficient, unavailable, deficient design, inoperative." The list, as with other models, is incomplete. Lacking, for example, is adequate consideration of equipment and environmental factors.

Swain and Guttmann (68) list performance shaping factors (PSFs) which are things that influence human performance. PSFs are of three types: External to the individual, internal to the individual, and stressors. Table 9 presents the categorization. Three classes of external PSFs are identified: situational characteristics, job and task instructions, and task and equipment characteristics. Two types of stressor PSFs are listed: Psychological stressors and physiological stressors. Internal PSFs are of only one type, organismic factors. The Swain and Guttmann model stresses classic human factors variables and downplays the "softer" socio-technical, organizational, and management variables. These soft variables are

TABLE 8. - Specific items identified for TOR analysis

Training:

Training not formulated or need not foreseen.
Instruction was given, but results show it didn't take.
Training available, but the employee was not assigned or did not attend.
Performance not in accord with policy or procedure.
Failure to provide training whose need had been specified.
Error blamed on faulty training when, in fact, the error stemmed from deficiencies in management systems.

Responsibility:

Duties and tasks not clear, or not accepted.
Conflicting goals.
Dual or overlapping responsibility.
Pressure of immediate tasks obscures full scope of responsibilities.
Buck passing, responsibility not tied down.
Job descriptions inadequate.
Hazard or problem - not recognized.

Decision & direction:

Bypassing, conflicting orders, too many bosses.
Decision too far above the problem.
Authority inadequate to cope with the situation.
Decision exceeded authority.
Decision evaded; power to decide not exercised.
Orders or directives failed to produce desired action. Not clear, not understood, or not followed.
Failure to investigate, and to apply the lessons of similar mishaps.
Hazard or problem - controls not developed.

Supervision:

Failure to orient or coach - new worker, unusual situation, unfamiliar equipment or process, etc.
Supervisor failed to Tell Why.
Supervisor failed to Listen.
Unsafe Act. Failure to correct before accident occurred.
Failure to supervise closely until proficiency was assured.
Honest error. Failure to act, or action turned out to be wrong.
Disorder or confusion in work area.
Job practice out of step with job training.
Initiative. Failure to see problems and exert an influence on them.

Source: D. A. Weaver Safety Associates (7).

Work groups:

Morale. Conflict, insecurity. Lack of faith in the boss or the future of the job.
Conduct. Supervisor sets a poor example.
Team spirit. Failure to pull together, uncooperative.
Rules. Not publicized, not clear. Unfair enforcement or weak discipline.
Clutter. Anything not needed in the work area.
Lack of things needed - tools, space, protective equipment, storage bins, etc.
Voluntary compliance. Work group sees little advantage to themselves.

Control:

Work flow. Inefficient or hazardous. Layout, scheduling, stacking, piling, routing, storing.
Unsafe condition.
Equipment. Insufficient, unavailable, deficient design, inoperative.
Procedure out of step with available technology; inadequate review and revision.
Procedure not available or not followed.
Deficient inspection, reporting, or maintenance.
Hazard or problem - controls not maintained.

Personal traits:

Work assignment - unsuited for this particular individual.
Poor work habits; careless of rules, tools, equipment, procedures, etc.
Health problem.
Inappropriate behavior or judgment.
Undesirable peer pressures influence work performance and risk taking.
Behavior not adjusted to the workplace.

Management:

Policy. Failure to assert a management will before the mishap at hand.
Goals. Not clear, or not converted into decisions and directions.
Span of attention. Too many irons in the fire. Inadequate development of subordinates.
Conflicting priorities not resolved. Excessive emphasis on short range accomplishments.
Coordination. Departments inadvertently create problems for each other.
Failure to encourage subordinates to exercise their power to decide.
Accountability. Failure to develop appraisal and measurement of key goals and objectives.
Staffing. Inadequate organization to cover necessary functions, or to use available human resources, or to cope with turnover and absenteeism.
Hazard or problem - not properly evaluated.

Source: D. A. Weaver Safety Associates (7).

TABLE 9. - Some performance shaping factors (PSFs) in human-machine systems

External PSFs		Stressor PSFs	Internal PSFs
Situational characteristics: Those PSFs general to one or more jobs in a work situation.	Task & equipment characteristics: Those PSFs specific to tasks in a job.	Psychological stressors: PSFs which directly affect mental stress.	Organismic factors: Characteristics of people resulting from internal & external influences.
Architectural features Quality of environment: Temperature, humidity, air quality, and radiation Lighting Noise and vibration Degree of general cleanliness Work hours/work breaks Shift rotation Availability/adequacy of special equipment, tools, and supplies Manning parameters Organizational structure (e.g., authority, responsibility, communication channels) Actions by supervisors, co-workers, union representatives, and regulatory personnel Rewards, recognition, benefits	Perceptual requirements Motor requirements (speed, strength, precision) Control-display relationships Anticipatory requirements Interpretation Decision making Complexity (information load) Narrowness of task Frequency and repetitiveness Task criticality Long- and short-term memory Calculational requirements Feedback (knowledge of results) Dynamic vs. step-by-step activities Team structure and communication Man-machine interface factors: Design of prime equipment, test equipment, manufacturing equipment, job aids, tools, fixtures	Suddenness of onset Duration of stress Task speed Task load High jeopardy risk Threats (of failure, loss of job) Monotonous, degrading, or meaningless work Long, uneventful vigilance periods Conflicts of motives about job performance Reinforcement absent or negative Sensory deprivation Distractions (noise, glare, movement, flicker, color) Inconsistent cueing	Previous training/experience State of current practice of skill Personality and intelligence variables Motivation and attitudes Emotional state Stress (mental or bodily tension) Knowledge of required performance standards Sex differences Physical condition Attitudes based on influence of family and other outside persons or agencies Group identification
Job and task instructions: Single most important tool for most tasks.		Psychological stressors: PSFs which directly affect physical stress.	
Procedures required (written or not written) Written or oral communications Cautions and warnings Work methods Plant policies (shop practices)		Duration of stress Fatigue Pain or discomfort Hunger or thirst Temperature extremes Radiation G-force extremes Atmospheric pressure extremes Oxygen insufficiency Vibration Movement constriction Lack of physical exercise Disruption of circadian rhythm	

Source: Swain & Guttmann (68).

incorporated as two or three specific PSF categories under situational characteristic external PSFs.

As part of this project on human error in underground mining, a general model of contributing factors in accident causation (CFAC) was developed and is shown in figure 7. The CFAC model includes the following six major categories of causal factors:

Management	Work Itself
Physical Environment	Social/Psychological Environment
Equipment Design	Worker/Co-worker

The model shown in figure 7 was developed from a review of the theoretical models of contributing factors discussed above and from the extensive mining and safety experience of the project team. The CFAC categories are sufficiently broad to encompass virtually all the factors included in the other models discussed. The unique features of the model are: (1) the emphasis given to management and social/psychological factors; (2) recognition of the human-machine-environment system by including separate categories for each of the components; and (3) its relative simplicity and ease of comprehension. The model is far more comprehensive than those developed by Osuna (36) (as cited in 40), Johnson (22), D. A. Weaver Safety Associates (7), Swain and Guttmann (68), or Hale and Hale (19). Although it does not attempt to describe the information-processing aspects of an accident occurrence, the CFAC model does include more categories of contributing factors than does the model of Smillie and Ayoub (64). Further, the CFAC model is less ambiguous than that proposed by Rasmussen (43) and includes more factors. The CFAC model, therefore, is a comprehensive model of the contributing factors in human errors, presented in a simple, easy-to-comprehend fashion.

Empirical Studies of Contributing Factors

Empirical studies of contributing factors usually involve analysis of a set of accident reports to uncover common causes contributing to the accidents. In some studies, the investigators conduct the accident investigations; in other studies, existing accident reports are analyzed. There have been many such empirical studies covering a wide range of accident domains, for example, German Air Force accidents (15), air traffic controller mishaps (8), merchant marine accidents (30), automobile accidents (11, 59), railroad freight yard accidents (25), chemical industry incidents (20), gold mining accidents (28), and underground coal mining roof fall accidents (39).

Although there are some common threads running through these studies, the findings, for the most part, are specific to the type of accidents being studied. To provide a flavor for the findings, and to concentrate on those domains that are most relevant to the mining industry, the last four studies listed above will be summarized.

Kashiwagi (25) interviewed 42 severely injured station yard railway workers engaged in the classification of freight cars and the composing of long trains. Forty-two items were rated present or absent in the accident investigations scenarios. The items were divided into the following categories (actual items are grouped under each category and the percentage of cases in which the factor was present is indicated):

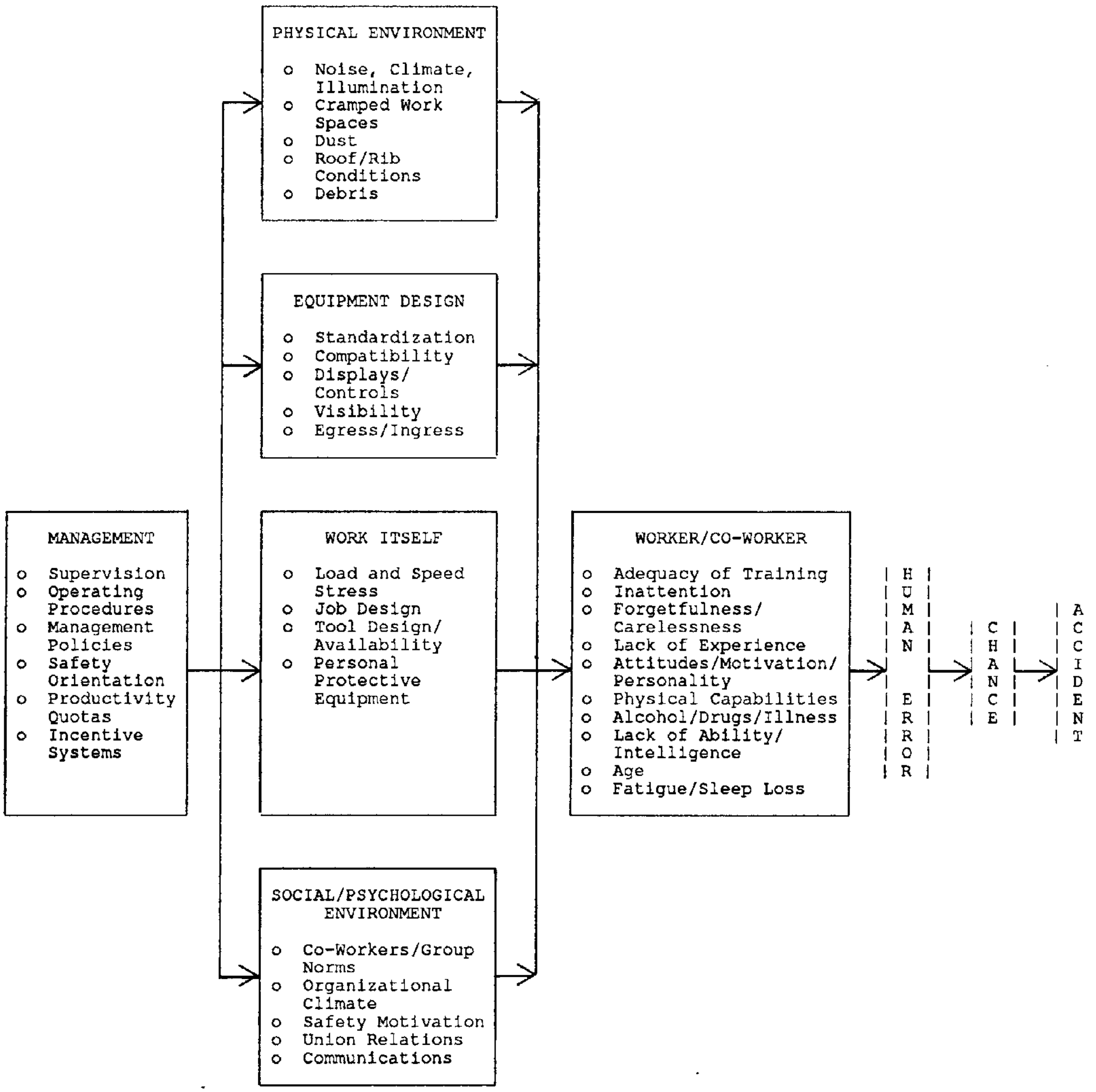

FIGURE 7. - Model of contributing factors in accident causation (CFAC).

Environment:

- Unfavorable weather (26%)
- Working in classification yard (50%)

Managerial Factors:

- Insufficient education (19%)
- Laissez-faire for unsafe customs (38%)

Time of Accident:

- Engaged in the work at night (40%)
- After working for a long time (55%)
- At the beginning of a specific work (45%)
- In the midst of a specific work (38%)
- At the end of a specific work (17%)

Workplace Factors:

- Defects in the car structure (29%)
- Insufficient illumination of footing space (21%)
- Inappropriate layout of working space and instruments (21%)
- Narrow working space (10%)

Type of Work Being Performed:

- Operating the brake (21%)
- Dealing with an automatic coupler (17%)
- Riding on a moving freight car (19%)
- Stepping onto and off of a moving freight car (29%)
- Operating during walking (14%)
- Work for pushing off of freight cars (26%)
- Work other than pushing off of freight cars (33%)
- Engaged in preparatory work (40%)

Related Actions:

- Inappropriate interpersonal communication (33%)
- Forced work (24%)
- Drastic change in the working situation (40%)
- Interference with other workers (31%)

Behavior of the Victim:

- Insufficient preparation for the work (21%)
- Performing the task alone (33%)
- Reckless behavior (24%)

Psychological Condition of the Victim:

- In a state of fatigue (24%)
- In a hurry or in a flurry (36%)

Working with ease or speedily (17%)
Paying attention to co-workers at work (26%)
Concentrating attention (26%)
Distributing attention to various points (19%)

Personal Attributes:

Large profile fluctuation in addition test (26%)
Normal profile fluctuation in addition test (45%)
Small profile fluctuation in addition test (29%)
Low score in intelligence test (29%)
Professional career of < one year (26%)
Professional career of one year (33%)
Professional career of two years (19%)
Professional career of three or more years (21%)

Using a sophisticated ortho-oblique-type binary data decomposition, Kashiwagi uncovered the following three patterns (scenarios) of error leading to accidents: (1) failure of strenuous performance in relation to fatigue and poor communication; (2) veteran's mistakes in teamwork, possibly due to hasty operation or distractions; and (3) errors caused by certain defects of machines or inappropriate workspaces. A review of Kashiwagi's binary items reveals a rather limited set of variables. With such a truncated set of data, it is no wonder that only three error patterns emerged. A fuller data set might have yielded more comprehensive results.

Hayashi (20) reported on the analysis of 284 accidents from the Japanese chemical industry. The following causes were discovered (number in parenthesis is the percentage of accidents attributed to that cause):

Inadequate standard operational procedure (19%)
Error in recognition or confirmation (15%)
Error in judgement (14%)
Poor inspection (12%)
Inadequate directives (10%)
Inadequate communication of operational information (10%)
Operational error (6%)
Unskilled operation (6%)
Imperfect maintenance (2%)
Other (6%)

Hayashi, in classifying the accidents, attributed a single cause to each accident. This seems somewhat simplistic and probably does not capture the richness and complexity of the actual causal mechanisms.

Lawrence (28) analyzed 405 fatal underground gold mining accidents to determine the human errors involved and the cause of each type of error. Lawrence assumed that all fatal accidents involve some type of human error. A total of 794 errors were identified (one incidence could involve more than one human error). Table 10 presents the results of the analysis. The major types of human error were a failure to perceive a warning and underestimation of hazard. Inadequate inspection techniques was the cause of 74% of the failure-to-perceive-a-warning errors. Lawrence could not, or did not, identify causes for underestimation-of-hazard errors.

TABLE 10. - Causes of 794 human errors leading to fatal accidents in underground gold mining

Human error	Cause (n)	%	% of total
Failure to perceive a warning (285)	Inadequate inspection technique (212)	74.0	
	Neglecting to inspect (14)	5.0	
	Obstruction to line of sight (4)	2.0	
	Inattention or distraction (4)	1.5	
	Masking noise (2)	<1.0	
	Other (4)	1.5	
	Mixture of these (42)	15.0	
		100.0	36.0
Failure to recognize a perceived warning (33)	Inadequate information (10)	30.0	
	Lack of training (4)	12.0	
	Lack of experience (3)	9.0	
	Other (3)	9.0	
	Mixture of these (13)	40.0	
		100.0	4.2
Underestimation of hazard (196)	Causes not known (196)	100.0	24.7
Failure to respond to a recognized warning (140)	Underestimation of hazard (127)	91.0	
	Other (13)	9.0	
		100.0	17.5
Responded to warning but ineffectively (109)	Negligence or carelessness (19)	17.0	
	Standard practice inappropriate (17)	16.0	
	Well intended but ineffective direct action (17)	16.0	
	Other (2)	2.0	
	Mixture of these (54)	49.0	
		100.0	13.7
Inappropriate secondary warning (31)	Causes not known (31)	100.0	3.9
Total (794)			100.0

Source: Lawrence (28).

Peters and Wiehagen (39) attacked the problem of accident causation in a manner different from the studies discussed above. Rather than investigate specific accidents, the investigators interviewed a sample of 143 underground coal mine employees to determine their opinions as to why miners sometimes neglect to correct roof fall hazards and why miners sometimes walk beneath unsupported roof. In previously discussed studies, the investigators inferred or classified the causes for the behavior or accident. Peters and Wiehagen, on the other hand, solicited the opinions of workers as to the reasons for engaging in unsafe behavior.

The following were the percentages of miners who agreed with each of the reasons for why miners neglect to correct roof hazards:

1. They don't take enough time to look for roof problems. (81%)
2. They don't realize how dangerous roof problems are. (68%)
3. They dislike doing the type of work necessary to correct the problem. (58%)
4. They think it is someone else's responsibility. (51%)
5. They don't have the tools or materials to correct the problem. (51%)
6. They don't want to risk getting hurt. (48%)
7. They don't know how to correct the roof problem. (36%)
8. They believe their supervisor thinks that taking care of roof problems is unimportant. (11%)

The following were the percentages of miners who agreed with each reason for why miners go beneath unsupported roof:

1. They are trying to save some time. (79%)
2. They have often seen other people do it. (72%)
3. They do not realize they have gone beyond the edge of supported roof, and did not intend to do so. (66%)
4. It takes too much time to set temporary supports. (60%)
5. They do not believe it is unsafe to do so. (50%)

As can be seen, a dominant theme in the above reasons relates to not wanting to take the time or effort to inspect or correct a hazardous situation. Another theme is the underestimation of the hazard. These results correlate well with the results of Lawrence's (28) study of gold mine human error accidents. Inadequate inspection technique, neglecting to inspect, and underestimation of hazard accounted for 65% of the almost 800 errors identified by Lawrence.

Empirical analyses of accidents and mishaps can yield valuable information, but often the results are difficult to apply outside of the specific arena in which the original data were collected. It is often difficult to infer causation from the analysis of accidents because the necessary information is usually not available. The people involved in the incident may be unable or unwilling to reveal information or to explain the motivations and rationale behind their behavior. In some cases, after-the-fact explanations are created by the involved people to rationalize their behavior, or they will create information because it seems as though it must have been that way to make sense out of the situation. These sorts of biases are inherent in any eyewitness report, and become especially acute when the witness may also share in the blame.

Discussion

Human error involves a deviation from some norm or standard, but there is no agreed upon source of standards against which to judge behavior. Human errors, therefore, are established after-the-fact, and usually after some negative consequence has occurred. Human error is something most people would like to eliminate, but doing so might deprive people of the opportunity to learn from experience. A corollary of this is that punishing people for making errors may inhibit innovation and creativity and may stifle advancements in learning.

Human error is involved with accidents, but to what degree is still an open question. Estimates range from 4% to 90%. The underlying assumptions, including the definition of human error and the investigative tenacity of the investigator, determines, in great part, how much human error will be found to contribute to accidents.

Numerous taxonomies of human error have been proposed, but all fail to provide much useful, generalizable information. Some disregard the psychological, perceptual, and cognitive aspects of humans, and instead classify errors based on their overt descriptive properties. Other classification schemes concentrate on the internal information processing functions of the individual. These latter schemes are difficult to apply in real-world settings because the data necessary for classification are often not available to the investigator.

Causal models of human error are really compilations of the various factors that influence human performance. The better models include person, equipment, task, environment, and organizational factors. Most models, however, neglect one or more of these broad categories and concentrate on a limited set of factors.

In summary, it appears that despite the vast amount of literature on human error, the field is still in its infancy. There is little agreement on definitions, classification schemes, or causal models. The theoretical discussions seem to coalesce around information processing theories. As advances are made in the information processing domain, so too will progress be made in the field of human error. In the near future, there is neither much hope of any great theoretical breakthroughs, nor is there likely to be any real practical applications flowing from this field. The best approach is probably to continue the empirical investigations of accidents/incidents in an effort to understand the mechanisms of human error within a very circumscribed environment. Such data are more likely to have some practical effect, if for no other reason than people in that environment will become more aware of the role and causes of human error within their domain.

METHODOLOGY: DATA COLLECTION

Overview

The two goals of the data collection methodology were to: (1) secure the cooperation of a sample of mines that would provide a broad, typical range of accidents for investigation; and (2) collect relevant information that would allow assessments to be made of the contributing causes involved in those accidents.

The sample of mines used in this study should not be considered truly representative of the underground mining industry; however, the sample does represent a wide range of typical medium-to-large mining operations. Several factors made it impossible to obtain a completely representative sample. The accident investigation procedures required a long-term commitment from the mine and considerable on-site time to coordinate the data collection efforts. It was not easy to find mines willing to commit themselves to the time and effort required. The target population was the entire underground mining industry, including both coal and noncoal mining. The nature of the industry would have required a very large sample of mines to capture its diversity. There were, however, not enough resources in the contract to undertake such an endeavor. A total of 20 mines, operated by five companies, agreed to participate.

The data collection focused on all non-fatal, MSHA-reportable injuries. Such injuries are well documented by mines and represent a class of accidents that carry important consequences to the industry. Non-fatal, MSHA-reportable injuries provided a data base of accidents large enough for analysis. Further, this class of injury was consistently tabulated across mines and was less open to interpretation than would be near-miss accidents. A total of 338 accidents were investigated over a 29-month period.

The data collection methodology was intended to extend beyond the "typical" investigation of accidents. Typical investigations in the mining industry, as performed by mining companies or government authorities, tend to focus on documentation of the incident for legalistic purposes. Considerations such as culpability, liability, workers' compensation, and government reporting requirements become major issues; analysis, in the scientific sense of the word, becomes a secondary issue. This is not to say that mining companies do not recognize the need for scientific accident analyses. In fact, most mine safety directors realize that accident analyses are important for the improvement of working conditions, but they often lack the background, manpower, or analytic resources to go much beyond a legalistic investigation.

The data collection approach used in this project involved a systems approach to accident causation. The approach provided more than a mere identification and description of the immediate accident/injury events. The approach placed emphasis on the identification and understanding of the events and circumstances leading up to, and surrounding the accident. A member of the project team conducted an independent investigation of each accident. Interviews were conducted with the injured person and, where possible, other involved parties and witnesses. Where necessary, and possible, the accident site was visited and the equipment involved was inspected. Data were collected from January 1985 through May 1987.

The remainder of this section will present the rationale behind the sampling plan, and descriptions of the sample mines. The data collection procedure will be described, including the procedures followed to conduct an investigation, and how the results were summarized into a case report. Finally, a discussion of the strengths and weaknesses of the methodology will be presented.

Sampling Plan

The major goals of the sampling plan were to: assure an adequate number of accidents for reliable analyses, provide accidents that were typical of those occurring in the mining industry, sample mines from the various segments of the industry, and stay within the budgetary constraints of the contract.

According to MSHA Mine Injury and Worktime, Quarterly (70-72) reports, the non-fatal days-lost (NFDL) injury rates per 200,000 person-hours for the years 1985 through 1987 were as shown in table 11(A). Assuming 2,000 hours per person-year, these numbers reflect the number of injuries per 100 workers per year. NFDL injury rates increased during the 3-year period in which data were being collected for this project. During this same period, the average number of employees decreased as shown in table 11(B). The proportion of the underground labor force in coal, metal, and nonmetal, however, has remained remarkably consistent over these years. The average percentages are as follows:

Bituminous Coal	85.6%
Metal	9.9%
Nonmetal	4.5%

If these percentages are applied to the average NFDL injury rate over the 3-year period (table 11(A)), the weighted average across the entire industry of NFDL injuries per 100 workers per year is 8.7. To obtain 100 accidents per year, a minimum sample for one year, approximately 1,150 workers would have to be included in the sample each year. The sampling plan was developed, therefore, to insure that at least that many workers would be represented in the mines sampled. In addition, the plan was to include approximately 85% coal and 15% metal/nonmetal employees if possible.

Because a mine's participation in the project was voluntary, selection was primarily governed by the mine operator's willingness to participate. Mines were selectively contacted in an attempt to obtain a broad sample of mining companies. Within each industry, coal and metal/nonmetal, underground mines were sought that represented a variety of major mining methods, union affiliations, and company sizes.

The selection of the sites included, in addition to willingness to cooperate, consideration of the following factors:

1. Size of the mine, i.e., number of employees (small mines have higher injury rates than do large mines).
2. Seam height (low-seam mines have higher injury rates than do high-seam mines).
3. Mining methodology (e.g., conventional, continuous, longwall).
4. Geographic area (different states or areas have different injury rates).
5. Unionization.

TABLE 11. - Non-fatal days-lost injuries per 200,000 person-hours and average number of employees for the years 1985-1987 in the underground coal, metal, and nonmetal industry

a. Non-fatal days-lost injuries per 200,000 person-hours

	1985	1986	1987	Average
Bituminous coal	7.68	7.83	12.46	9.3
Metal	4.89	5.96	6.11	5.6
Nonmetal	4.25	4.33	4.44	4.3

b. Average number of workers

	1985	1986	1987
Bituminous coal	87,423	80,446	74,008
Metal	10,261	8,895	8,743
Nonmetal	4,579	4,255	3,940
Total	102,263	93,596	86,691

Source: U.S. Mine Safety and Health Administration (70-72).

6. Safety attitudes and practices of management (it is recognized that it is more difficult to gain access to mines that do not have positive safety attitudes).
7. Mineral mined.
8. Type of equipment used.

Participating Mines

A total of 20 mines were included in the sample. Seventeen (17) were underground bituminous coal mines and three (3) were metal/nonmetal mines. The 20 mines were operated by five different companies. Table 12 summarizes the key attributes of each mine. The sample represents a broad, diverse sampling of underground mines. The sample places an emphasis on coal mines because the majority of labor hours and accidents occur in that industry.

The sample included approximately 2,050 underground miners working approximately 3.5 million labor hours during the 29 months of data collection. The percentage of workers in the sample from coal mines was 92%. This is slightly higher than the sampling plan projection, but not unreasonably so. During the data collection period, the size of the labor force in the participating mines declined slightly. This was not unexpected given the general decrease in the mining labor force nationwide during this same period.

TABLE 12. - Descriptions of participating mines

Mining company/ mine	Commodity	Type	Number of underground employees	Union affiliation
1-1	Zinc	Open stoping	70	Yes
1-2	Zinc	Open stoping	70	Yes
2-1	Coal	Continuous	39	Yes
2-2	Coal	Continuous	217	Yes
2-3	Coal	Continuous	217	Yes
2-4	Coal	Continuous	97	Yes
2-5a	Coal	Continuous	30	Yes
2-5b	Coal	Continuous	60	Yes
2-6	Coal	Continuous & longwall	235	Yes
2-7	Coal	Continuous & longwall	235	Yes
3-1	Limestone	Room & pillar	30	Yes
4-1	Coal	Continuous	150	Yes
4-2	Coal	Continuous	158	Yes
4-3*	Coal	Continuous	Unknown	Yes
5-1	Coal	Continuous - low-seam	40	No
5-2	Coal	Continuous - low-seam	120	No
5-3	Coal	Continuous - low-seam	120	No
5-4	Coal	Continuous - low-seam	45	No
5-5	Coal	Continuous - low-seam	80	No
5-6	Coal	Continuous - low-seam	40	No

*No accidents occurred during study period.

Accidents Investigated

At each mine, all MSHA-reportable, non-fatal accidents were investigated. This included non-fatal lost days (NFDL) and no days lost (NDL) injuries. NDL injuries involve restricted duty and medical care incidences. The project specifically excluded fatalities because they result in extensive federal investigation, tend to be emotionally charged, may involve ongoing litigations, and often there are no witnesses to the accident. Therefore, no fatalities were included in the data base.

One accident could result in multiple MSHA-reportable injuries. This occurred on one occasion. In this case, each MSHA-reportable injury was investigated separately, but all were later pooled into a single accident description. The focus in this study was on accident causation rather than injury causation; hence, multiple injury accidents were counted as a single incident.

A total of 338 accidents were investigated during the 29-month data collection period. This is an average of 140 accidents per year, 40% more than originally planned. Of these, 195 were NFDL and 143 were NDL accidents. Prorating the number of NFDL and NDL accidents industry-wide in 1987, a total of 17,017 NFDL and 6,048 NDL accidents occurred in the underground coal, metal, and nonmetal mining industry during the period in which accidents were being investigated for this project. The industry-wide ratio of NFDL to NDL injuries does not correspond to the ratio found in this study. The NFDL accident numbers reported by MSHA are probably more accurate than are the NDL figures cited. We believe that the MSHA Mine Injury and Worktime, Quarterly (70-72) data for NDL injuries is probably an underestimate of the actual number, due to non-reporting of NDL injuries by many mining companies. The 195 NFDL accidents investigated during this project represents 1.1% of all NFDL injuries occurring in the industry during the same period of time.

Data Collection Instruments and Procedure

To facilitate collection of relevant accident information, a set of interview guides were developed. Although the investigators were experienced accident researchers, the guides provided a structure for collecting the required data elements and served as stimuli for exploring circumstances and events surrounding the accident. Table 13 summarizes the data collection guides.

Specific guides were developed for the five most common types of accidents as reported by MSHA's Mine Injury and Worktime, Quarterly (70-72). The five guides were used for investigating slip-and-fall, material handling, handtool, machinery/ haulage, and fall-of-ground accidents. In many cases, more than one guide was used if the accident involved elements of more than one type of accident.

Previous experience in accident investigations has shown that each accident is somewhat unique. Simple question-by-question administration of the items on a guide fails to provide complete information and tends to irritate the interviewee with irrelevant questions. It was our experience that the interviewee often found it difficult to relate the circumstances of an accident in a manner dictated by a structured guide. The investigator, therefore, was permitted considerable professional license in conducting the investigations, and used the data collection guides as "memory joggers" rather than as strict experimental protocol.

Each mine was visited every 4 to 6 weeks. All injuries occurring since the last visit were investigated. In some cases, the involved parties were not available for interviewing at that time, and the investigation was held over to the next reporting period. Fortunately, most cases were relatively simple events resulting in relatively minor injuries. Generally, the people being interviewed had no trouble recalling the events of the accident. We found that the time between the occurrence of the accident and the investigation served to defuse the situation, and the interviewee seemed more willing to discuss the incident and factors that may have played a role in the injury than if he or she had been questioned immediately after the incident.

A typical investigation proceeded as follows:

1. Investigator reviewed mine/MSHA accident reporting documentation.
2. Injured employee (IE) was introduced to the investigator, and the goals of the project were explained.

TABLE 13. - Summary of data collection instruments

Title	Content type
1. Demographic and general information:	Accident information Injury information Worker information
2. Initial statement form:	Investigator's note pad for investigation interviews
3. Specific accident factors (non-accident type specific):	Worker characteristics Work characteristics Environmental factors
4. Specific accident factors (accident type specific):	Potential causal factors specific to classifiable accident types
a. Slip-and-fall accidents:	Type of fall characteristics Walking/working surface characteristics Task activity characteristics Footwear characteristics
b. Material handling accidents:	Load characteristics Material handling equipment characteristics Handling/lifting characteristics Task considerations
c. Handtool accidents:	General tool characteristics Handle characteristics Switch characteristics Use characteristics Workspace characteristics Maintenance characteristics
d. Machinery/haulage accidents:	Equipment design characteristics Equipment/task familiarity characteristics Equipment use characteristics Equipment maintenance characteristics Safety equipment/personal protective equipment characteristics
e. Fall-of-ground accidents:	Area and fall characteristics Task familiarity characteristics Task/activity characteristics
5. Possible additional contributing accident factors:	Worker Work design Social environment Management
6. Diagram of accident site and equipment:	Investigator's note pad for documentation of worksite layout, equipment/personnel locations, etc.

3. IE described the accident, including:
   a. initiating situations,
   b. sequence of events leading to accident,
   c. consequences of events/accident, and
   d. other peripheral information.
4. Investigator directed specific questions to the IE and sought needed clarifications.
5. IE suggested preventative measures/procedures, including those which were:
   a. in-place but failed at the time of the accident, and
   b. not in-place, but should have been.
6. Mine safety representative was questioned, separately, to verify information obtained from IE and to suggest extenuating circumstances.
7. When appropriate, witnesses and supervisors were interviewed to verify information and fill in details.
8. If possible, the accident site and equipment involved were inspected.
9. Final check with safety representative was made to verify all information collected and observations made.

On the average, each case involved approximately 1.5 hours of interviewing, plus any site and/or equipment inspections. All mine employees were interviewed on a voluntary basis at mutually convenient times and locations. Only twice did employees refuse to be interviewed. In both cases, adequate information was available from other sources. Interviews were held at mine offices, change rooms, job sites, employees' homes, and even in hospitals. On some occasions, it was necessary to conduct the interview over the telephone. In all cases, a reasonable amount of privacy was maintained to assure frank discussion of the incident and circumstances of the accident. Union employees were allowed to have a union safety committee member in attendance, but this right was rarely exercised.

Reporting the Case

When the investigation was completed, the investigator developed a narrative summary of the facts and circumstances behind the accident. The narrative included:

Sequence of events leading up to the accident/injury,
Surrounding events and circumstances,
Assumptions made by the investigator,
Evaluation of the relative validity of the various data sources,
Resolution or interpretation of conflicting evidence, and
Supporting diagrams of worksite and/or equipment.

In addition to the narrative report, the investigator completed a form that summarized basic background information on all people involved in the accident, the mine and specific worksite information, and the injury particulars. These reports formed the basis by which the expert raters assessed the contribution of various causal factors in the incident. The rating process will be discussed in the next section of this report.

Strengths of the Sample and Data Collection Methodology

The sample of accidents was larger than originally planned. The additional data permitted a more reliable analysis of the factors contributing to underground accidents. The sample provides a broad perspective on the major types of underground accidents.

Mines were given the right to exclude any case from use in this study. Fortunately, no cases were excluded by any of the mines participating in the study. The sample of accidents represents all the MSHA-reportable cases occurring at the participating mines during the study period; and hence, there is no mine-specific bias with respect to the accidents included in the sample.

The accident investigation methodology was primarily designed to maximize the validity and reliability of the data collected. Four attributes of the methodology contributed to this objective: (1) the use of investigators that were trained in human factors and the systems approach to accident investigation; (2) the use of independent investigators to collect data rather than relying on government- or mine-supplied data; (3) focusing on causality rather than culpability; and (4) the use of a semi-structured interview technique rather than a rigid structured approach to data collection.

The use of investigators trained in human factors assured that vital human factors and other, seemingly peripheral, issues were addressed and relevant information was collected. Most MSHA, union, and mine safety investigators are not trained in human factors or the systems approach to accident investigation. The approach used by the researchers was clearly different from that used by union, government, and industry investigators. In fact, it was not uncommon for safety directors at the participating mines to comment that we asked questions they never thought to ask and explored areas they never considered in their investigations.

The fact that our investigators were independent of industry, union, or MSHA created an atmosphere of trust between management, workers, and the researchers. This trust provided an opportunity to collect complete, honest recollections of accident events and surrounding circumstances. The value of this was recognized by the participating mines, as well as by several MSHA and UMWA officials.

Focusing on causality rather than culpability further facilitated the data collection. Once it was made clear to the interviewees that "fixing blame" was not the purpose of the investigation, workers were more open in their discussion of an incident than would have been the case if blame was being assigned. Both industry and government people contacted for this project viewed our approach as an unbiased investigation of the causes of mining accidents and believed that the results would be of value to the industry.

The semi-structured interview technique contributed to both the validity and completeness of the data collection effort. Miners perceive each accident to be a unique situation composed of a combination of freak events. They often resent being asked standardized questions that do not seem to recognize the unique aspects of their case. The approach used, however, allowed the investigator to bring in information about the operation of the mine or working section gleaned from past interviews that could not have been captured in a structured question-by-question interview approach. Furthermore, individual workers tend to be highly variable in style and manner of communication, and the semi-structured format allowed the investigator latitude in tailoring the interview to the worker's style and manner. The result was that rapport between the miners and researchers was much higher than would have been expected in such a potentially stressful situation.

Limitations of the Methodology

Due to the difficulty in obtaining cooperation from a large number of mining companies, the sample mines are not truly representative of the industry. Although the sample includes all the major types of mining, including room-and-pillar, pillar retreat, stope mining, high-seam, low-seam, continuous, and longwall, the relative proportion of each does not match the industry proportions. A recognized bias is that the sample is composed of large- and medium-size mines. Small mines were not used due to the high cost associated with collecting data and the small number of accidents that occur at any given mine.

With only five companies included in the sample, there was a limited range of management factors represented. It was recognized at the outset of this project that it would be difficult to secure the cooperation of companies that had poor safety attitudes. The resulting sample, therefore, represents companies that have a positive attitude toward safety and maintain active safety departments.

The validity of this study was very much dependent on the quality and completeness of the data collected by the accident investigator. Data collection was, in some cases, hampered by the delays between the occurrence of the accident and the investigation. In many instances, this could be several weeks. In some cases, the involved parties were not available when the investigator made the site visit. This added additional time delays to the process. In almost all cases, however, the nature of the accident was simple enough that those involved could reconstruct the events and the mine's investigation (carried out very soon after the incident) was used to collaborate the information collected.

Some information that would have been helpful, could not be collected. In many instances, miners could not, or would not, say what they were thinking when they acted as they did. Many situations were so commonplace that the workers were virtually on "auto-pilot" and could not remember specifics. In some cases, the events occurred so rapidly that they were unobservable. It is thus likely that the involvement of some contributing factors would be underestimated. For example, the influence of social factors or individual characteristics, such as personality or family-related stress, might be underestimated because of the difficulty of obtaining such data.

METHODOLOGY: ATTRIBUTION OF CONTRIBUTING FACTORS

Overview

One purpose of this project was to develop a methodology for assessing the causes of underground mining accidents with special emphasis on the role of human error. By its very nature, assessing the causes or contributing factors to an accident is a judgmental process. The approach taken here, therefore, was to use experts to assess, in a systematic and reliable manner, the relative contribution of various factors to the occurrence of accidents.

Seven experts, knowledgeable in the areas of mining, accident investigation, human factors, and human error were used to assess the relative contribution of various contributing factors inherent in accident cases. The factors rated by the experts were the following: management, physical environment, equipment, social climate, work task, worker characteristics, perceptual-cognitive-motor error, and "other." Worker characteristics and perceptual-cognitive-motor error were assessed separately for the injured employee (IE) and any involved co-worker (CW).

Each factor was defined, and the raters were trained on how to apply the definitions to actual cases. Practice sessions were held to establish an acceptable baseline level of interrater reliability. During Phase I of this project, 92 accident cases were rated and analyzed using this system. Based on the experiences gained, the definitions were refined and additional rating conventions established. An additional training session was held to familiarize the raters with the refined factor definitions and conventions. The raters then rated the accident cases as they were collected. In addition, interspersed with the new cases, the original 92 cases from Phase I were rerated using the new factor definitions. Unfortunately, one of the seven raters withdrew from the project and did not rate all of the cases.

The interrater reliability was computed on each case for each possible pair of raters. Unreliable raters were dropped on a case-by-case basis. The average interrater reliability was then computed for the remaining raters. For each case, ratings from reliable raters were averaged to yield estimates of the relative contribution of the various factors. The reliability of the average ratings was computed using a standard estimation formula. In cases where the reliability of the averaged ratings was below 0.70, the case was rerated by the experts.

Raters

Seven (7) experts were selected with expertise in one or more of the following areas: human factors, mining, accident investigation, and human error. The rating team included a mining engineer and a mine safety director. The members of the team were selected, in part, because of their appreciation for the systems approach to accident investigation and their understanding of the contribution of factors other than operator error to accidents.

The rating team consisted of the following seven people: Mark S. Sanders, Ph.D.; Brian E. Shaw; H. Harvey Cohen, Ph.D.; David Meister, Ph.D.; Robert H. King, Ph.D.; Susan Faerber; and Frank Linkous. Unfortunately, Dr. Meister had to withdraw from the rating team because of other professional commitments. Before withdrawing, Dr. Meister rated 141 of the 338 accidents investigated. Each of the other six members of the team rated all 338 cases. Table 14 summarizes the primary and secondary areas of expertise represented by these individuals. Following table 14 are short biographical sketches of each person.

TABLE 14. - Areas of expertise of the rating team members

Team member	Human factors	Human error	Safety	Accident investigation	Mining
Sanders	P	S	P	S	S
Shaw	P	S	S	P	S
Cohen	P	S	P	P	
Meister	P	P	S	S	
Faerber			S	P	
King			S	S	P
Linkous			P	S	P

P = Primary area of expertise
S = Secondary area of expertise

Mark S. Sanders, Ph.D. Dr. Sanders served as project monitor and co-principal investigator. He has been involved in mining safety and health research for the past 16 years. Dr. Sanders is a recognized expert in human factors and is the senior author of a major textbook on human factors (54), and a textbook on human factors in mining (55). Dr. Sanders has conducted several accident investigations and safety analyses in mining and other industries.

Brian E. Shaw. Mr. Shaw was co-principal investigator and the principal accident investigator for the project. Over the past 9 years, he has participated in several underground mining projects and has performed task analyses of virtually all underground mining tasks. He has developed training materials related to a wide variety of underground mining jobs and is an MSHA-certified instructor (IS&IU). Mr. Shaw is a trained human factors specialist and has participated in several safety- and human error-related human factors projects.

H. Harvey Cohen, Ph.D. Dr. Cohen is a human factors and safety expert who has specialized in the field of occupational safety and health for the past 17 years. This work has involved developing methods for conducting accident investigations and computer-based analysis of accident data in many industry studies, including underground mining.

David Meister, Ph.D. Dr. Meister is a recognized expert on human error and human reliability. He has published several books on human factors, human reliability, and human factors data collection methods.

Robert H. King, Ph.D. Dr. King is Associate Professor at the Colorado School of Mines where he has maintained an active mining research program. He teaches courses on all aspects of mine engineering and is a MSHA-certified instructor. Before entering academia, Dr. King was a mine foreman at a large western coal mine.

Susan Faerber. Ms. Faerber served as the alternate accident investigator for this project. During the past 8 years, she has assisted in collecting and processing accident data in several industry-specific studies, including the development of novel methods for analyzing narrative descriptions of accident scenarios generated by in-depth accident investigations.

Frank Linkous. Mr. Linkous is a mining and mine safety specialist with both industrial and government experience. For the past 8 years, he has been Manager of Health and Safety for a major underground coal mining company. Prior to working for industry, Mr. Linkous was acting Division Chief for a state Mining Regulatory Agency.

Definition of the Rating Factors

The working hypothesis of this study was that not all accidents are caused by human error, and that when human error is a factor, it is rarely the only factor involved. Most accidents are the result of several interacting forces which significantly increase the probability of an accident. The major classes of factors assessed in this project came from a review of the accident causation literature and were formulated into the model shown in figure 7. Ten (10) factors were assessed by the rating team. The factors were:

1. Management
2. Physical Environment
3. Equipment
4. Work Task
5. Social Climate
6. Worker Characteristics - Injured Employee
7. Worker Characteristics - Co-Worker
8. Perceptual-Cognitive-Motor Error - Injured Employee
9. Perceptual-Cognitive-Motor Error - Co-Worker
10. Other/Miscellaneous (Not Elsewhere Classified)

Early in the project, an initial small sample of accidents was rated by the rating team. The raters apportioned 100 points among the factors according to the perceived degree of contribution to the accident. The team met to discuss the ratings and the cases. Refinements were made to the categories, and conventions and guidelines were established for attributing the relative contribution of each factor. The system was used to evaluate 92 cases during Phase I of the project. The results of the ratings were analyzed and additional refinements were made to the definitions. Again, the team met and rated a small sample of cases using the new definitions. Additional conventions and guidelines were established. This procedure insured that the rating team understood the factors and procedures. Ultimately, the original 92 cases were rerated using the revised definitions and guidelines.

The following are the final definitions, guidelines, and conventions for each factor:

Management. Refers to policies, procedures, and practices by all areas and levels of management on a mine-wide basis. Does not include specific actions by a member of management just because he or she is management (salaried supervisor). Specifically, this factor included:

- Unsafe or inadequate SOP
- Propagation, acceptance, or development of unsafe SOP
- Lack of enforcement of SOP
- Inadequate emphasis on safety or safety inspections
- Failure to identify obvious safety problems
- Failure to adequately rectify known safety problems
- Inadequate management support for repair or preventative maintenance (including materials, manpower, time)
- Overemphasis on production at expense of safety or excessive production pressures
- Lack of, or inadequate, training (formal and OJT)
- Inappropriate job placement policies or procedures
- Lack of, or inadequate, supervision where it is clearly called for
- Inadequate or improper manpower or equipment supplied (given that reasonable alternatives were available and practical).

Raters were given the following guidance when rating this factor:

1. Minimize witch-hunts and scapegoating by considering the "reasonableness" of the situation. When implicating management as a cause, caution must be exercised to prevent "unjust" ratings in this factor. One must consider the degree to which reasonable alternatives exist, both within current technology and within the mine (as we understand it to operate). For example, if an accident occurs because a worker is in a pillar retreat area performing a necessary task, it would be unfair to implicate management because the accident wouldn't have occurred if a robot vehicle had been used.

   Similarly, one must consider the degree to which reasonable warnings, indicators, or predictors exist in management-implicated cases. This will not necessarily eliminate management involvement, but may somewhat temper the degree of involvement. "Freak accidents" seem to require this type of consideration. Some freak accidents may really be chance or "acts of God," but we must also consider the degree to which they were, or may have been, predictable. Some accidents may also involve management because management failed to implement reasonable and adequate monitoring plans to predict and prevent the accident.

   In an extension of this thought, given adequate ability to predict, we must consider the timeframe in which management could act. That is, when implicating management for failure to act on a situation, consider whether a reasonable amount of time existed between the warnings/predictors of a problem situation and the accident. If a countermeasure can be implemented quickly and completely, but wasn't, management should be implicated because they had warnings as well as reasonable time to fix the problem before the accident happened. For a situation where long-term countermeasures have been started (but an accident occurred before they could be considered reasonably effective), it seems as though management's involvement may be less.

2. When situations are under direct control of management, also consider the perceptual/cognitive potential of the decision-making person(s). For instance, management factor could be implicated where production pressures (at the expense of safety) are an ongoing fact of life, but the perceptual-cognitive-motor factor should also be considered when the production pressure differs from the norm. A production "contest" is a situation where the controlling managers impose a deviant production pressure on a global level; hence, management should be implicated. For production pressures on a localized level, such as when a shiftboss imposes an excessive production or speed requirement, the rater should consider both management and co-worker perceptual-cognitive-motor error or co-worker characteristics.

3. SOP is not always a management problem! The question of the existence of a formal SOP has been raised in many of the cases. In situations where it is reasonable that a task be documented by a formal (written) SOP, but one does not exist or is not known or understood by the workers, management would be justly implicated. When an SOP exists, but is not followed, the consideration must be split between the management factor (training or inadequate SOP, or failure to enforce SOP) and perceptual-cognitive-motor error on the part of the SOP violator. For simple tasks, it may not be reasonable to expect a formal SOP to exist. An example would be the worker who is getting on or off a machine and slips because of mud on his or her boots. The act of slipping was the accident event, but it is unreasonable to expect a formal SOP or extensive training in how to wipe one's feet before mounting equipment. This example should probably consider the work task, physical environment, and perceptual-cognitive-motor error factors rather than management.

Physical Environment. Relates to mine environmental conditions which impact the accident over and above the environmental conditions resulting from standard or required mine engineering/industrial hygiene practice. Does not include equipment workstations. Specifically, this factor included:

- Heat
- Dust, fumes, gasses
- Noise
- Physical dimensions of mine/worksite
- Cramped environmental workspace
- Illumination.

Raters were given the following guidance when rating this factor:

1. Where there is a specific failure to apply local area environmental controls, consider why the failure occurred; e.g., management or perceptual-cognitive-motor error.

2. For "low illumination" situations (especially caplamp only), the illumination requirements of the task must be considered before physical environment is implicated. Caplamp illumination is a mining baseline condition and cannot be directly implicated as inadequate lighting without considering the actual need for more light and the degree to which it would be reasonable to

expect/provide additional lighting. Most of the time, this will require assumptions based on the task type, location, and specific situation, because miners tend to accept caplamp as adequate in all situations.

3. Incidents caused by insufficient environmental space must be evaluated in terms of both the mine design and engineering characteristics, as well as the circumstances surrounding the task. For example, in a low-seam mine, all manual materials handling tasks will be conducted with "poor" posture as compared to high-seam or surface operations. The poor posture is directly caused by the seam height, and there is no other way it could be done. Hence, physical environment should be implicated.

   When the physical environment limitation is correctable, meaning that the worker could have done it in a different location or in a different manner, one must look to the next level of causation by asking, "Why was this physical limitation in place?" Perceptual-cognitive-motor error may be part of the explanation if the worker had alternatives, but misjudged the risks involved in the situation or accepted a known high-risk situation. Work task may be involved if the task <u>had to</u> be done in a restricted workspace or if there were no other reasonable ways of doing the task.

4. Normal background noise should be included as physical environment. A certain amount of machine noise is expected from heavy diesel equipment, percussive drills, and conveyor belts, even when they are muffled or running normally. Often the normal level will be quite high (90-96 dbA) and complicated by the worker's requirement to wear hearing protection. In these conditions, it may not be unusual for a worker to be unable to hear the roof/back "talking" just before a piece falls and hits him or her. Perceptual-cognitive-motor error, in this example, shouldn't be implicated because the worker didn't have the opportunity to hear the noise, so couldn't conceivably have misperceived or failed to perceive the rock "talk." We should be asking why the worker didn't hear it; hence, physical environment -- specifically noise -- might be the causal agent.

5. Dust, fumes, and gasses are controllable items via required mine engineering. A test of reasonableness is in order when these items are involved. For example, high dust levels at an ore dump probably should be considered as a controllable situation through water spray or ventilation. An accident involving dust probably was predictable and the dust could have been controlled. In such a case, management would be involved for failure to identify or correct a known hazard.

   A dust-in-the-eye situation occurring from dust blown from an underground ventilation fan (assuming it was operating normally, was correctly hung and vented, and the worker was just strolling by) probably should be considered a physical environment causation.

6. Rockfalls (including falls of ground from the roof, back, or ribs) cannot be attributed to the physical environment just because the rock which fell is part of the physical environment. Had the worker not been there, the rock would have fallen without incident. So we must ask why the worker was there, had the proper safety precautions been taken, or did the task absolutely require the worker to be near unsafe ground. Depending on the evidence and situation,

perceptual-cognitive-motor error or work task should be implicated accordingly.

Equipment. Refers to machinery and/or tools involved in the accident, safety devices (including canopy), and personal protective equipment. Also includes malfunctioning equipment that was directly involved in the accident. Specifically, this factor included:

- Sharp edges, exposed wiring, hot surfaces
- Control-display layout
- Ability of equipment to perform intended function
- Design for maintainability
- Inadequate clearances
- Unguarded moving parts
- Visibility.

Raters were given the following guidance when rating this factor:

1. Do not include this factor just because a maintenance task was being performed on a malfunctioning piece of equipment, unless the design of the equipment itself contributed to the actual accident.

2. Visibility problems can pose a rating problem when asking why the problem exists. In general, visibility is best treated descriptively in this factor category rather than trying to assume the underlying rationale behind the situation. This is especially true when visibility-enhancing alternatives, either accessory devices or alternative equipment designs, were possible.

   Assuming that a visibility-enhancing device, like a prism (for example), originally existed on the equipment but was modified and made ineffective, improperly maintained, or was removed, then we could consider the management or perceptual-cognitive-motor error contributions to causality. If such additional devices could have been installed, but weren't (either due to exclusion for the original equipment design or not purchased as options/after-market enhancements), the attribution of causality becomes more complex. When clear-cut evidence is provided that indicates specific and undeniable management involvement (i.e., failure to identify or rectify known safety problem), the management factor should be implicated. Otherwise, the assumptions of management involvement should be withheld and the attribution of causality (albeit descriptive) should be placed on equipment design.

3. Implication of equipment should be carried only to the point where the equipment could have reasonably been redesigned to reduce the accident probability. In other words, state-of-the-art design alternatives may exist which would remedy the situation, but would be unreasonable within the given context of underground mining equipment. Although no specific guidelines can be provided, we must also maintain a general concern for the working life and realistic limits of upgrading/replacing the mining equipment.

4. Within the confines of this study, we cannot investigate the potential sources of failure within the O.E.M. design process. Hence, O.E.M. design must be treated somewhat descriptively within the equipment design factor rather than

seeking evidence of assuming potential causal sources of the designers and manufacturers. Similarly, where enhancements or modifications were made by the mine itself, and the design is faulty, we are usually unable to investigate the logic and intent of the designer.

Work Task. Refers to the procedures and design of the work task itself, given that the work task was designed and/or performed in a reasonably safe manner. Especially important are concerns with aspects of the work task which can impinge on even the safest and most well-designed task. Specifically, this factor includes:

- Task-specific communications/coordination between workers
- Required repetitive or heavy physical labor
- Pacing induced by task itself
- Task that requires worker exposure to hazardous situations.

Raters were given the following guidance when rating this factor:

1. When an unsafe/inadequate SOP was being followed (or one didn't exist), consider management.

2. When a procedure was used which varied from the SOP or some reasonably well-known safe procedure, consider the sources of the deviation, e.g., perceptual-cognitive-motor error and/or management.

3. For speed stress, when not machine-regulated/induced, consider possible management involvement. Equipment-controlled pacing problems should include consideration of equipment design, as well as the work task.

4. Certain tasks can be considered to inherently require exposure to hazardous situations. Examples include manually barring down loose rock and sampling or inspecting in caving areas. Sources of hazards may include working in proximity to potential physical hazards, or other task-imposed hazards. For example, the previously mentioned tasks are required to be performed extremely close to unsafe ground, and there may not be a reasonable alternative. These tasks also may create the unsafe condition -- such as when the worker must watch his/her feet, the muckpile, the back or ribs, and the scaling bar, all at the same time. If a worker slips on a loose piece of rock because he or she was concentrating on a perilously loose rock in the roof, it was the nature of the task which was more causal than the perceptual-cognitive-motor error of not seeing the rock which was stepped on. When these tasks are performed correctly and cautiously, exposure to hazards may be considered a contributing cause and work task would be implicated.

Social Climate. Refers to the general social and work group climate. Specifically, this factor includes:

- Group norms of risk-taking
- Horseplay
- Cooperation vs. competitiveness
- General disregard for safety among the work group
- Labor relations
- Seasonal absenteeism
- Acts of aggression.

Raters were given the following guidance when rating this factor:

1. A distinction must be made between horseplay (in general) and specific acts of horseplay. Horseplay, in the general sense of group acceptance or support, should be considered a social climate consideration. The specific acts of horseplay may overlap with perceptual-cognitive-motor error in the sense that the worker(s) involved may have failed to perceive the hazards or consciously accepted high risks.

2. General disregard for safety or acceptance of risk-taking must consider the group norms specific to the accident. Any perceptions that miners are greater risk-takers than the rest of society should not be considered. (Research indicates that they are no more risk-taking than any other industrial population.)

Worker Characteristic (Injured Employee). Refers to limitation of the worker which directly contributed to the accident. Includes agents/conditions which temporarily or permanently alter these characteristics. Specifically, this factor included:

- Anthropometric/sensory strength and physiological characteristics
- Effects of substance abuse or medication usage
- Sleep loss; family stress
- Intelligence, experience, or level of training
- Individual's attitude, motivation, and mental health
- Malingering/repeat offender.

Raters were given the following guidance when rating this factor:

1. Experience, job placement, and training may overlap with management insofar as an individual may have been placed in the wrong job, was improperly supervised given his/her experience and training, or was not given proper training.

2. Intelligence may overlap with the perceptual-cognitive-motor error if the worker was capable of knowing he or she was doing something dumb!

3. In back injury cases, a weak back should be rated as causal only if direct evidence exists. When clearly evident from prior accident history, a weak back may be implied and rated as causal if circumstances dictate. When no direct or blatant circumstantial evidence exists, a weak back should not be implied just because the case involved a back injury.

Worker Characteristic (Co-Worker). See Worker Characteristic (Injured Employee).

Perceptual-Cognitive-Motor Error (Injured Employee). Refers to faulty human information processing of perceptual stimuli, and the processing of cognitive information regarding the degree of risk or hazard. Specifically, this factor included:

- Failure to perceive a perceivable hazard
- Misinterpretation of risks involved
- Accepting a known risk of high level
- Forgetting or neglecting to do something worker knew should have been done
- General inattention or carelessness.

Raters were given the following guidance when rating this factor:

1. To implicate perceptual-cognitive-motor error, raters must consider the worker's level of experience and training. For example, the worker had to understand the risks before he or she could accept an unreasonably high risk, and/or had to be capable of perceiving a hazard before he or she could misperceive or fail to perceive the hazard. Furthermore, consideration must include the degree to which it is reasonable to expect a person to perceive the hazard and assess the risk.

Perceptual-Cognitive-Motor Error (Co-Worker). See Perceptual-Cognitive-Motor Error (Injured Employee).

Other/Miscellaneous. Refers to factors not covered by the above nine factors. Specifically, this factor might include the element of chance; a freak occurrence that could not reasonably have been foreseen; or a freak series of events that happened to come together at a specific time that individually, or at some other time, would have been considered within normal bounds. Raters were instructed to exhaust all other possible explanations before implicating this factor.

With each case description, a rating sheet was given to the rater. The rating sheet provided space to allocate 100 points across the 10 factors defined above. For each factor that was allocated points, the rater provided a short justification. In addition, for each case, the raters suggested countermeasures that they felt would reduce the likelihood of the accident or the severity of the injury.

Combining the Ratings for Each Case

For each accident case, the matrix of interrater correlations was computed across the 10 factors. The intercorrelation between any two raters indicated the extent to which they rated a case similarly. From this master intercorrelation matrix, the average intercorrelation for each rater with all the other raters was computed. This average intercorrelation is a measure of how well one rater agreed with the other raters. The average of these interrater correlations is an estimate of the reliability of a single rater. In our study, however, the ratings from the individual raters were averaged to yield average factor ratings for each case.

It is a well established fact that averages of individual ratings are more reliable than the individual ratings themselves. That is, we would expect the average rating from a group of raters to vary less over time than would the individual ratings themselves. There is a formula available for estimating the reliability of an average rating from a number of raters, knowing the average reliability of a single rater. This formula is the Spearman-Brown Prophecy Formula (18) and is given below.

$$r_{xx} = \frac{Xr}{1 + (X-1)r}$$

where: r_{xx} = reliability of the average

X = number of raters being averaged together

r = average intercorrelation between the raters being averaged

The effect of averaging several raters can dramatically increase the reliability of the resulting ratings as shown in figure 8. For example, if the average interrater correlations was 0.50, and four raters' ratings were averaged, the reliability of those average ratings would be 0.80. There are no hard and fast rules regarding what is an acceptable level of reliability for ratings; however, it is common to expect reliabilities to be above 0.70 (this indicates that 70% of the rating variance is systematic and 30% is error). The decision was made, therefore, to accept Spearman-Brown reliabilities above 0.70 as acceptable. From figure 8, it can be seen that a Spearman-Brown reliability of 0.70 corresponds to an average interrater correlation of .25 for 7 raters, .28 for 6 raters, .32 for 5 raters, and .37 for 4 raters.

If the Spearman-Brown reliability was above 0.90 with all raters included, no attempt was made to increase the reliability by removing the rater with the lowest average intercorrelation with the other raters. If the reliability was between 0.70 and 0.89, the rater with the lowest average intercorrelation was removed. The average intercorrelation among the remaining raters was determined, and the Spearman-Brown reliability recalculated. If the reliability did not increase by at least 0.05, the rater was not dropped and the average ratings for each factor were computed using all the raters. If the Spearman-Brown reliability was below 0.70, raters were removed, based on their average intercorrelation with the remaining raters, until the Spearman-Brown exceeded 0.70. In all but two cases, only one or two raters had to be removed to achieve the 0.70 goal. In two cases, three raters had to be excluded. If a Spearman-Brown reliability of 0.70 could not be achieved even when three raters were excluded, the case was set aside and rerated by the entire rating team.

Rerating Low Reliability Cases

Out of the 338 cases, only 11 required rerating. The cases were sent back to the raters with complete information on how the other team members rated the cases. In addition, the justifications were summarized and any ambiguities were addressed. This procedure corresponds to the Delphi technique for obtaining group judgments. The procedure was very effective. A Spearman-Brown reliability above 0.70 was achieved in all cases after rerating.

Strengths and Limitations of the Methodology

The strengths of the attribution and rating methodology stem from the use of a multi-disciplinary team of raters and the use of a rating scale based on a comprehensive model of accident causation. Flexible rules and guidelines for rating helped maintain the diversity of opinion rather than hammering everyone's opinions into some preconceived mold. The data analysis and rerating procedures insured that the final average ratings for each case would have acceptable reliability. High reliability is a prerequisite for validity, but is not the same thing as validity. In the absence of any other independent assessment of the attribute being rated, however, high reliability is often taken as evidence of the validity of the ratings. In essence, if several independent raters all agree in their judgment, then it is likely that what they are rating corresponds to the definition of the rating.

The limitations of the methodology are in some cases the consequence of its strength. To insure acceptable reliability, raters were often eliminated from a case, thus their perspectives on the causes of an accident were lost. A review of the average ratings before and after removing unreliable raters, however, showed that including the raters usually resulted in equalizing the ratings across the 10 categories.

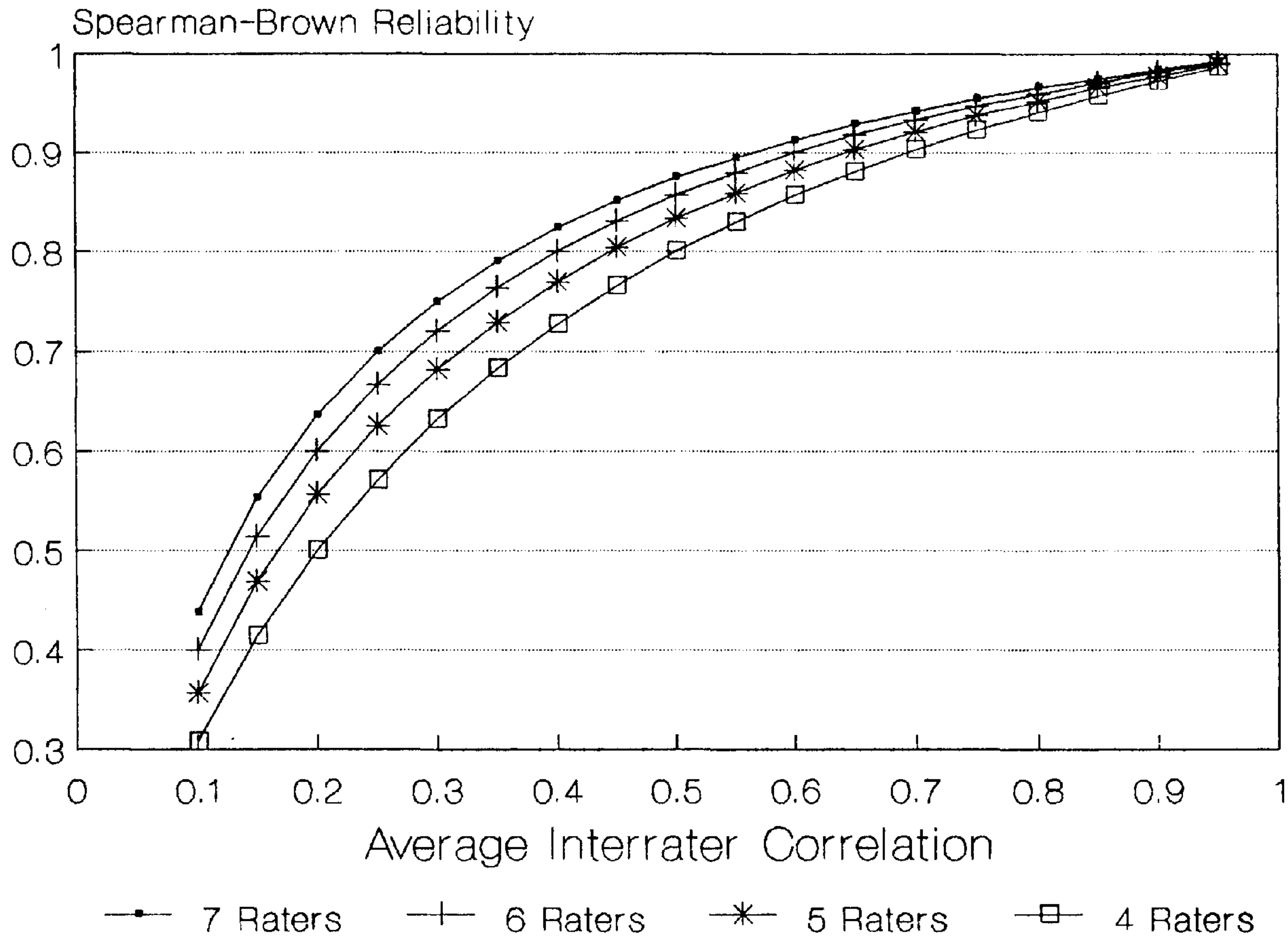

FIGURE 8. - Spearman-Brown reliability as a function of the average interrater correlation and the number of raters combined.

Removing the raters seemed to sharpen differences between rating categories which would be desirable for purposes of statistical analysis (e.g., cluster analysis, factor analysis, and analysis of variance).

Flexible decision rules maintained diversity of opinion, but carried with it the limitation of ambiguity and a lowering of reliability. The averaging process, however, insured that adequate reliability was maintained.

A major limitation of this methodology was that the ratings could only be as good as the accident investigation and the data summarized by the investigator. In some cases, the information was incomplete because it was not available; in other cases, information from sources was contradictory or ambiguous. Sometimes, the information was inconclusive and, hence, the raters had to make assumptions about what might have happened. In addition, any bias in the way an accident case report was written probably influenced the ratings. Despite the incompleteness, contradictions, and ambiguity of some case reports, the raters were, on the whole, very reliable.

All in all, the methodology was empirically sound and reliable, and the data generated should yield valid information regarding accident causation.

RESULTS: ACCIDENT DATA BASE DESCRIPTION

Overview

This section presents the basic descriptive information about the 338 cases investigated during this project. The results are organized around the following basic questions: Who was injured, what was the injury, when did it occur, where did it occur, and how did it occur? The purpose was to provide a description of the accident data base and to provide some perspective for the next section of this report that deals with the causal attribution data.

One cannot consider that this project's data base of accidents is truly representative of the industry. It does represent the full range and scope of accidents occurring underground; but, undoubtedly, the proportions of the various types of accidents are not the same as for the entire industry. No attempt was made to normalize the results based on MSHA accident statistics because the project included NDL injuries, and the MSHA NDL injury frequencies are somewhat suspect and probably under-represent the true values in the population. In addition, the project cases were collected over a 29-month period, and it would be very difficult to normalize over that period of time because the accident picture was changing.

Who Was Injured?

Sex

Of the 338 cases, 98% of the injured employees were males. Only five cases involved a female worker as the injured party.

Age

The median age of the injured employees was 34 years, with a range from 21 to 64 years of age. The following are the percentages of cases categorized by the age group of the injured employees:

Age Group	% of Cases
<30 yrs	24.0
30-39	49.0
40-49	18.0
50-59	9.0
60+	<1.0

Although workers were coming and going during the study period, the percentage of accidents is consistent with expectations based on the approximate age distribution of the work force at the participating mines.

Job Classification

Table 15 presents the major job classifications of the injured employees. A total of 33 different job classifications are represented in the data base, but table 15 only shows the top 10 classifications which accounted for about 75% of the cases. Fifty percent (50%) of the injuries occurred to equipment operators (roofbolter, continuous miner, shuttlecar), laborers, mechanical repairmen, and shiftbosses/foremen.

TABLE 15. - Classifications of injured employees

Job classification	% of cases
Roofbolter operator	16.7
Laborer	11.0
Mechanical repairman	10.4
Continuous miner operator	7.1
Shuttlecar operator	6.3
Shiftboss/foreman	6.3
Faceman	4.2
Stoping mason	4.2
Belt conveyor man	4.2
Scaler	3.9
Other	25.7
Total	100.0

Experience

Figure 9 presents cumulative distributions of (1) experience in the job classification the injured person was working in at the time of the injury; (2) the injured employee's experience at the mine; and (3) the injured employee's total mining experience. The following are the median years of experience and ranges for each type of experience:

Type of Experience	Median	Range
Total Mining	9 yrs	<1 to 36 yrs
At Mine	8	<1 to 36
In Job Classification	3	<1 to 20

During the 29 months of the study, the mining industry underwent a substantial attrition of its labor force. Little new hiring took place, and in some cases, miners were laid off at the mines in our sample. The result of this is that the labor force at the participating mines was comprised of more-experienced workers. The typical high incidence rate among inexperienced workers did not appear, because there were few such workers at the mines. It should be pointed out, however, that 50% of the injuries occurred to workers with 3 or less years of experience in their job classification.

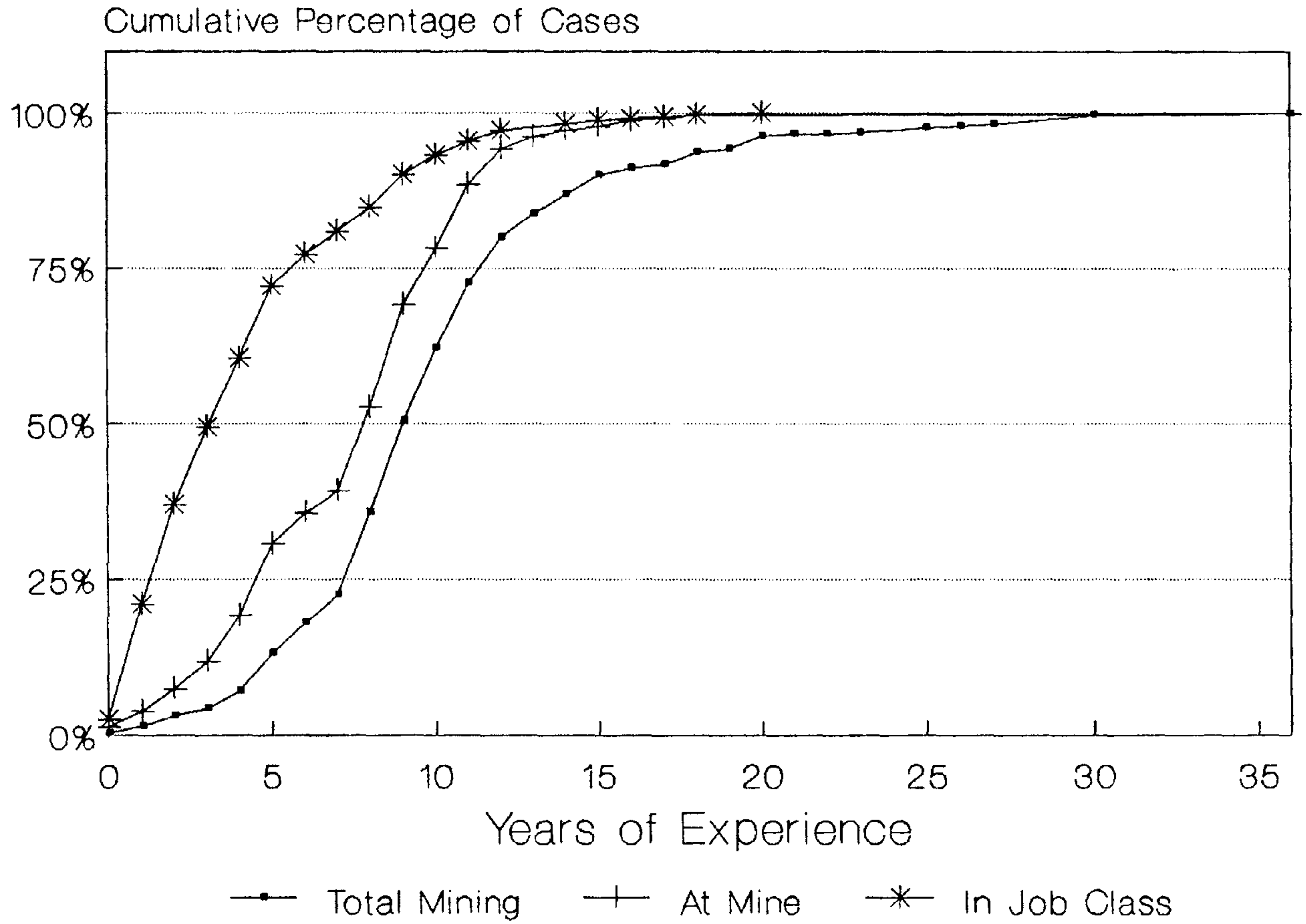

FIGURE 9. - Cumulative distribution of cases based on amount of experience of injured employee.

What Was the Injury?

Nature of the Injury

Table 16 presents the number and percentage of cases involving various types of injuries. As can be seen, a wide variety of injuries were represented, with the majority being sprain/strain, contusion, and laceration injuries.

TABLE 16. - Distribution of cases by nature of injury

Nature of injury	Number of cases	% of total
Sprain/strain	108	32.0
Contusion	70	21.0
Laceration	56	16.0
Fracture	37	11.0
Dust in eye	13	4.0
Avulsion/amputation	9	3.0
Abrasion	7	2.0
Multiple	12	3.0
Other	26	8.0

Part of Body

Table 17 presents the number and percentage of cases involving injuries to various parts of the body. The two parts of the body most often injured were the upper extremities (principally the finger/thumb) and the trunk (principally the back).

Severity of Injury

By and large, the injuries were relatively minor, with only eight injuries resulting in disability. Injuries that required only a doctor's visit, with neither days lost nor restricted days, accounted for 38% of the cases. The majority of the cases (55%), however, involved some days lost as a result of the injury. Injuries resulting only in restricted duty accounted for 5% of the cases. Combining disability and days lost injuries, NFDL injuries accounted for 58% of the cases. MSHA injury statistics for the underground industry over this same period shows that NFDL injuries account for 77% of all non-fatal injuries. As discussed previously, the 77% figure probably represents an under-reporting bias with respect to NDL injuries. By under-reporting NDLs, the proportion of reported injuries classified as NFDL appears larger than it might actually be.

Figure 10 shows the distribution of number of days lost for lost-time injuries. Almost half (46.5%) of the lost-time injuries resulted in one week or less of days lost; however, 12.5% of the lost-time injuries resulted in more than 8 weeks of days lost. The median days lost for lost-time injuries was nine days.

TABLE 17. - Distribution of cases by part of body injured

Part of body	Number of cases	% of total
Head/face	56	16.6
Neck	18	
Eyes	16	
Other	22	
Trunk	90	26.6
Back	61	
Shoulder	13	
Other	16	
Upper extremities	105	31.1
Finger/thumb	55	
Hand/wrist	32	
Arm	10	
Other	8	
Lower extremities	71	21.0
Knee	23	
Leg	15	
Foot	12	
Ankle	12	
Other	9	
Multiple parts	16	4.7

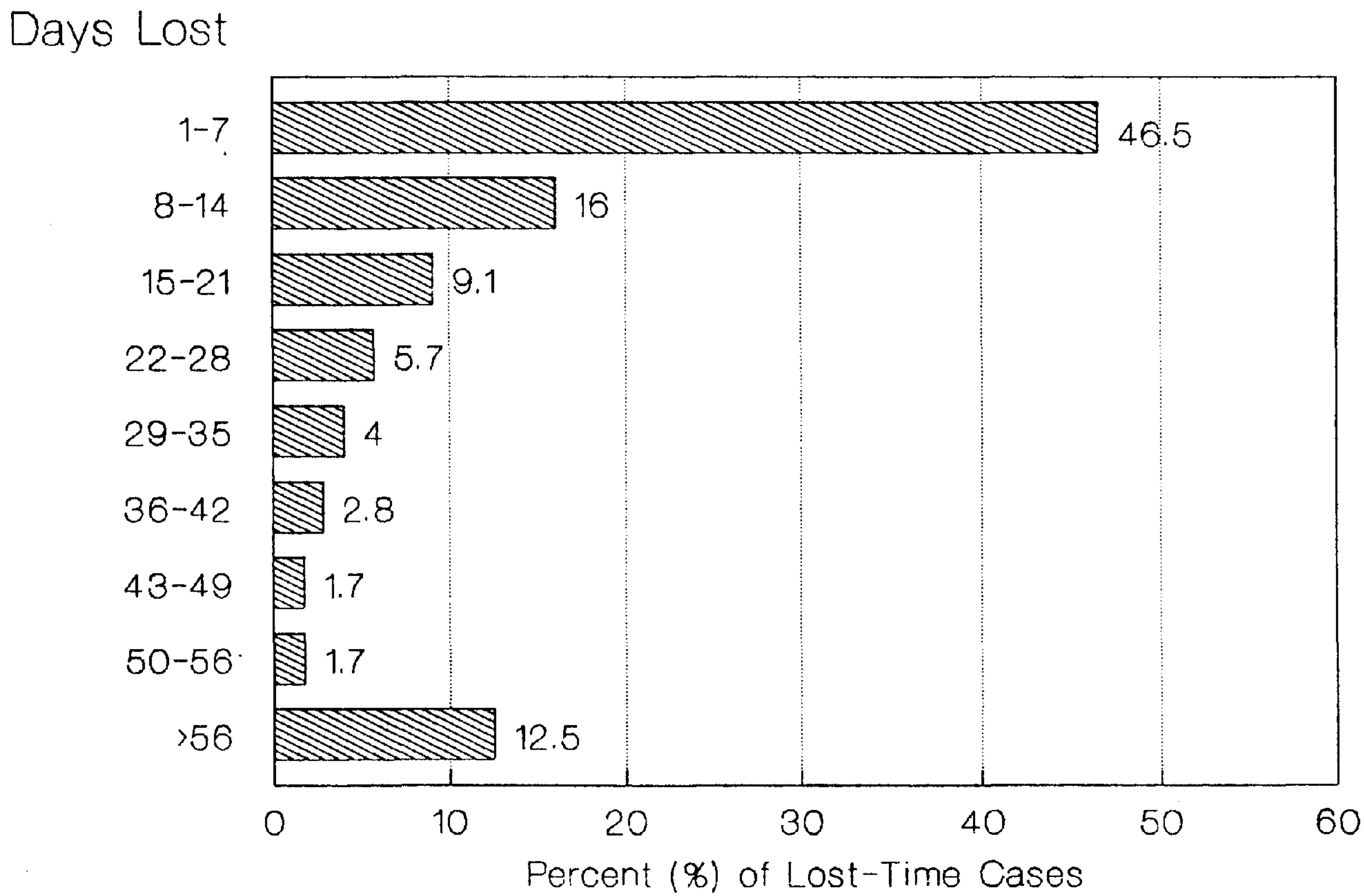

FIGURE 10. - Distribution of number of days lost for days-lost injuries.

When Did the Injury Occur?

Day of the Week

The distribution of injuries by day of the week is shown in figure 11. The number of injuries over the weekdays (Monday through Friday) shows a declining trend from the beginning of the week to the end, with the peak number occurring on Tuesday. The low number of injuries on the weekends is due to the fact that there are fewer workers working then. A Chi Square analysis was performed to test the hypothesis that injuries occurred randomly across the five days (Monday - Friday). The hypothesis could be rejected at the 0.10 level, which is marginally significant. Therefore, there is some evidence that the injuries were not equally probable over the five days, but the evidence is not strong.

Shift

Three shifts were identified: day, swing, and night. The proportion of injuries occurring during these three shifts showed no difference between day (38%) and swing (37%) shifts, but fewer injuries on the night shift (25%). The smaller number of injuries on night shift is due to the smaller number of people working nights at the participating mines.

Time into Shift

Figure 12 shows the distribution of injuries as a function of amount of time into shift that elapsed when an injury occurred. There is a greater probability that an injury will occur during the first 4 hours of the shift (63%) than in the last 4 hours (37%).

Where Did the Injury Occur?

Type of Mine

More than three-quarters (77%) of the injuries occurred in coal mines. This is not as high as would be expected considering that coal mines accounted for 92% of the workers in the sample.

Type of Mining Method Being Used

Table 18 shows the number of injuries occurring by type of mining method. Not surprisingly, room-and-pillar operations accounted for the vast majority (75%) of the injuries, as this was the most prevalent type of mining represented in the participating mines.

Location in the Mine

The working section of the mine (including the face and muckpile) accounted for 43% of the injuries. Haulage and travelways accounted for 37.5% of the injuries. Maintenance areas accounted for only 12.5% of the cases. The remaining 7% of the cases occurred in other areas including inactive sections and construction sites.

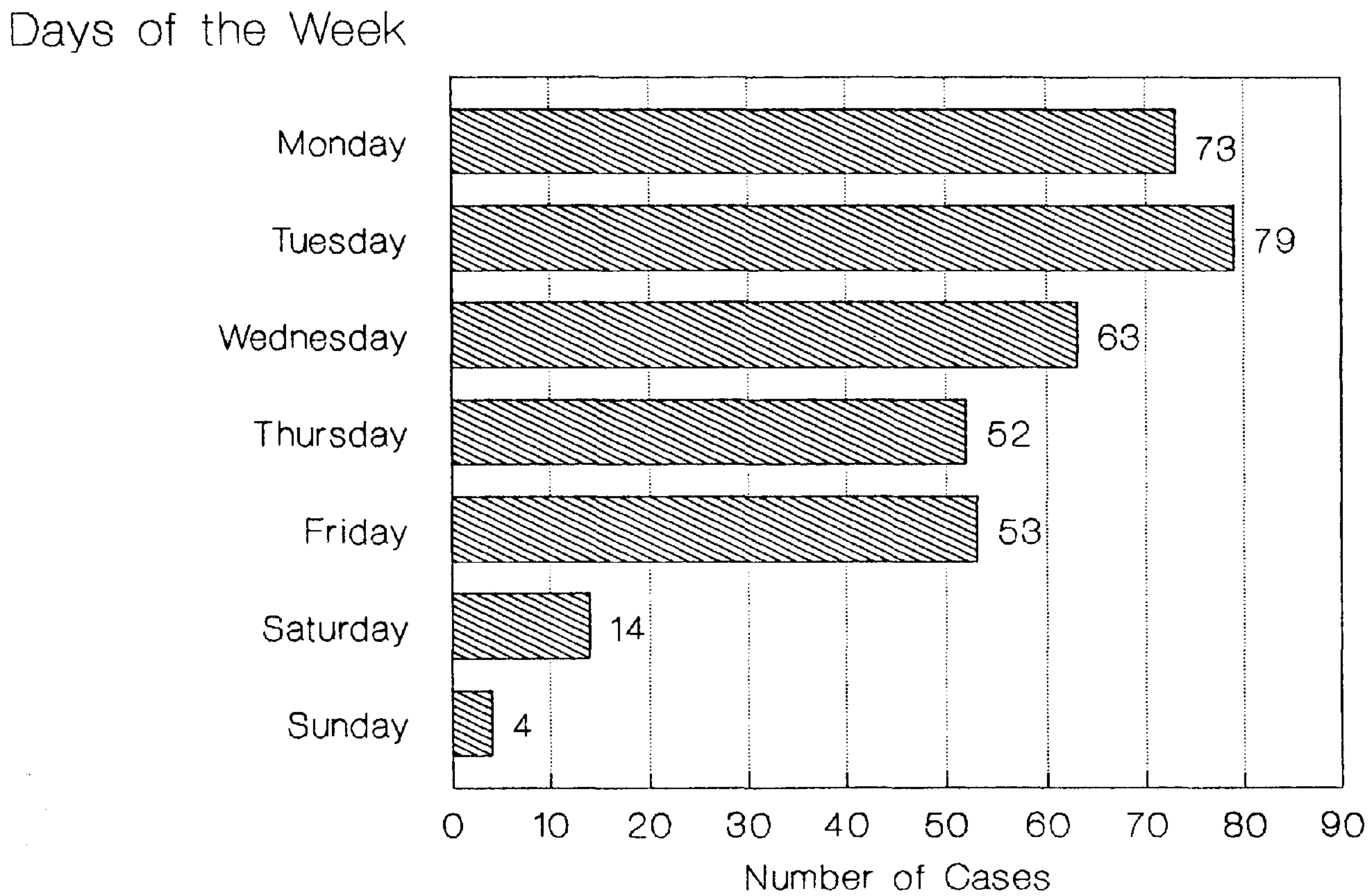

FIGURE 11. - Distribution of cases by day of week the accident occurred.

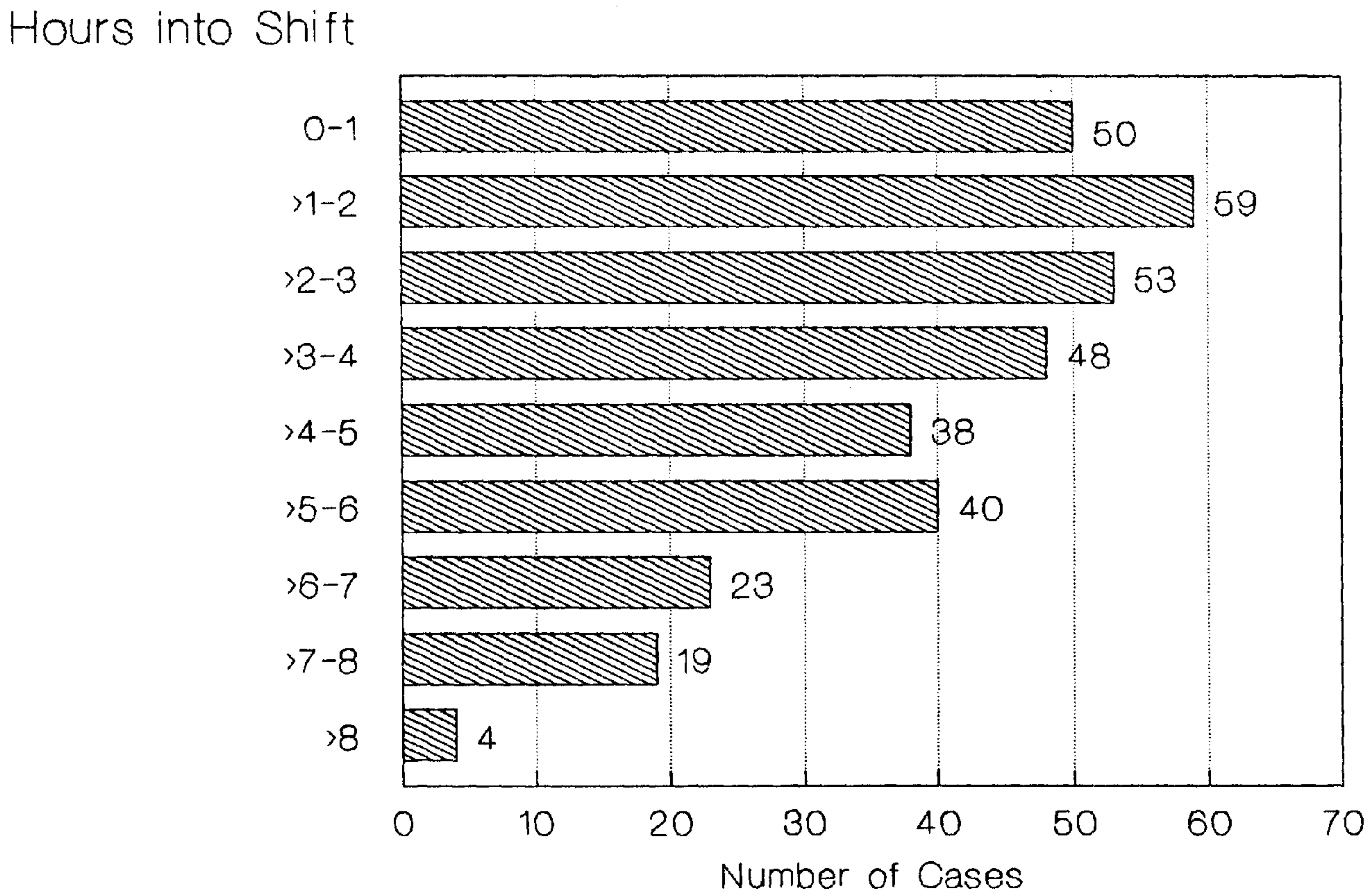

FIGURE 12. - Distribution of cases by hours into shift when accident occurred. (Number of cases = 334; 4 cases had missing data.)

TABLE 18. - Distribution of injuries as a function of mining method

Mining method		Number of injuries
Room-and-pillar		253
High seam	232	
Low seam	21	
Pillar retreat		8
Open stoping		75
Longwall		2

How Did the Injury Occur?

Accident Type

Table 19 shows the number and percentage of cases representing various accident types. The most common type of accident was being struck by an object, with almost half of these being caused by falling objects.

Equipment Involved

Table 20 shows the number of times various equipment was involved in a case. Involvement in a case does not infer contribution to, nor causation of, the accident or injury. The numbers add up to more than 338 because, in some cases, there was more than one piece of equipment involved. As would be expected, the major mining machines were involved in the greatest number of cases, with roof/rockbolters being involved most often. It should be noted that in 25% of the cases, no equipment was involved.

Tools and Supplies Involved

Table 21 shows the number of times various tools and supplies were involved in a case. Involvement in a case does not infer contribution to, nor causation of, the accident or injury. The numbers add up to more than 338 because, in some cases, there was more than one item involved. Electrical conductors were involved in 27 cases. The next highest involved items related to roof support activities: scaling bar (22 cases), rock/roof bolts (18), and drill steels (18). It should be noted that in 38% of the cases, no tools or supplies were involved.

TABLE 19. - Distribution of injury cases by accident type

Accident type		Number of cases	% of total
Struck		156	47.0
by falling object	75		
by stationary object	28		
by flying object	24		
by moving object	18		
by other	11		
Overexertion		59	17.0
Lifting	31		
Pulling	15		
Other	13		
Caught between		45	13.0
Moving & stationary	39		
Other	6		
Miscellaneous		31	9.0
Bodily reaction	24		
Rub/abrade	7		
Falls		30	9.0
Same level	14		
To lower level	14		
Other	2		
Other		17	5.0

TABLE 20. - Number of cases in which various types of equipment were involved

Equipment	Number of cases
Roof/rockbolter	59
Continuous miner	38
LHD/scoop loader	36
Conveyor: Fixed	28
Shuttlecar	19
Locomotive - Rail	15
Utility truck	12
Mine car - Rail	10
Supply trailer	10
Other	49
(No equipment involved	86)

TABLE 21. - Tools and supplies involved in the cases

Tools/supplies	Number of cases
Electrical conductor	27
Scaling bar	22
Rock/roof bolt	18
Drill steel	18
Metal components, NEC	17
Ax/hammer	15
Non-power tools, NEC	13
Brick	10
Steel rail	10
Chain/rope/cable	9
Metal, NEC	9
Containers, NEC	7
Other (30 different items)	73
(No tools or supplies involved	129)

Discussion

From the above results, it is clear that the 338 cases in the data base represent a wide range of accident types and injuries. The people and equipment involved are consistent with expectations. Although the sample is not strictly representative of the population, it does represent a comprehensive sampling of the population of underground non-fatal mining accidents.

Industry conditions during the data collection period were such that few new miners were being hired; and, in some cases, labor forces were being reduced. Production demands, for the industry as a whole, were soft. These factors must be kept in mind when evaluating the data.

RESULTS: CONTRIBUTING FACTORS

Overview

This section presents the analyses of the contributing causal factors for the 338 accident cases in the project's data base. Despite the cautions in previous sections regarding representativeness of the accident cases, the ratings of causality which were made by the rating committee indicate a high degree of consensus. This consensus was statistically assessed during the rating procedure, thereby insuring that all cases in the data base met or exceeded a rather stringent interrater reliability requirement.

The results presented in this section are organized around the various analyses conducted on the contributing factor data:

- o Interrater Reliability
- o Factor Analysis of Contributing Causal Factors
- o Contributing Causal Factors: Degree of Contribution
- o Contributing Causal Factors: Primary and Secondary Factors
- o Contributing Causal Factors: Detailed Discussion of Each Factor
- o Contributing Causal Factors and Worker Experience
- o Contributing Causal Factors and Accident/Injury Characteristics
- o Cluster Analysis of Cases Based on Causal Factor Ratings

Interrater Reliability

Least reliable raters were removed when either their removal would substantially improve the resulting average interrater reliability, or in order to achieve at least a 0.70 Spearman-Brown coefficient. For 40 cases (12%), all 7 raters were included; for 84 cases (25%), 6 raters were included; for 120 cases (36%), 5 raters were included; for 92 cases (27%), 4 raters were included; and in 2 cases (<1%), less than 4 raters were included.

The average intercorrelation between raters across the 338 cases ranged from 0.29 to 1.0, with a mean of 0.67. Figure 13 presents a histogram of these average intercorrelations. As can be seen, over 80% of the cases yielded average intercorrelations above 0.50.

The interrater reliability of the average ratings (estimated by the Spearman-Brown formula) ranged from 0.70 to 1.0, with a mean of 0.90. Figure 14 shows a histogram of the Spearman-Brown coefficients computed. Fifty-eight percent (58%) are above 0.90. The average ratings for each case, therefore, can be considered quite reliable.

Factor Analysis of Contributing Causal Factors

An intercorrelation matrix of the 10 factors (table 22) revealed mostly negative correlations because of the ipsitive nature of the ratings. That is, the sum of the ratings for each case always equaled 100. Thus, as one factor increased in importance, other factors decreased. Nine correlations were statistically significant ($p<.05$). Although significant, these correlations were relatively low ($r = -.20$ to $.30$) and accounted for a small proportion of the variance (.04 to .09). The factors, therefore, are relatively independent of each other.

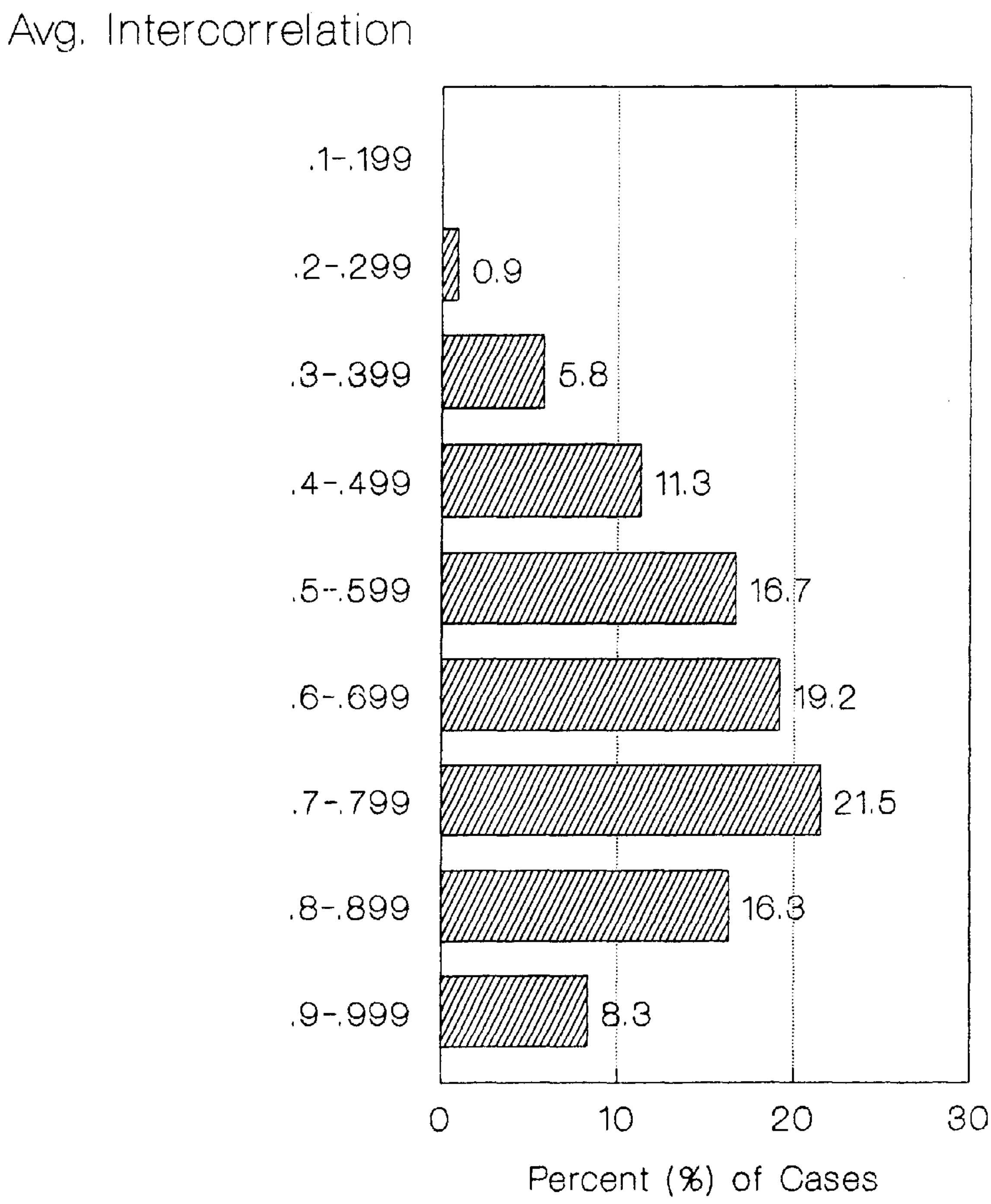

FIGURE 13. - Distribution of average interrater correlations for all 338 rated cases.

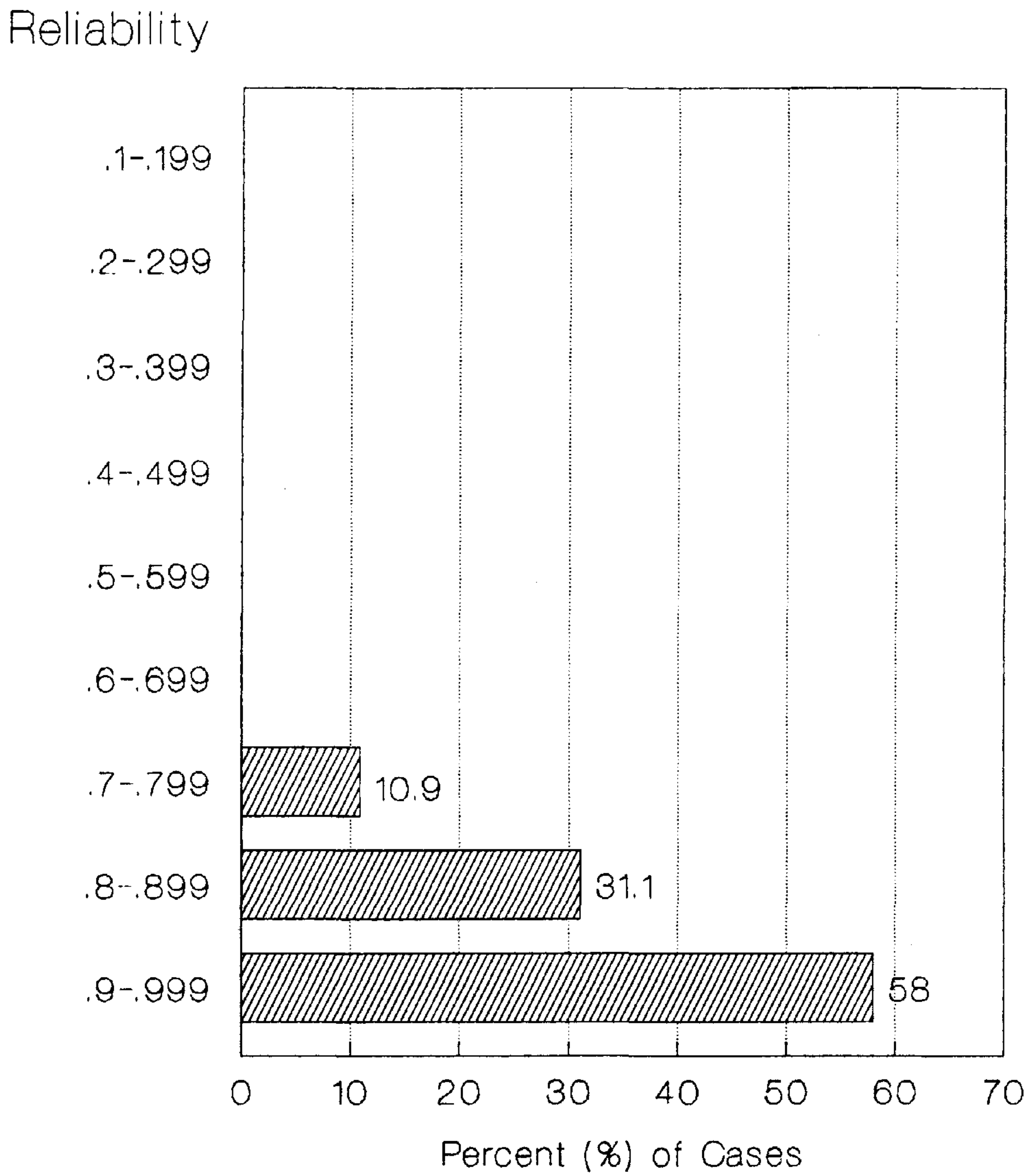

FIGURE 14. - Distrubution of Spearman-Brown reliabilities for all 338 rated cases.

TABLE 22. - Intercorrelation matrix of contributing causal factors

	MGT	PE	EQ	WT	SC	WC/IE	WC/CW	PCM/IE	PCM/CW
PE	-0.045								
EQ	-0.027	-0.140							
WT	-0.287*	0.111	-0.222*						
SC	0.011	-0.111	-0.004	-0.078					
WC/IE	-0.209*	-0.124	-0.147	-0.099	0.073				
WC/CW	-0.041	-0.056	-0.018	-0.055	0.039	0.004			
PCM/IE	-0.246*	-0.218*	-0.257*	-0.271*	-0.071	-0.111	-0.083		
PCM/CW	0.006	-0.137	-0.087	-0.201	0.053	-0.139	0.301*	-0.152	
OTHER	-0.163	-0.031	-0.085	0.001	-0.082	0.085	-0.054	-0.259*	-0.125

*Significant at $p<.05$.

Key:
MGT - Management
PE - Physical Environment
EQ - Equipment
WT - Work Task
SC - Social Climate
WC/IE - Worker Characteristics-Injured Employee
WC/CW - Worker Characteristics-Co-Worker
PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
OTHER - Other/Miscellaneous

The significant intercorrelations indicate that as management increased in causal importance, work task, worker characteristics-IE, and perceptual-cognitive-motor (PCM) error-IE factors tended to decrease in importance. As equipment increased in importance, work task, and PCM error-IE tended to decrease in importance. In the cases where PCM error-IE was rated high, the contributions of all other factors, except those associated with the co-worker and social climate, tended to be rated lower. When PCM error-CW was rated high, worker characteristics-CW also tended to be rated high.

To further explore the relationships between the contributing causal factors, a factor analysis was conducted to determine if any smaller set of underlying factors could account for the causal factor rating variance. A principal components factor analysis, with Varimax rotation, was performed on 9 of the 10 contributing causal factors. Social climate was excluded from the analysis so that singularity did not exist among the causal factors and the statistical requirements for factor analysis were met. Because the rating data are ipsitive (always total 100), each variable is a linear combination of the other factors (i.e., singularity exists). By excluding one factor, singularity is reduced and the results are more stable. The social climate factor was excluded because it was implicated in only a few cases and was never a significant contributor to accident causality.

Five underlying factors were identified from the factor analysis which accounted for 72% of the common variance among the contributing causal factors. Table 23 shows the rotated factor loading matrix. Factor loadings are the correlations between each causal factor and each underlying factor identified by the factor analysis. Because the causal factors are relatively independent of one another, the factors identified by the factor analysis essentially represent, at most, two causal factors. The first factor analysis factor (FA1) is essentially a co-worker factor with high factor loadings for the co-worker's characteristics and co-worker PCM error. FA2 shows high factor loadings for physical environment and work task and represents a non-behavioral factor. FA3 shows a high negative loading on injured employee PCM error and represents a lack of the PCM error-IE factor. FA4 is somewhat difficult to interpret. It shows a high positive loading for other/miscellaneous and an equal negative loading for management. Finally, FA5 is clearly an injured employee's worker characteristics factor. Equipment was the only causal factor that did not load highly on the five factor analysis factors identified. Equipment, however, did load moderately on two factors, FA2 and FA3.

TABLE 23. - Rotated factor matrix

	FA1 (Factor 1)	FA2 (Factor 2)	FA3 (Factor 3)	FA4 (Factor 4)	FA5 (Factor 5)
MGT	-.01727	-.09439	.32604	-.73750*	-.26061
PE	-.13499	.67805*	.12890	-.14503	-.13252
EQ	-.22150	-.48162	.57440	.04599	-.15934
WT	-.07745	.73677*	.01008	.27899	.00064
WC/IE	-.06209	-.09611	.02542	.00543	.98181*
WC/CW	.78511*	-.03234	.05337	.02454	.06980
PCM/IE	-.18720	-.31793	-.90455*	.00132	-.12336
PCM/CW	.83330*	-.11883	-.01744	-.07124	-.14177
OTHER	-.05845	-.00349	.29214	.73532*	-.19755
% of Variance	17.5	16.1	14.3	12.7	11.5

*Significant factor loadings.

Key:
- MGT - Management
- PE - Physical Environment
- EQ - Equipment
- WT - Work Task
- SC - Social Climate
- WC/IE - Worker Characteristics-Injured Employee
- WC/CW - Worker Characteristics-Co-Worker
- PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
- PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
- OTHER - Other/Miscellaneous

The results of the factor analysis were not particularly illuminating and the resulting underlying factors identified are hard to interpret due to the negative factor loadings. To facilitate discussion, the original 10 contributing causal factors will form the basis for presenting the results of this project.

Contributing Causal Factors: Degree of Contribution

Figure 15 shows the mean rating for each contributing causal factor, averaged across the 338 cases. PCM error for the injured employee averaged almost one-third of the causality of the cases investigated. Management and work task had the next highest mean ratings with 15.4 and 16.1, respectively.

The average ratings are somewhat misleading because of the skewed nature of the ratings for most factors. In general, for each factor, there is a preponderance of cases in which the factor was not involved at all (factor rating equals zero), and very few cases with high levels of involvement. The following are the percentage of cases in which each causal factor was involved (i.e., factor rating greater than zero):

Management	73%
Physical Environment	52%
Equipment	50%
Work Task	76%
Social Climate	14%
Worker Characteristics-IE	40%
Worker Characteristics-CW	4%
PCM Error-IE	93%
PCM Error-CW	32%
Other/Miscellaneous	38%

PCM error-IE was involved, to some extent, in nearly all the cases. Management and work task were involved in approximately three-quarters of the cases. Equipment and physical environment were involved in about half the cases. Worker characteristic-IE, PCM error-CW, and other/miscellaneous were involved in about one-third of the cases. Social climate and worker characteristics-CW were involved in very few cases.

Figure 15 showed the overall average involvement of each factor across all cases, including those with no involvement. Now, a reasonable question is, "What is the degree of contribution of each factor for only those cases in which it was a factor at all?" Figure 16 presents that data. PCM error-IE, when it was involved at all, tended to account for about one-third of the causal contribution of the case. When the other factors were involved in a case, the average degree of contribution was relatively consistent, ranging from 13.5 points (physical environment) to 22.3 points (PCM error-CW). The exceptions are social climate and worker characteristics-CW which had low levels of contribution when they were involved.

The section titled "Contributing Causal Factors: Detailed Discussion of Each Factor" discusses each of the contributing causal factors in more detail.

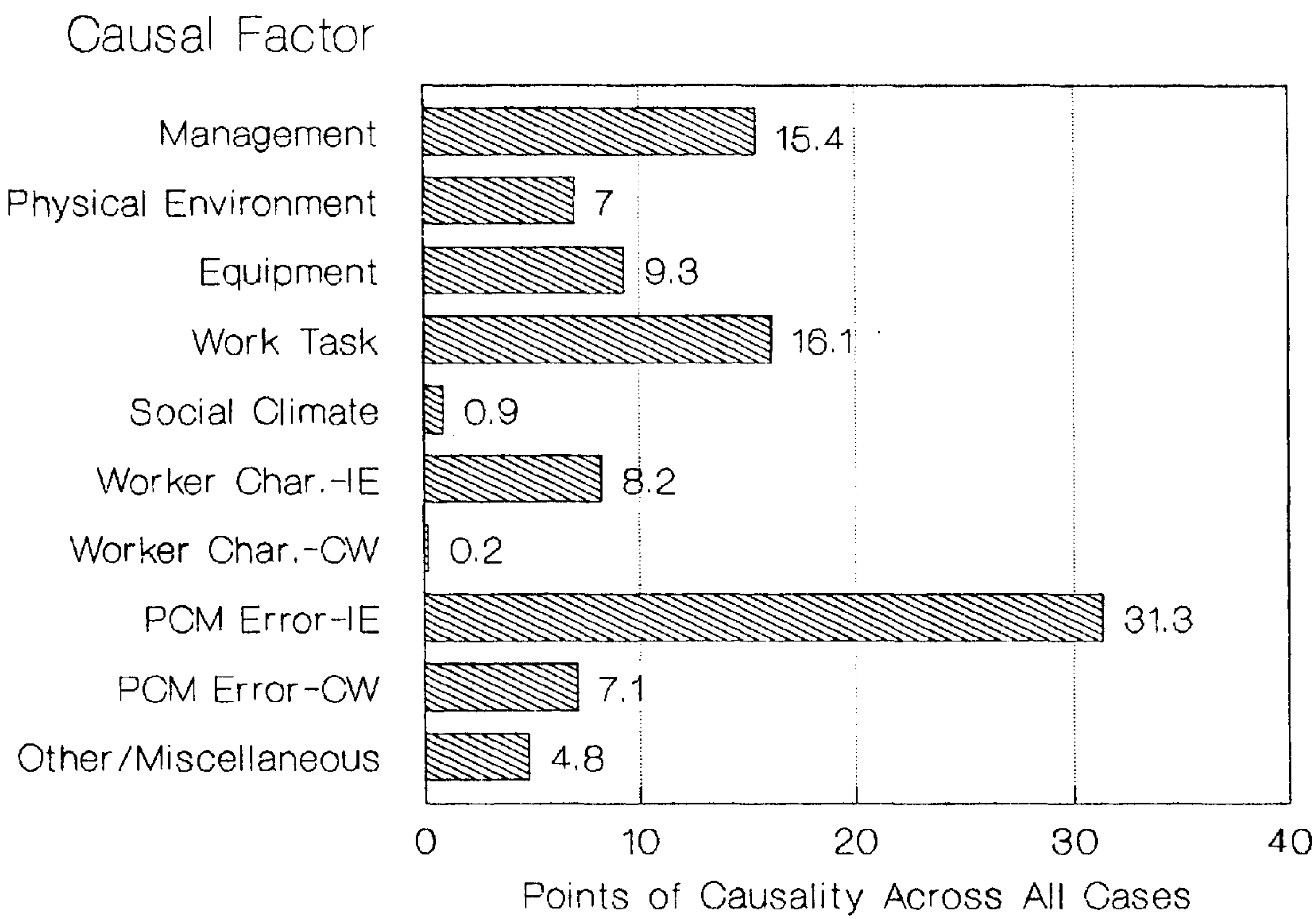

FIGURE 15. - Average causal involvement of each factor across all cases (n=338).

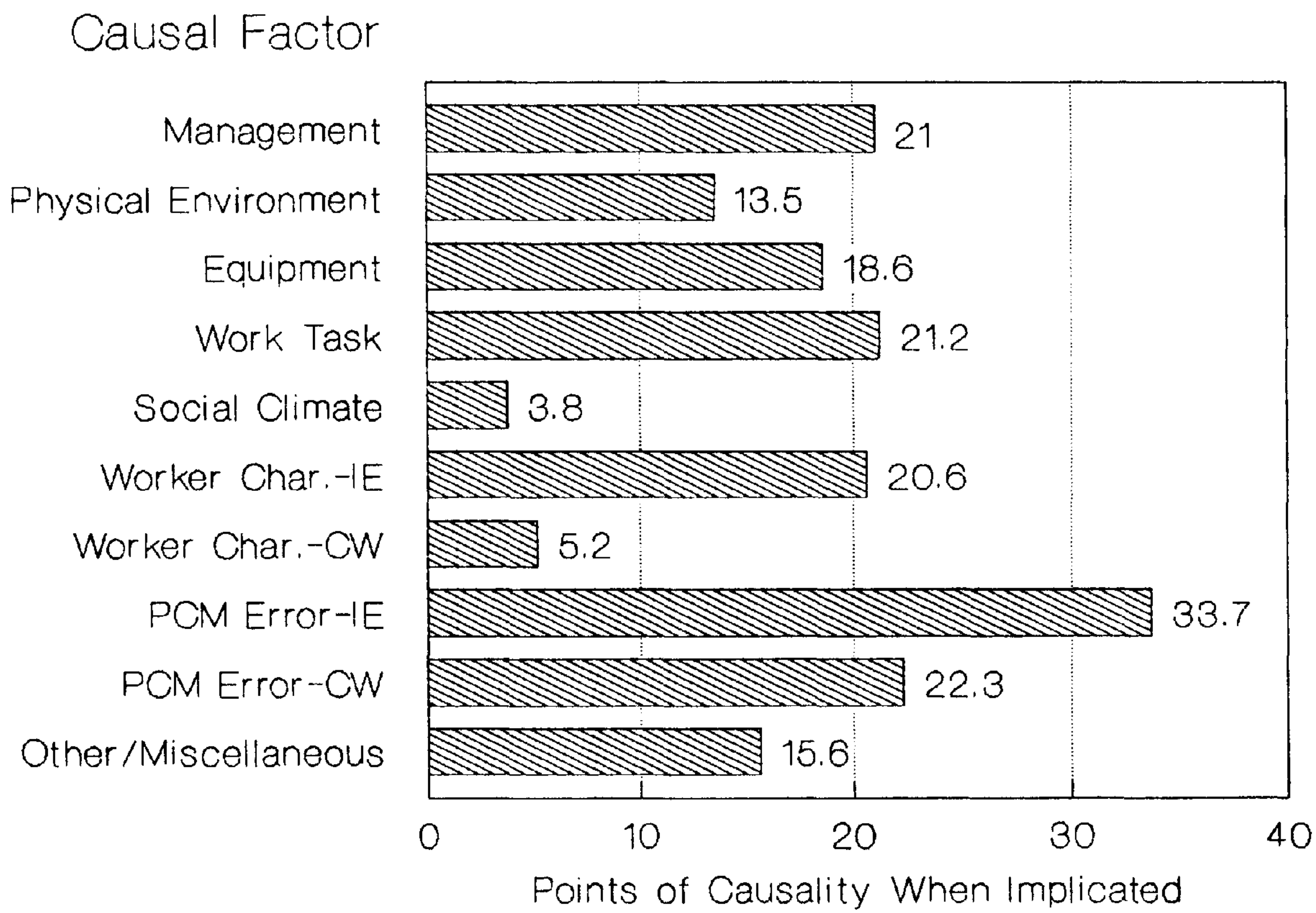

FIGURE 16. - Average causal involvement of each factor only for cases in which the factor was implicated.

Contributing Causal Factors: Primary and Secondary Factors

For each case, primary and secondary contributing causal factors were identified based on the ratings of contribution, given the factors in that case. A factor greater than 30 points was considered a primary factor. In cases where no factor was over 30 points, the highest factor was considered primary. Each of the other factors having 14 or more points was then compared with the first identified primary factor. If the highest of those remaining factors was within 10 points of the first primary factor, that factor was also considered primary. The highest remaining factor having 14 points or more was then compared with the last factor judged to be primary and, if it was within 10 points of that factor, it too was considered primary. The process continued until the highest remaining factor with 14 or more points was more than 10 points below the last factor judged to be primary. Although it might appear that this process could yield many primary factors, in reality, only 16 cases had three primary factors, and only one case had four primary factors identified (the maximum number of primary factors identified). Secondary factors were factors not considered primary, but were rated equal to, or greater than, 14 points. Consider the following example:

Management - 13 points (less than 14 points - not secondary)
Physical Environment - 29 points (Primary Factor - within 10 points of first identified primary factor)
Equipment - 39 points (Primary Factor - over 30 points and highest rated)
Work Task - 0 points
Social Climate - 0 points
Worker Characteristics-IE - 1 point (less than 14 points - not secondary)
Worker Characteristics-CW - 0 points
PCM Error-IE - 18 points (Secondary Factor - greater than 14 points, but more than 10 points below last identified primary factor)
PCM Error-CW - 0 points
Other/Miscellaneous - 0 points

The definitions of primary and secondary factors are basically arbitrary. The specific rules for defining primary and secondary were developed from a careful review of the actual ratings given the 338 cases. The purpose of defining primary and secondary factors was merely to simplify the presentation of the data. It was obvious that for any case, there were only a few factors that "stood out." By defining primary and secondary, it would be possible to focus on those factors and ignore factors that showed very low levels of contribution (less than 14 points). Factors with ratings less than 14 points are probably within the range of "noise" inherent in the entire rating process, and not worthy of extensive examination. One measure of the utility of this approach is an assessment of the number of points accounted for by primary and secondary factors for a case. The primary and secondary factors identified for each case accounted, on average, for 85 of the 100 points possible. Therefore, analyses of primary and secondary factors capture the majority of the causal variance.

Further, it should be pointed out that the analysis of primary and secondary contributing factors does not presuppose that these factors are necessary and sufficient conditions for the occurrence of the accident, or that these factors are somehow linked into a causal chain such that if any one of the factors were removed, the accident would not have happened. Rather, the notion of causality adopted here is a probabilistic model of causation. The presence of a factor only increases the probability that the accident would occur. The accident could have still occurred if the factor was not present; however, the probability of occurrence would be less than if the factor was present. The factors identified are CONTRIBUTING factors to causation, not causal factors, per se. The term "contributing causal factor" will be used as a shorthand notation for this conceptualization.

Table 24 shows the percentage of cases involving various numbers of primary and secondary factors. Just 12% of the cases involved only a single factor. The remaining 88% of the cases involved some combination of multiple primary factors, or a combination of primary and secondary factors, with most cases (58%) involving one primary factor and one or more secondary factors. Although the causes usually involved more than one factor (i.e., multi-causal in nature), the number of factors involved was small, rarely more than three. This is due, in part, to the ipsitive nature of the ratings. All factors cannot be rated high for one case.

TABLE 24. - Percentage of cases cross-tabulated by number of primary and secondary factors identified

		Secondary Factors Identified				
		0	1	2	>2	Total
Primary	1	12%	32%	23%	3%	70%
Factors	2	16	8	1	---	25
Identified	>2	4	1	---	---	5
Total		32%	41%	24%	3%	100%

The percentage of cases in which each factor was rated as a primary or secondary factor is shown in figure 17. For example, in 10.4% of the cases, the equipment factor was rated as a primary contributing factor; and in an additional 10.1% of the cases, equipment was rated as a secondary factor. Thus, overall, equipment was either a primary or secondary factor in 20.5% of the cases.

PCM error-IE was a primary or secondary factor in approximately three-quarters of the cases investigated. Management was involved as a primary or secondary factor in almost half the cases. Work task, equipment, and physical environment were each primary or secondary factors in about 20% of the cases.

Contributing Causal Factors: Detailed Discussion of Each Factor

Each contributing factor will be discussed in turn, presenting the distribution of that factor's ratings across all cases; an example case where the factor was considered as primary; and an analysis of why the factor was involved in cases in which it was a primary factor.

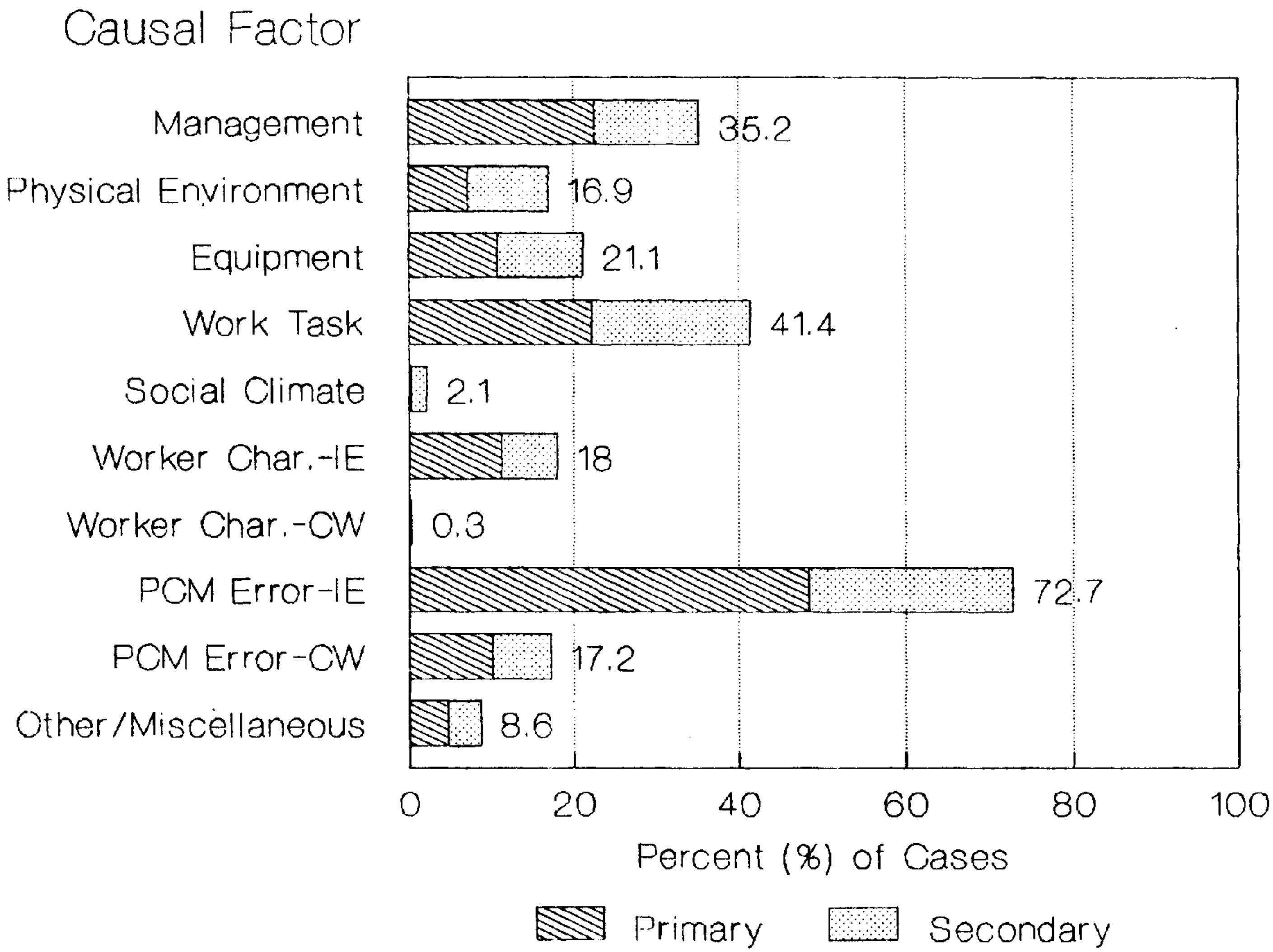

FIGURE 17. - Percentage of cases in which each factor was rated as a primary or secondary factor. (See text for definitions of primary and secondary.)

Management

Figure 18 shows the distribution of average ratings on the management factor. As can be seen, management was not implicated in 27% of the cases. When management was involved, it contributed an average of 21 points to the causality.

A case in which management was the primary factor involved a vehicular accident resulting from a faulty brake preventative maintenance program. The rating for management was 76%.

> A co-worker was driving a rubber-tired vehicle used to transport workers into the mine. The brakes on the vehicle failed, and the vehicle hit the haulageway wall. The jolt caused the IE to hit his head on the protective canopy. At this mine, bad brakes on vehicles were a chronic problem. The transport vehicles had been in service for about 10 years and had good historical data on their brake reliability. Management was considered a prime causal factor because they had not instituted an adequate preventative maintenance program for brake replacement, and they did not require a start-of-shift vehicle inspection.

The management factor was the primary causal factor in 22.5% of the cases. A total of 14 underlying causes of management involvement in the causality of these cases were identified by the project rating team. More than one underlying cause could be identified for a case. The nine significant underlying causes of management involvement (i.e., cited in more than 5% of the management-primary cases) are:

- Failure to establish, maintain, or enforce formalized safe work procedures and practices (involved in 52.7% of the cases in which management was a primary factor)
- Inadequate or improper selection of safety equipment for known safety problems (23%)
- Failure of equipment maintenance system, either preventative or repairs (23%)
- Equipment required for safe job performance not identified and provided (18.9%)
- Inadequate solutions applied to safety problems (16.2%)
- Inadequate design or planning of mine facilities for safety (10.8%)
- Inadequate supply system (6.8%)
- Inadequate training (materials, content, methods, or frequency) (6.8%)
- Failure of mine facility (roadway/railway) maintenance (6.8%)

Management involvement centered around those aspects of the operation that are management's responsibility or over which management has control. Often, failure to perform a responsibility was the basis for implicating management in the case.

The 10 contributing causal factors were examined to identify other factors which also contributed to the causality of the case when management was rated as the primary causal factor. The mean ratings for the management primary cases are presented in figure 19. As can be seen, the majority of the causality, 65 points, is accounted for by two causal factors: Management (45 points) and PCM error-IE (20 points). The PCM error-IE role was often improper worker judgement in performing tasks which did not have established SOPs or a failure to adhere to an SOP due to risk-taking.

Management

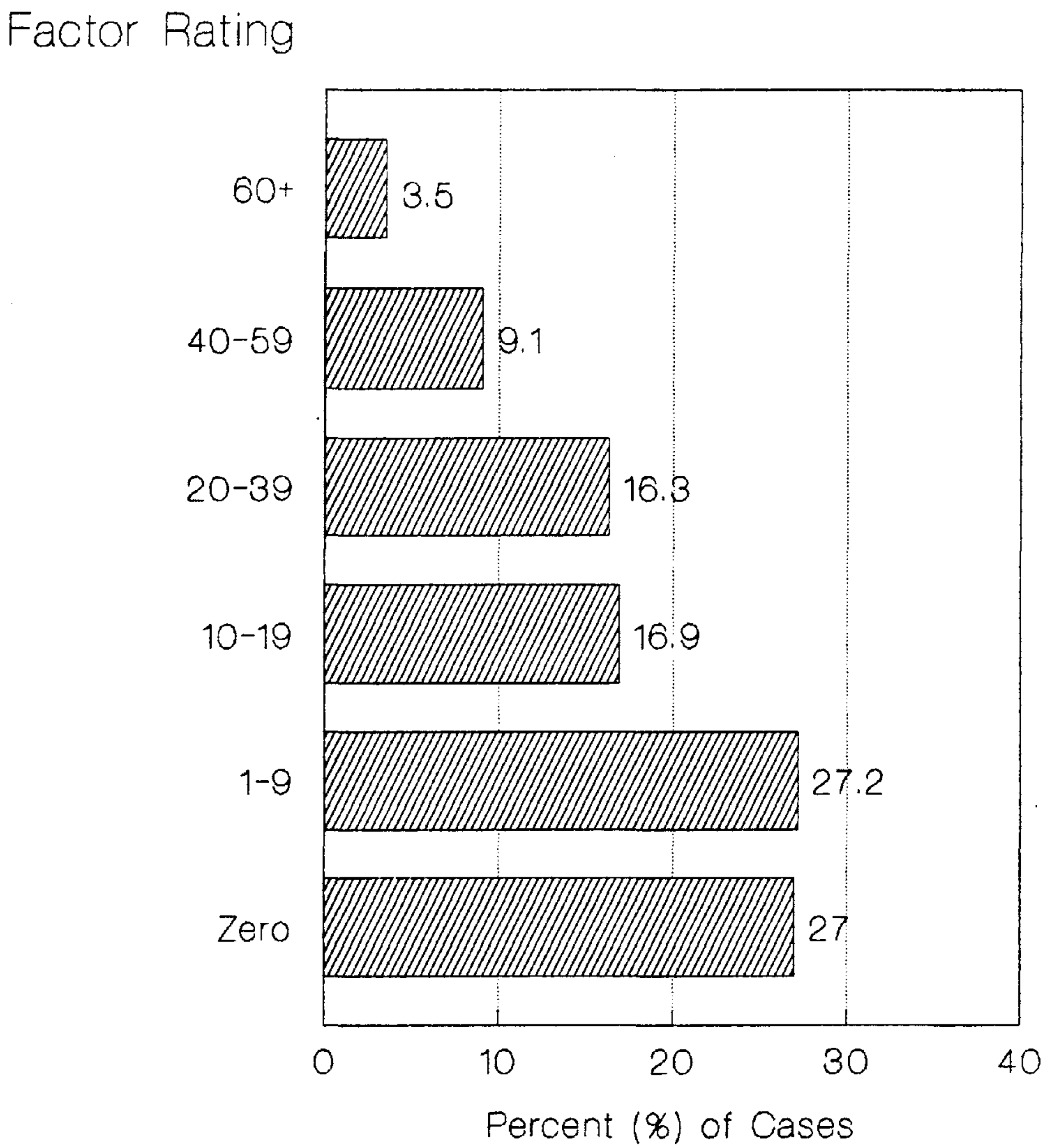

FIGURE 18. - Distribution of mean ratings for Management.

Management Primary Cases

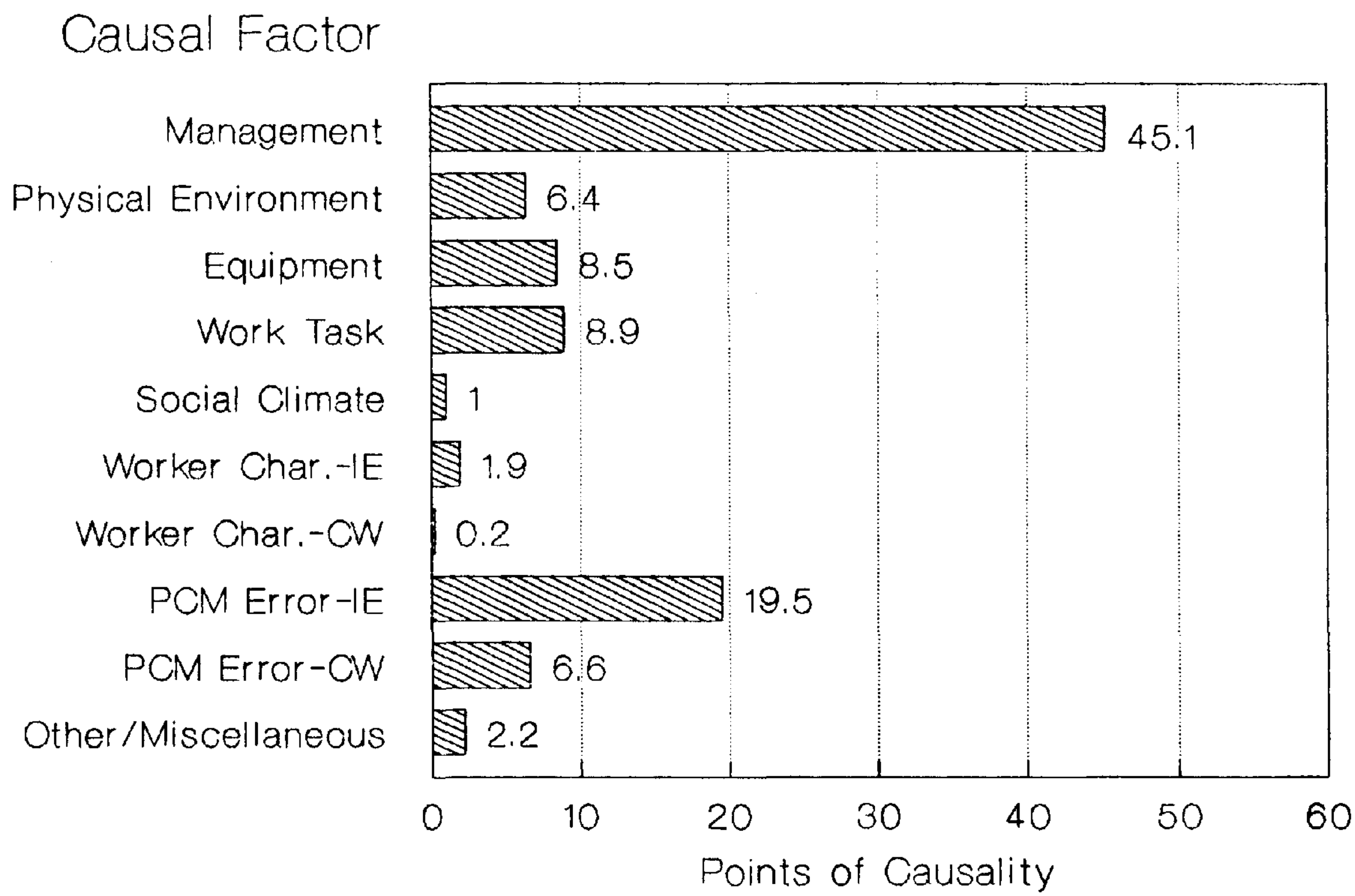

FIGURE 19. - Average causal involvement of each factor for those cases in which Management was a primary factor (n=76).

Physical Environment

The distribution of physical environment ratings across all cases is presented in figure 20. In almost half of the cases, physical environment was not implicated at all. When implicated, physical environment contributed an average rating of 13.5 points of the causality. An example of a case in which physical environment contributed significantly to the causality of the case involved a slippery bottom condition.

> The IE was walking through a haulageway to get to a machine he was to repair. To get to the machine, he had to walk through an ankle-deep puddle of mud. He slipped and twisted his knee. The mud puddle was created when the machine was washed off to facilitate the repair task. The worker had crossed the mud puddle a couple of times prior to the accident and had not encountered any slippery surface.

Physical environment was considered a prime factor (64 points) because the puddle was a normal environmental hazard and there was no other route available to the worker. Perceptual-cognitive-motor error-IE was also implicated as a secondary factor (20 points) because the worker became less cautious each time he traversed the puddle; he misjudged the risk involved.

The physical environment factor was implicated as a primary causal factor in 24 (7.1%) of the total cases. These cases primarily involved roof support, material handling or repair activities at the face, and employee walking/transportation activities. Three significant underlying causes of the involvement of physical environment in accident causality were identified. More than one underlying cause could be identified for each case. The percentages in parentheses indicate the percentage of cases in which the underlying cause was implicated.

- Bad roof/back conditions resulting from geological instability or anomalies (involved in 49.2% of the cases in which physical environment was a primary factor)
- Low roof height conditions (including both low-seam coal and low areas in high-seam coal) (48%)
- Irregular bottom/floor conditions (including geological causation, expected debris and water) (20%)

The mean ratings for the 10 contributing causal factors, when physical environment was primary, are presented in figure 21. The work task factor is the main secondary contributor in these cases, with an average rating of 25 points. Work tasks which involve inherently hazardous exposures or inherently hazardous tasks, such as ground support and scaling, tend to be performed in mine areas/conditions which are given high ratings on the physical environment factor. In cases in which physical environment is a primary factor, moderate contributions (about 10 points each) are seen for management and PCM error-IE factors.

Physical Environment

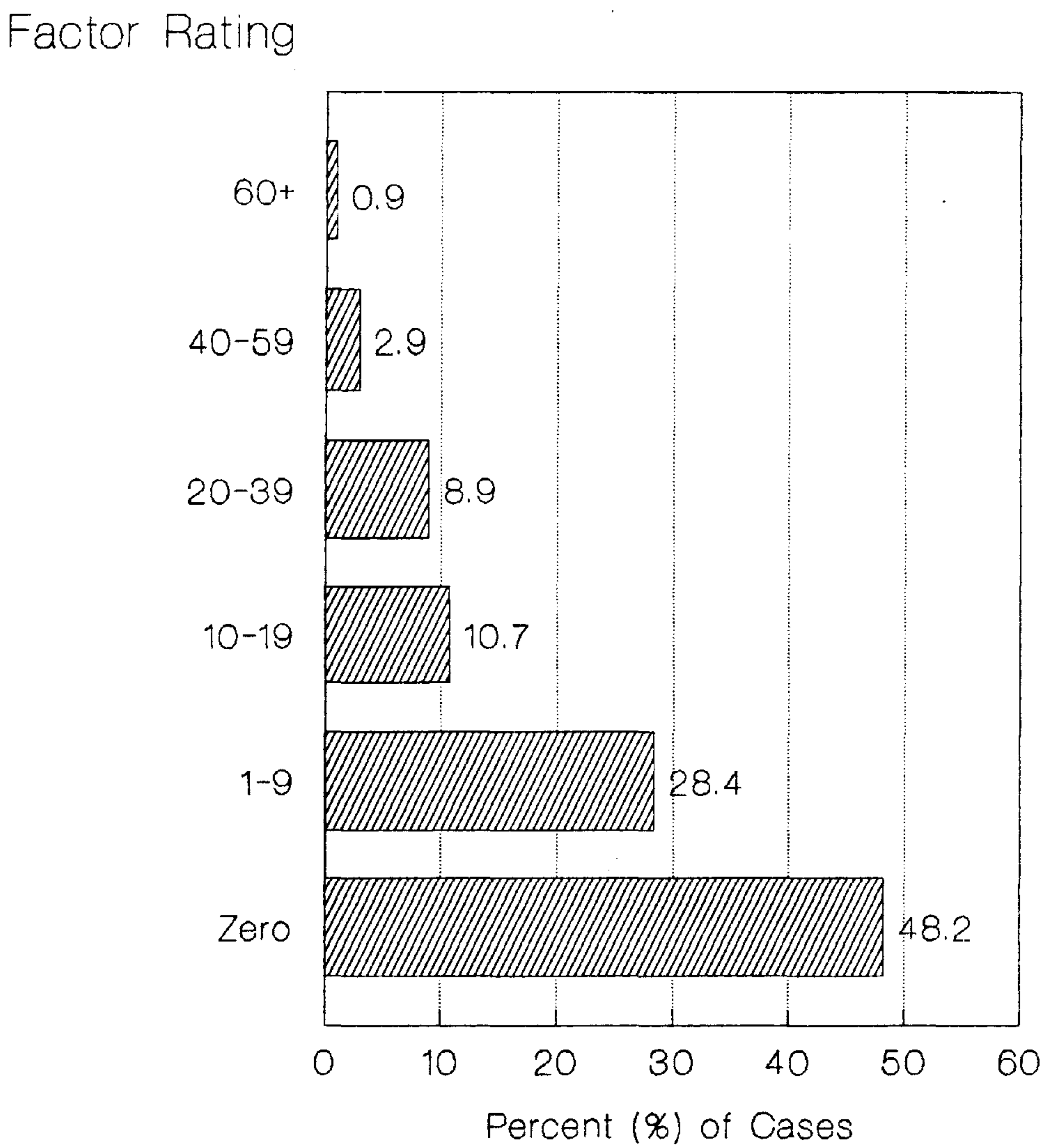

FIGURE 20. - Distribution of mean ratings for Physical Environment.

Physical Environment Primary Cases

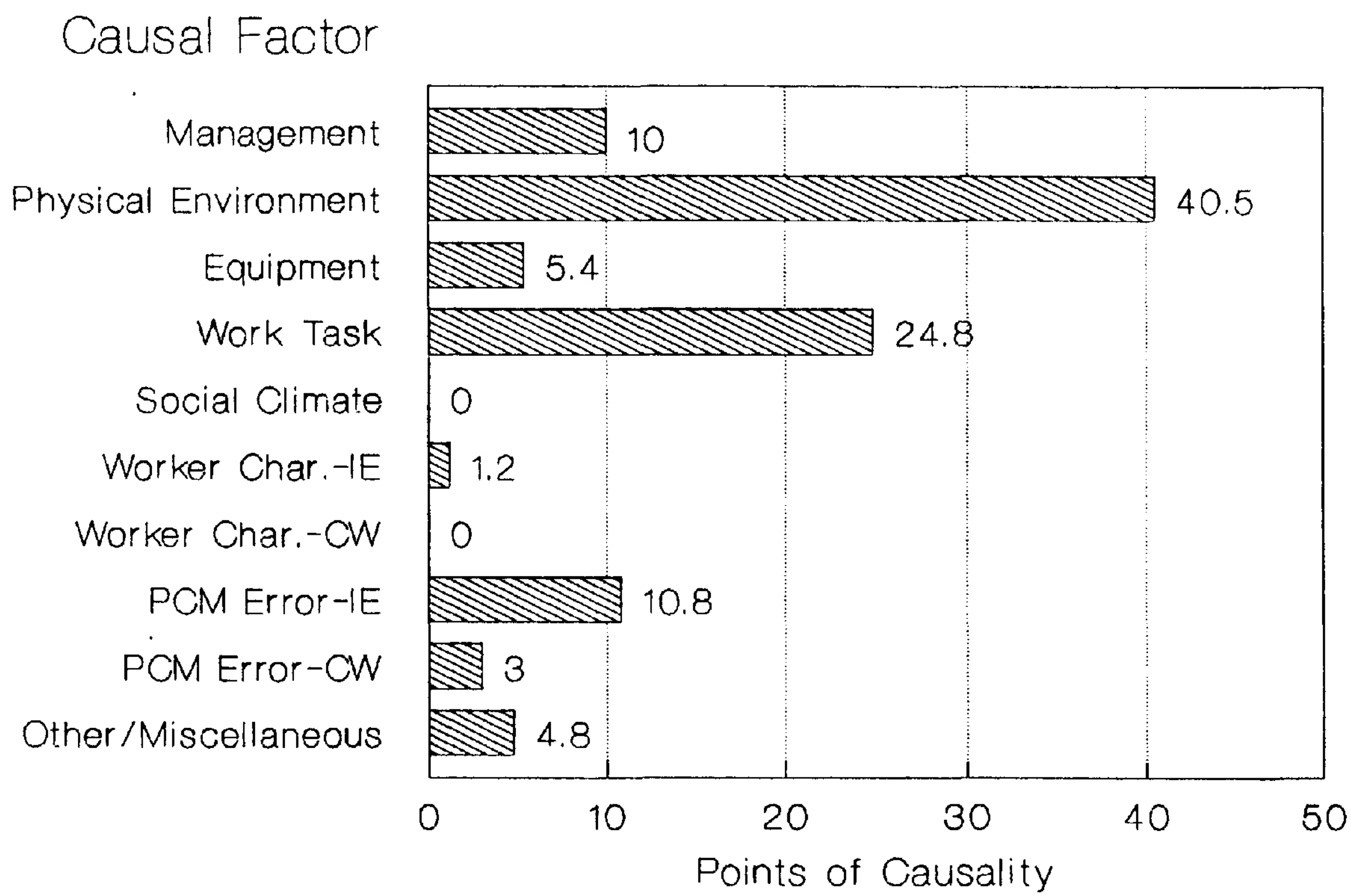

FIGURE 21. - Average cuasal involvement of each factor for those cases in which Physical Environment was a primary factor (n=24).

Equipment

Figure 22 presents the distribution of ratings across all cases for the equipment factor. Half the cases implicated equipment as a causal factor, with a mean rating of 18.6 points.

An example case in which equipment was a primary factor (84 points) involved poorly designed footholds which caused an operator ingress accident.

> A maintenance man was climbing on a load-haul-dump machine to perform a start-of-shift inspection. His right foot slipped off the step as he was climbing into the operator's compartment. He struck his shin against the edge of the machine. He was wearing work boots with deep lug soles. The bottom of the step was smooth steel with a smooth steel edge; there were no gripping surfaces, nor drainage channels for dirt and mud that collected in the foothold.

Equipment was implicated because the original design of the steps was inadequate, given the foreseeability that workers would be climbing on the steps in dirty, wet conditions.

The equipment factor was a primary causal factor in 36 cases (10.7%). These cases focused on equipment operation and maintenance incidents. The underlying causes (more than one underlying cause could be involved in each case) of equipment involvement as a contributing factor are:

Poor original equipment design for operational effectiveness (involved in 28.6% of the cases in which equipment was a primary factor)
Equipment malfunction (22.9%)
Inadequate OEM on-board safety system (22.9%)
Inadequate design/redesign of on-board safety equipment by mine operators (14.3%)
Inadequate cockpit/work area design for ingress/egress (11.4%)
Exposed sharp surfaces or pinch points (11.4%)
Visibility restrictions (11.4%)

The mean ratings for the contributing causal factors, when equipment was primary, are displayed in figure 23. The equipment factor, alone, accounts for over half of the causality. Two other factors also account for a meaningful portion, PCM error-IE (17 points) and management (11 points). PCM error-IE involvement often involved acceptance and use of equipment with known problems, including failure to request repair/modification of unsafe equipment, use of equipment in excess of specifications or known design limitations, or operation of equipment in an unsafe manner. Management was cited for their role in equipment and safety device selection, maintenance, or modification.

Equipment

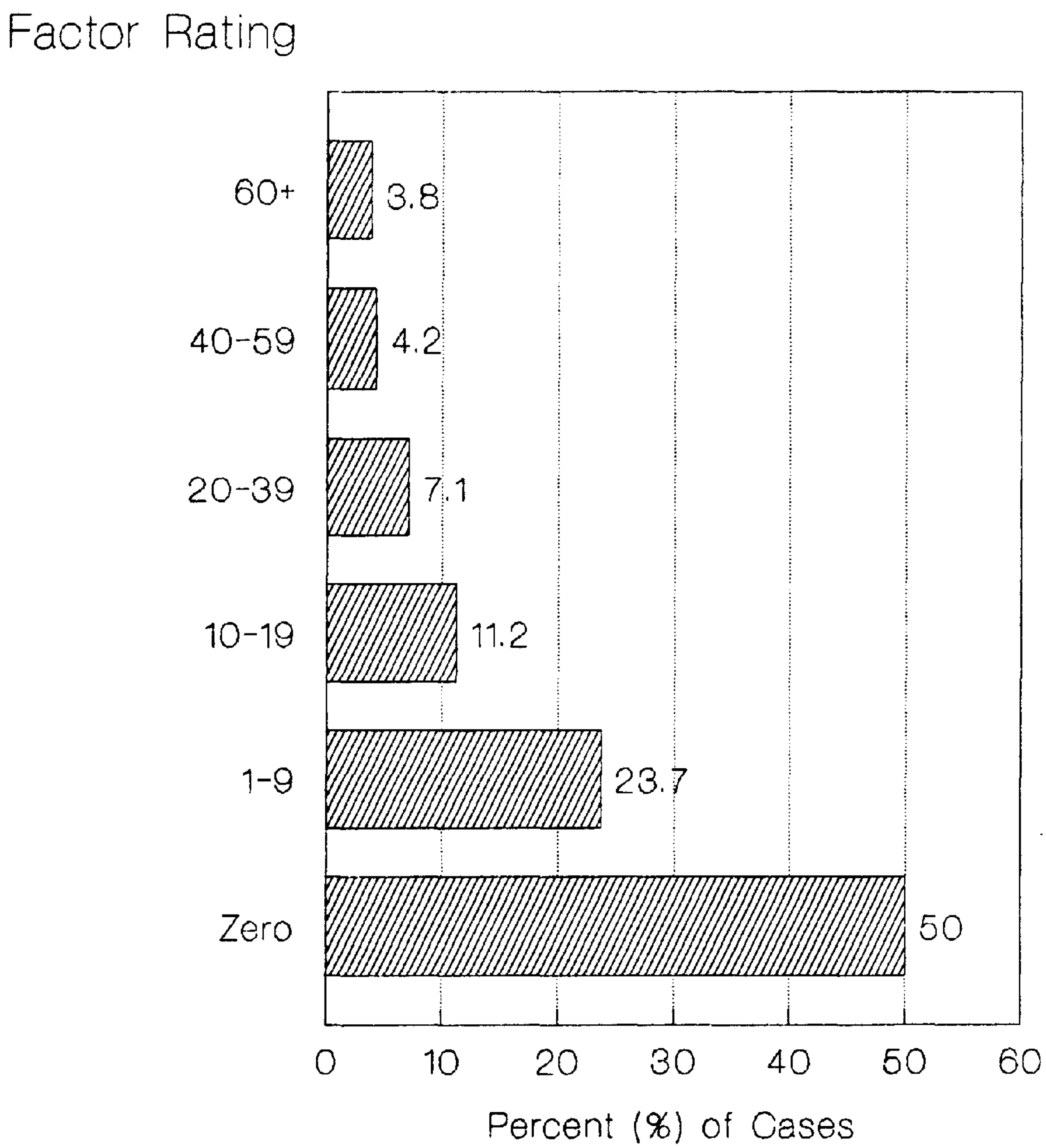

FIGURE 22. - Distribution of mean ratings for Equipment.

Equipment Primary Cases

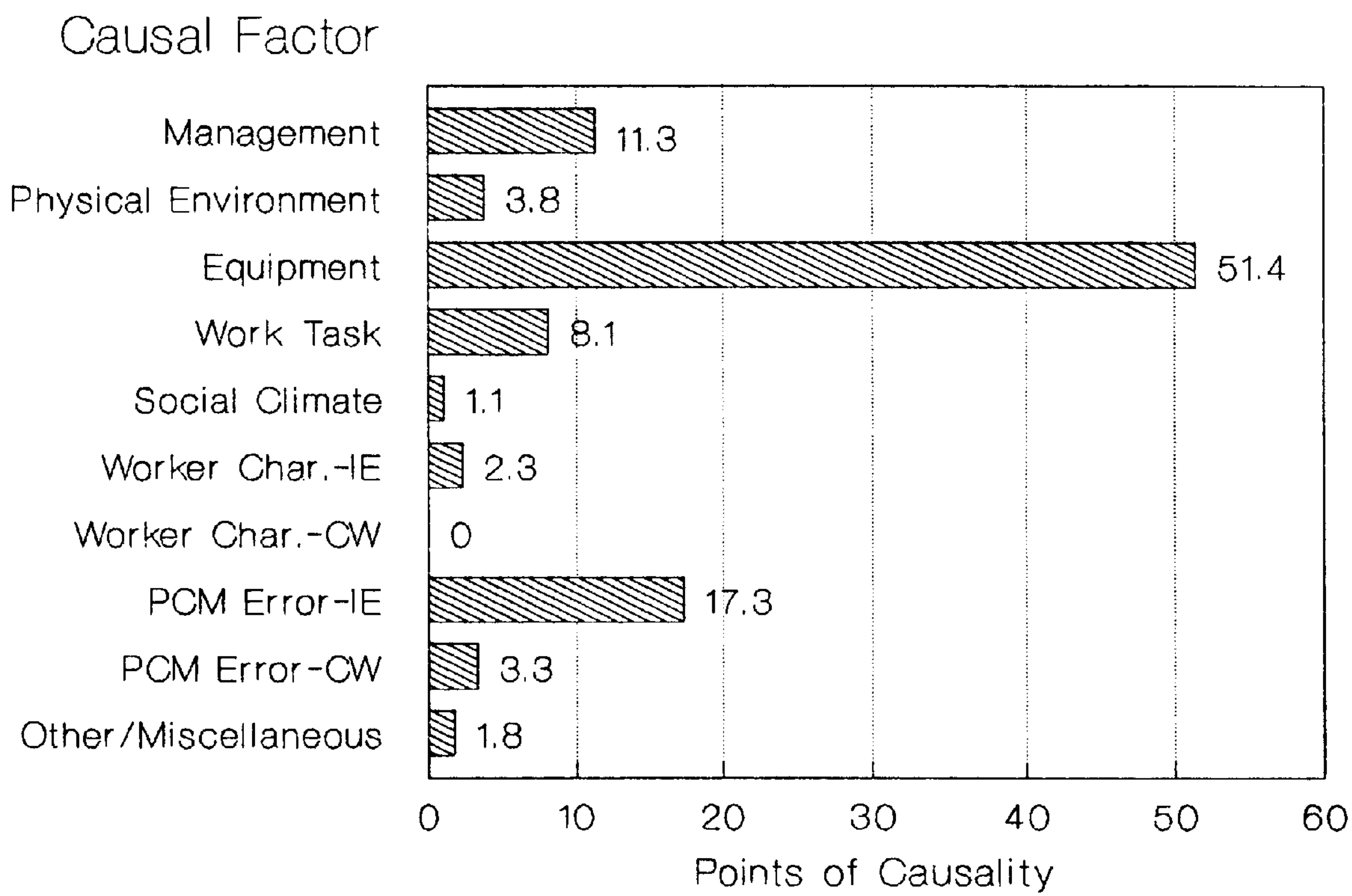

FIGURE 23. - Average causal involvement of each factor for those cases in which Equipment was a primary factor (n=36).

Work Task

As shown in figure 24, about 25% of the cases did not involve the work task factor. The mean rating, when work task was implicated, was 21.2 points.

An example of a case in which work task was a primary contributing factor involved manual scaling of loose rock at a production site.

> The IE was scaling overhead loose rock at a production site. To do this, he had to stand on the slope of a muckpile. He visually identified a rock that could fall. Following SOP, he put the tip of his scaling bar in a crevice of the roof and began prying upward on the bar. The rock was tied in very tight, but for safety it had to be removed. As he was exerting considerable force on the bar, the rock broke loose and he lost his balance; he fell against the wall and lacerated his arm.

Work task was considered primary (72 points) because the task required exerting large forces with unexpected releases of the rock. Perceptual-cognitive-motor error was considered a secondary factor (18 points) because it was felt that the worker might have exercised more care to maintain his balance in the event of a rapid breaking way of the rock.

Seventy-five accidents, 22.2% of all cases, were identified as having the nature of the work task as a primary contributing factor. Since this factor was one of the few factors where it, by its very nature, defines the underlying cause, only two underlying causes were identified. These were (1) the inherently hazardous nature of the task and (2) task-requirements exposure to inherently hazardous situations. Each of these underlying causes were identified in over 50% of the cases in which work task was a primary contributor. Tasks with an "inherently hazardous" component included manual materials handling, and some equipment maintenance and repair activities. Exposures to hazardous situations were observed in some cases involving roofbolting and manual scaling of loose back/roof or ribs.

The mean ratings for the causal factors, when work task was rated as the primary contributing causal factor, is presented in figure 25. PCM error-IE is seen to be associated with the work task primary cases, with an average of 20 rating points. This accounts for the role of the individual worker's judgment, risk-taking, and cognitive-perceptual abilities in hazardous tasks and environments.

Social Climate

The social climate factor was a primary factor in only one case investigated for this project. Part of the reason why this factor did not emerge as important is because of the difficulty of establishing evidence for its involvement. When involved at all (13.6% of the cases), it only contributed an average of 3.8% to the causality. This factor will not be discussed in detail due to insufficient data.

Work Task

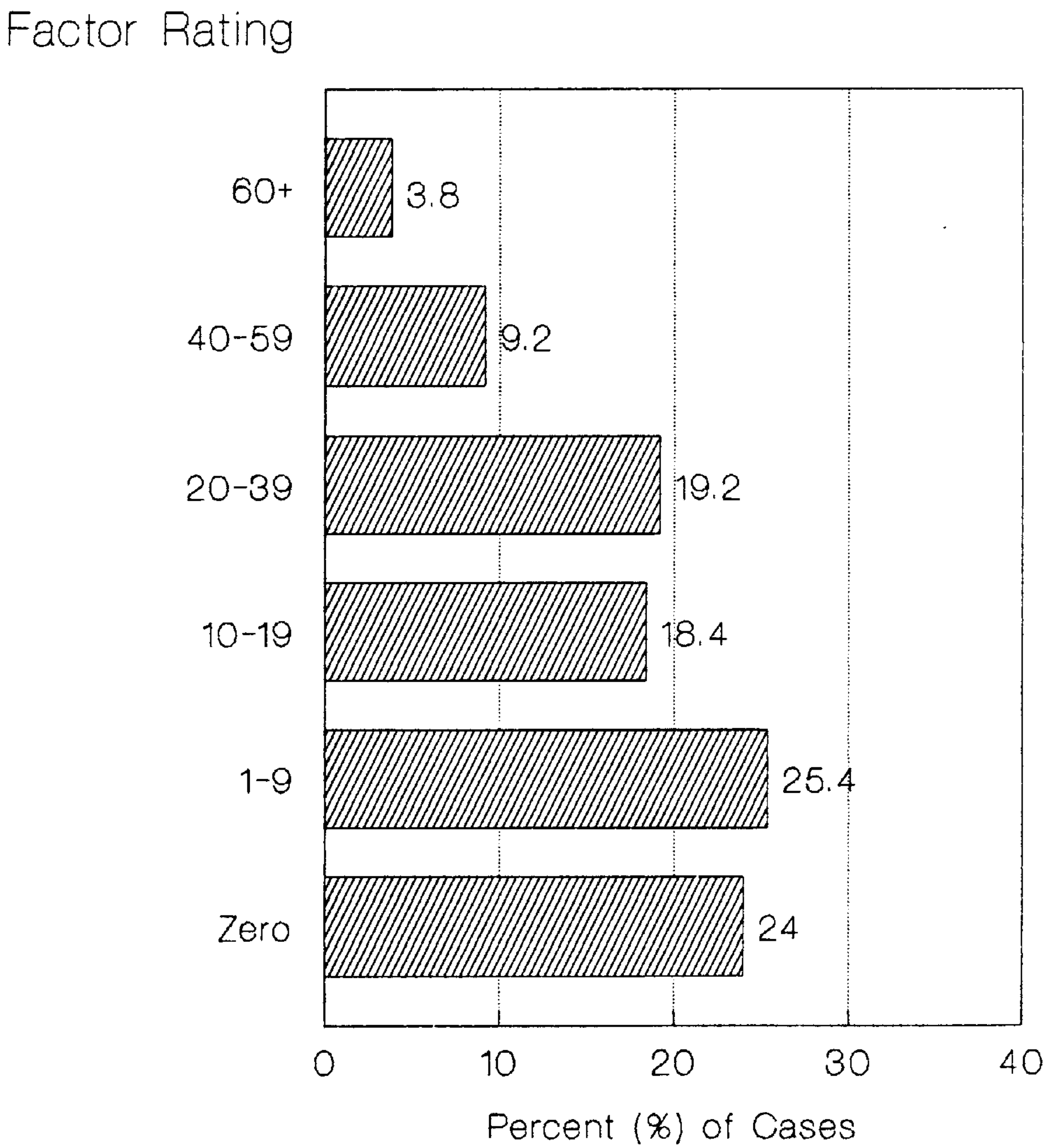

FIGURE 24. - Distribution of mean ratings for Work Task.

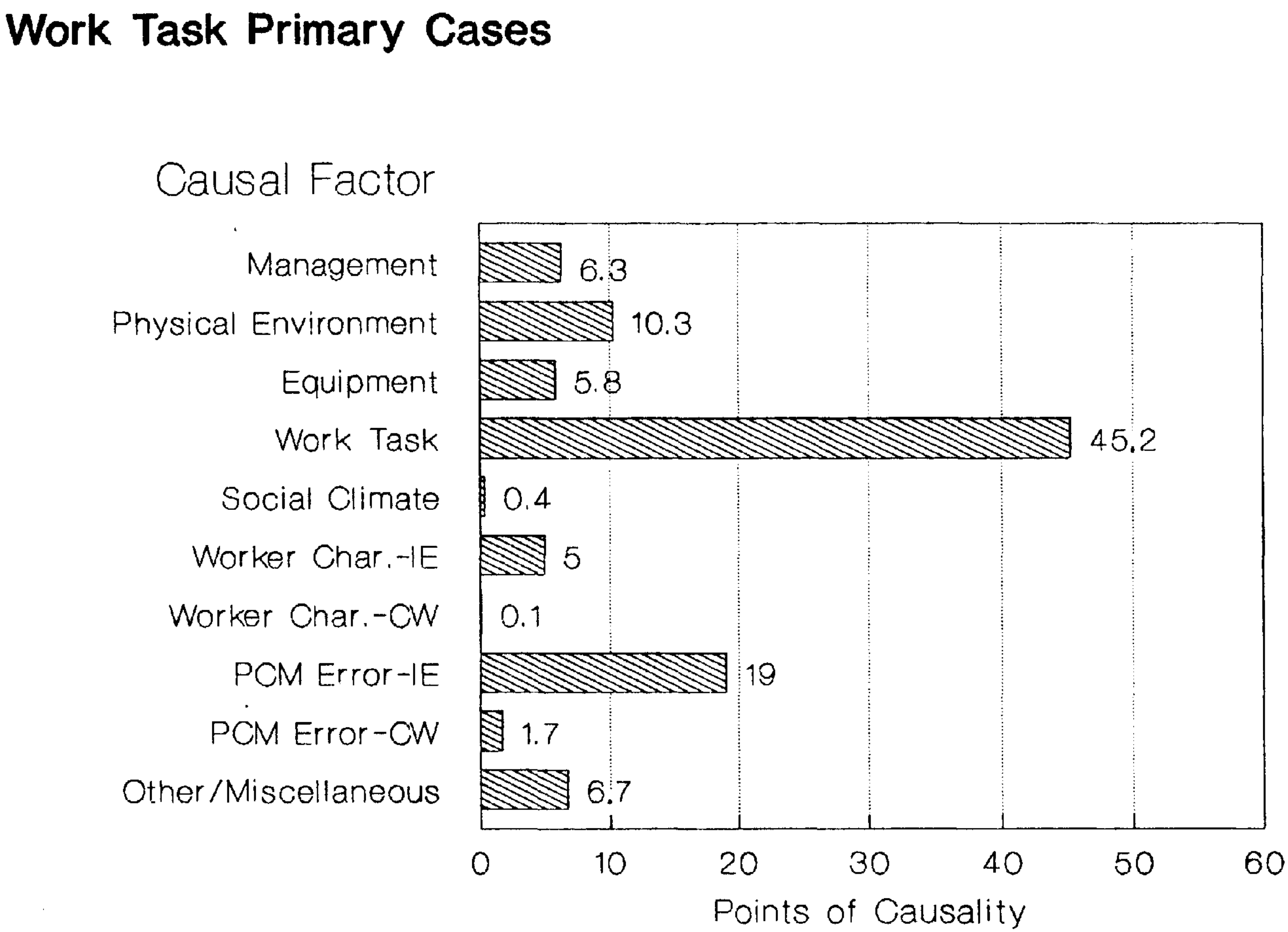

FIGURE 25. - Average causal involvement of each factor for those cases in which Work Task was a primary factor (n=75).

Worker Characteristics-IE

A distribution of ratings across all cases for worker characteristics of the injured employee is presented in figure 26. About 60% of the cases did not involve the injured worker's characteristics as a causal factor. When implicated, the injured worker's characteristics averaged 20.6 points of the causality.

A case involving a predisposition to back injury is a prime example of the involvement of the injured worker's characteristics.

> The IE was working on a stepladder performing light repairs to a piece of machinery. As he stepped off the ladder, he felt his lower back "pop." He had been working at eye level, with his arms at full, but not stretched, extension. All previous duties that day were extremely light. The IE had a history of back problems. Five months prior to this injury, he was under a doctor's care for a bone spur in the lower back. Under the union contract, if a doctor permits a worker to return to work, the mine cannot reassign him to other work unless the worker requests it.

Worker characteristics were considered the prime factor (95 points) because of the prior back problems which were believed to have been the cause of the injury.

The worker characteristics of the injured employee was found to be a primary contributor in 11.2% of the cases. Three underlying causes (more than one underlying cause could be identified from each case) were identified among these cases:

Predisposition to back injuries (involved in 36.8% of the cases in which work characteristics-IE was a primary factor)
Chronic health problem, including excessive weight (47.4%)
Chronic inappropriate judgment or behavior patterns (23.7%)

The mean ratings for all contributing causal factors, when worker characteristics-IE was primary, is displayed in figure 27. Two factors, PCM error-IE (22 points) and work task (13 points), are large secondary contributors to the causality. The PCM error-IE primarily involved worker decisions to perform tasks in excess of the worker's physical abilities (i.e., performing heavy lifting tasks with known back problems). The work task contribution was the requirement, by the inherent nature of the tasks, for heavy or repetitive physical exertion. Several of these incidents involved workers who returned to work from a similar injury apparently too soon, and were reinjured.

Worker Characteristics-CW

This factor was not implicated at all in 96% of the cases. In the 4% of the cases in which it was implicated, it contributed only an average of 5 points to causality. No further discussion of this factor will, therefore, be presented.

Worker Characteristics-IE

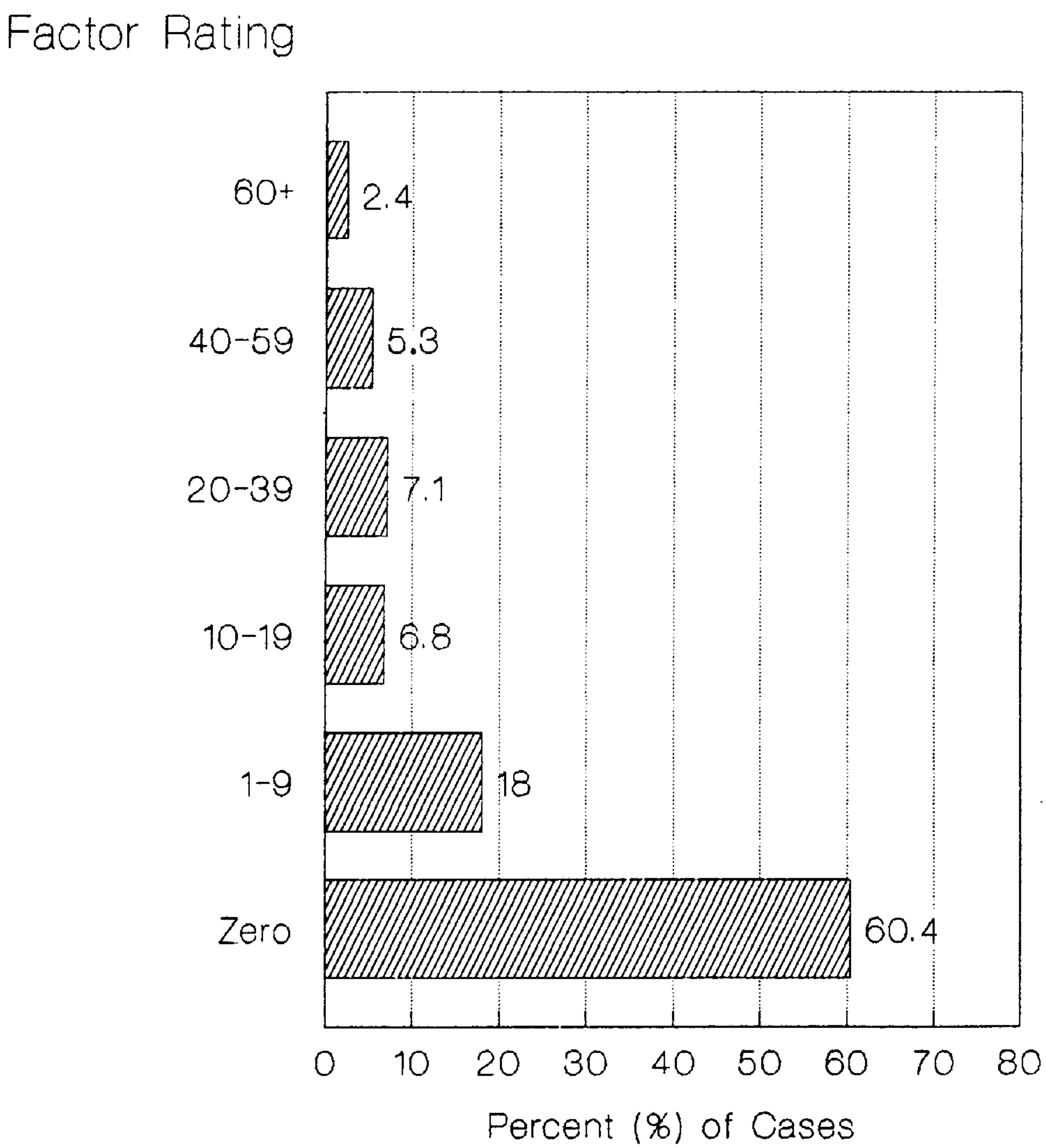

FIGURE 26. - Distribution of mean ratings for Worker Characteristics-IE.

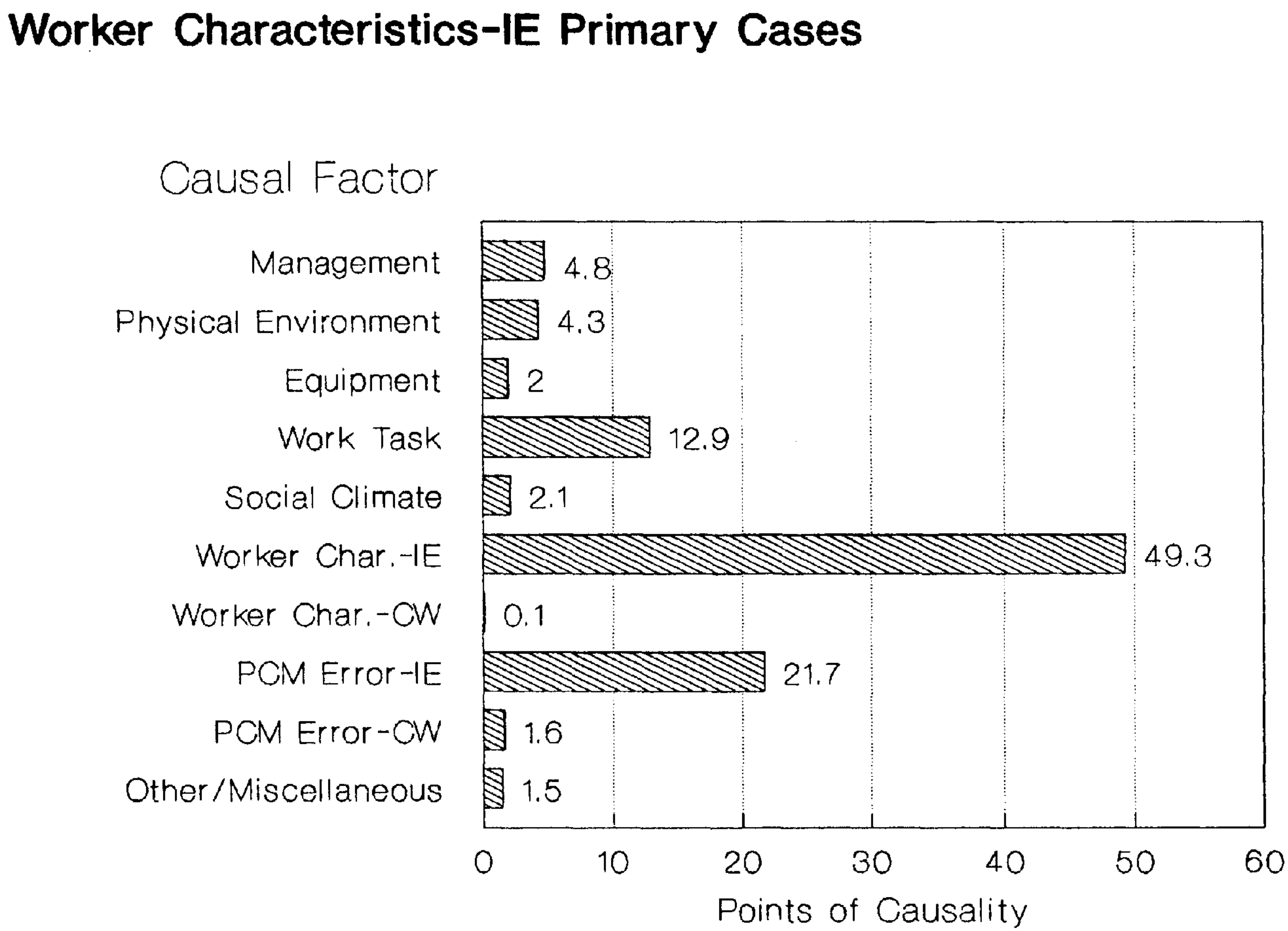

FIGURE 27. - Average causal involvement of each factor for those cases in which Worker Characteristics-IE was a primary factor (n=38).

Perceptual-Cognitive-Motor Error-IE

The distribution of ratings across all cases for the PCM error-IE factor is presented in figure 28. This factor was implicated in 93% of the cases, with a mean rating of 33.7% in those cases in which it was implicated.

An example of PCM error-IE as a primary causal factor involves misjudgment of risks and risk-taking during operation of a continuous miner:

> A continuous miner operator was cutting coal and loading it into a shuttlecar when a large rock became wedged in the conveyor of the machine. Rather than take the 2 or 3 minutes to break it with a sledge hammer that was available, the operator continued to operate the machine in hopes of dislodging the rock. Instead, the rock flipped up, landed in the operator's compartment, and struck the operator in the knee.

PCM error-IE was judged to have contributed 94 points of causality to this case.

In almost 50% of the accidents (164 cases), the PCM error-IE factor was implicated as a primary contributing factor. Five underlying causes (more than one underlying cause could be identified in each case) of this factor were identified by examining these cases:

Acceptance of risk of a high level (involved in 44.1% of the cases in which PCM error-IE was a primary factor)
Forgetting/neglecting to do something which the worker knew should have been done (29.8%)
Misinterpretations of the risks involved (25.5%)
General inattention or carelessness (20.5%)
Failure to perceive a hazard which was perceivable (11.8%)

Figure 29 shows the mean ratings for all contributing causal factors, when PCM error-IE was rated as the primary factor. As can be seen, PCM error-IE accounted for the majority of causality in these cases: over 50%. The management and work task factors each contributed 10 points, but the relative difference is so great that their degree of contribution can be considered only marginal. Overall, on average, when PCM error-IE is rated primary, it is the sole primary contributor to causality.

PCM Error-IE

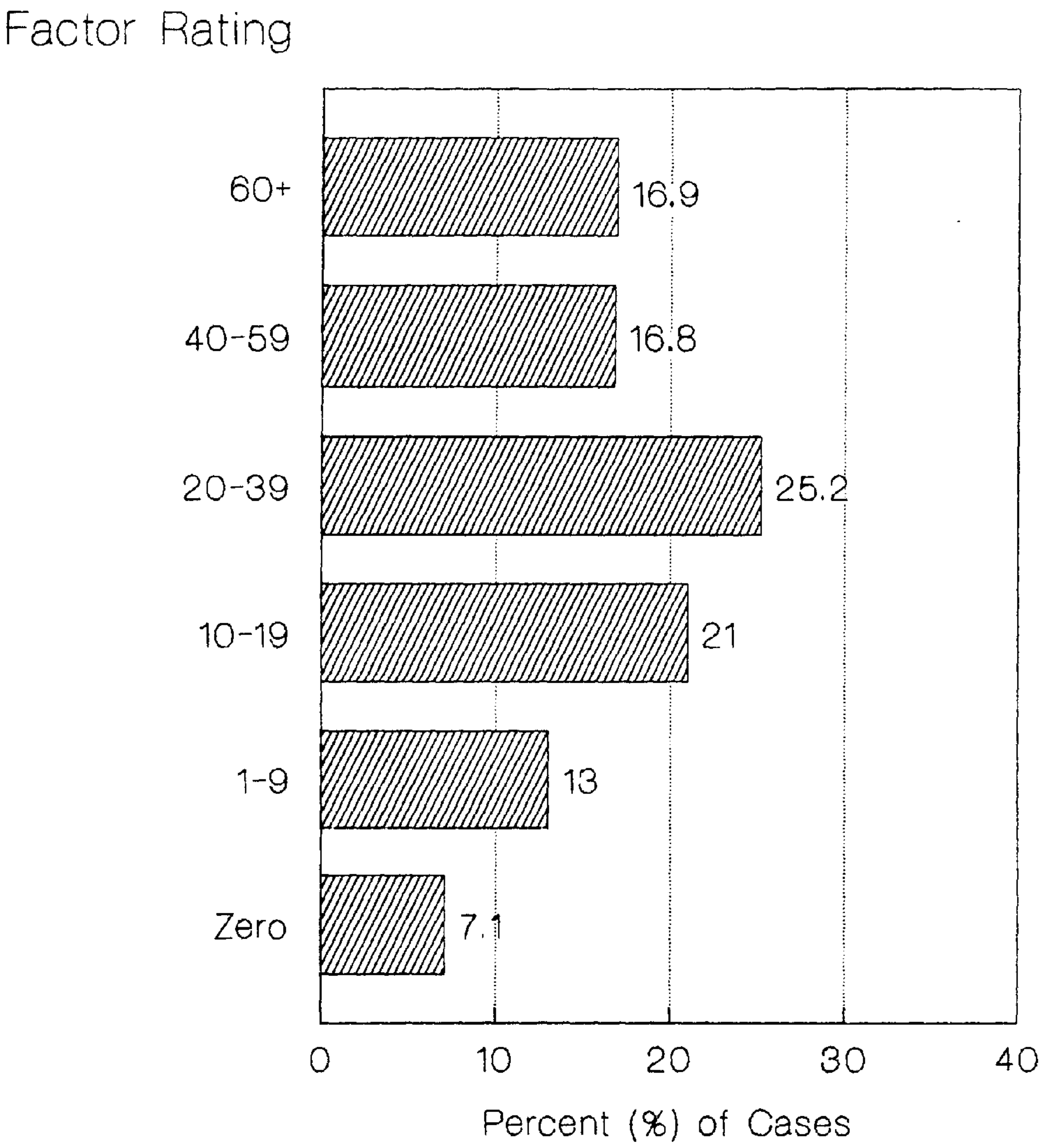

FIGURE 28. - Distribution of mean ratings for Perceptual-Cognitive-Motor Error-IE.

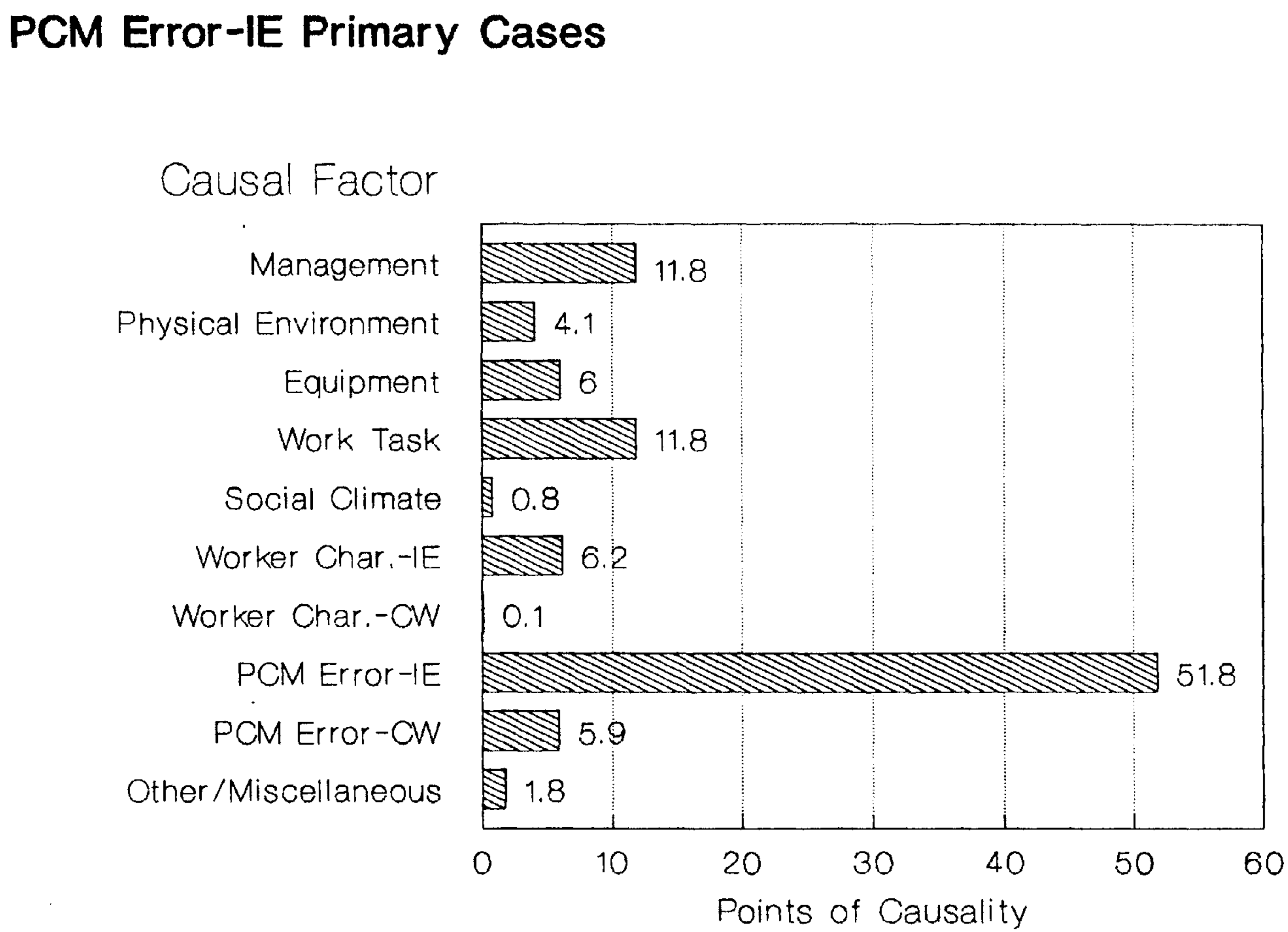

FIGURE 29. - Average causal involvement of each factor for those cases in which Perceptual-Cognitive-Motor Error-IE was a primary factor (n=164).

Perceptual-Cognitive-Motor Error-CW

The distribution of ratings for PCM error-CW across all cases is shown in figure 30. Although this factor was only involved in 32% of the cases, when it was, it accounted, on average, for 23 points of the causality of the case.

A case in which PCM error-CW was a primary causal factor (73 points) involved a co-worker's misjudgment of hazards when signalling the movement of a supply wagon:

> The IE and a crew of four other men were unloading supplies from a supply wagon. One of the tie-down chains became entangled, and the IE, while standing next to the wagon, tried to untangle it. A co-worker standing behind the wagon gave a verbal command to the operator to pull the wagon forward, which he immediately did. The tire ran over the foot of the IE. He did not have time to get out of the way when he heard the command to move the wagon.

PCM error-CW was implicated as a primary causal factor in 34 (10.1%) of the cases. These cases were examined for the underlying causes using the same taxonomy as in the PCM error-IE cases. More than one underlying cause could be identified in each case:

Acceptance of risk of a high level (involved in 38% of the cases in which PCM error-CW was a primary factor)
Forgetting/neglecting to do something which the worker knew should have been done (38%)
General inattention/carelessness (26%)
Failure to perceive hazard which was perceivable (12%)
Misinterpretation of the risks involved (12%)

The mean ratings for the 10 contributing causal factors, when PCM error-CW was primary, are shown in figure 31. PCM error-IE and management can be seen as being implicated for meaningful portions of the causality in these cases. PCM error-CW was implicated primarily in incidents involving teamwork or inter-work group interactions. Thus, PCM error-IE (the "other" part of the team) and management (in terms of responsibility for SOPs which optimize team processes and performance) were also rated as contributory.

PCM Error-CW

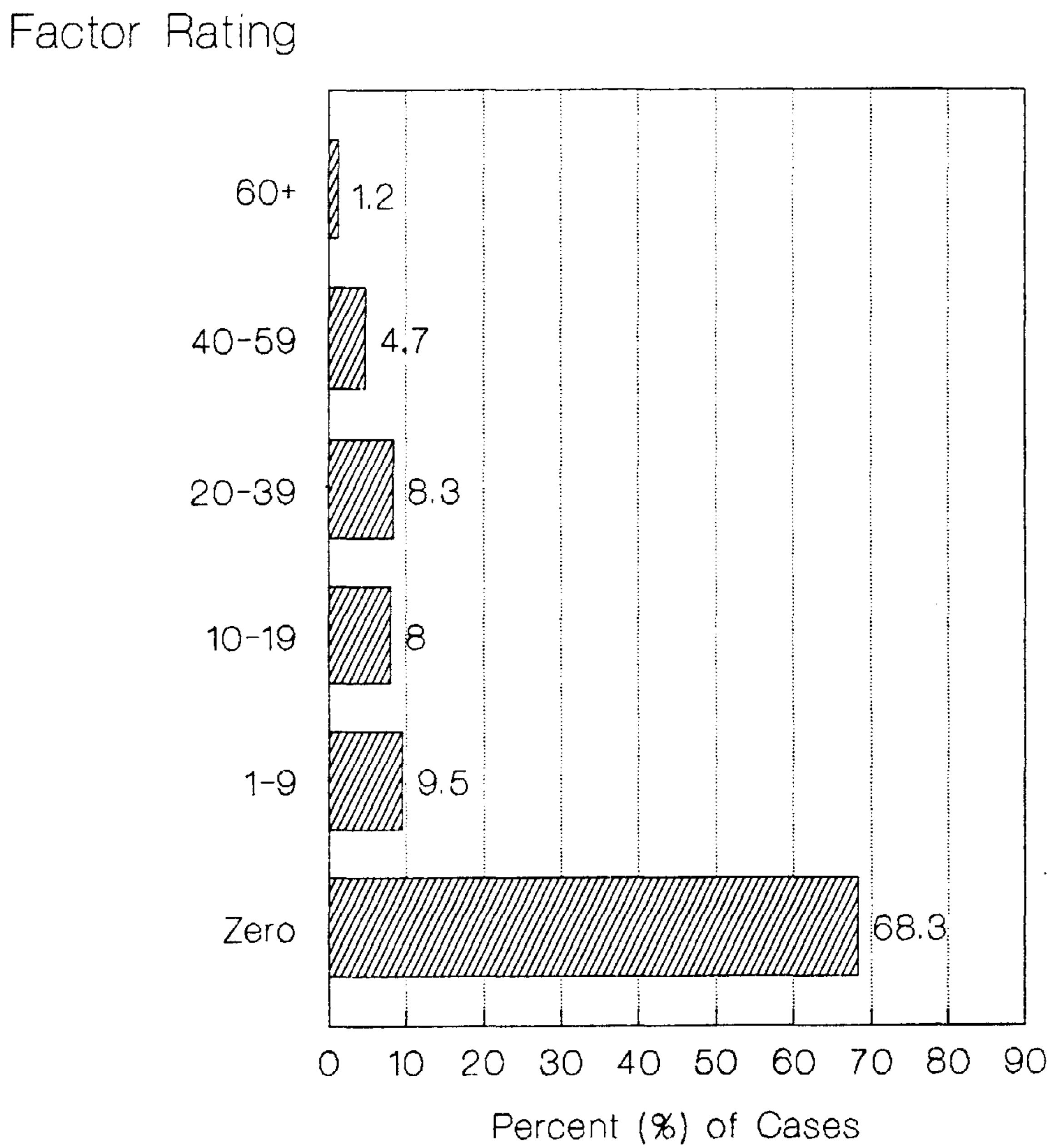

FIGURE 30. - Distribution of mean ratings for Perceptual-Cognitive-Motor Error-CW.

PCM Error-CW Primary Cases

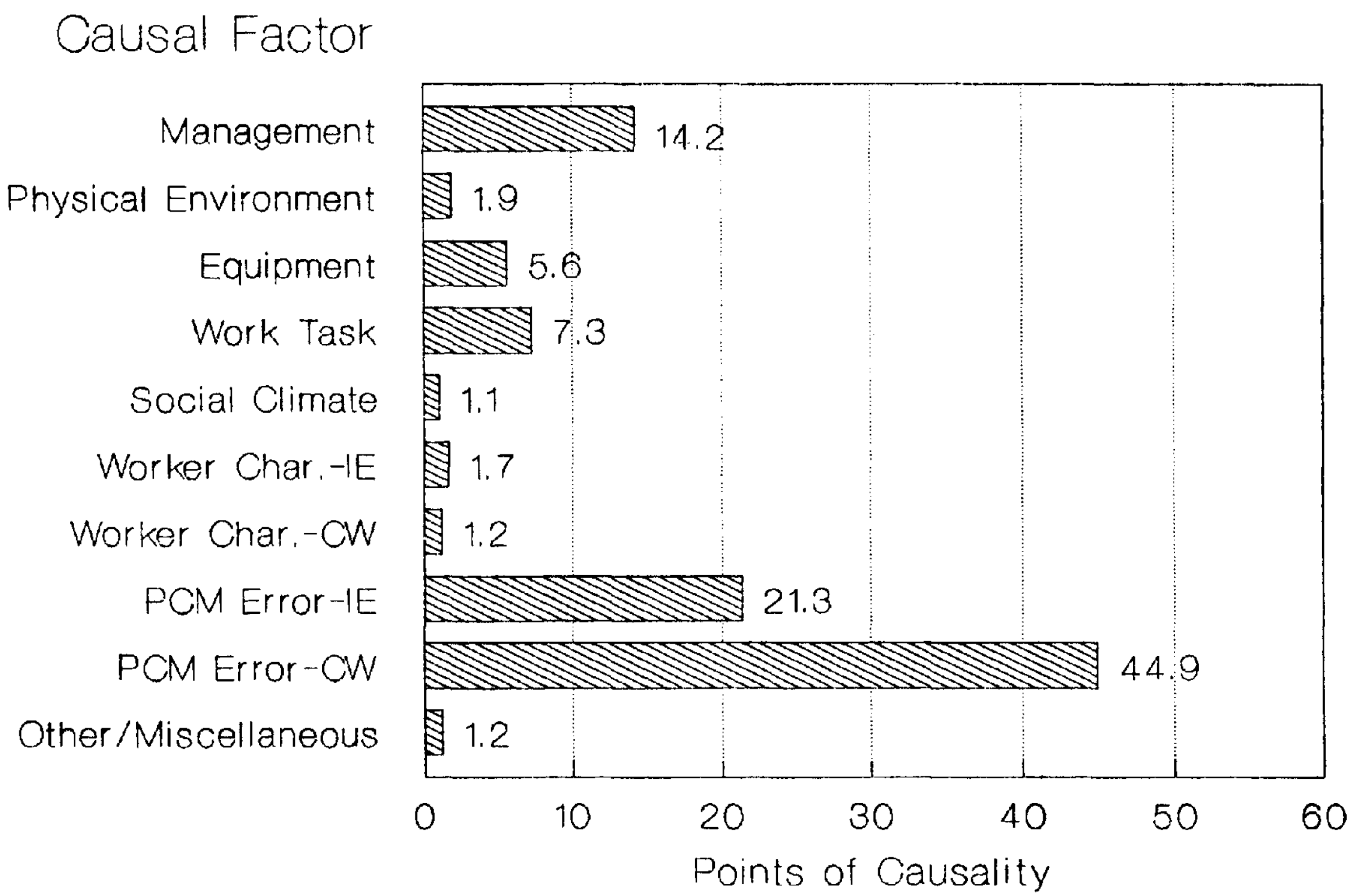

FIGURE 31. - Average causal involvement of each factor for those cases in which Perceptual-Cognitive-Motor Error-CW was a primary factor (n=34).

Other/Miscellaneous

The distribution of ratings across all cases for the other/miscellaneous factor are shown in figure 32. In almost 70% of the cases, the other/miscellaneous factor was not implicated at all. When implicated, however, this factor averaged 16 points of causality.

An example case where this factor was considered primary involved an unanticipatable rib failure.

> The IE had just pulled up in a golf cart to a telephone mounted in a permanent area of the mine. As he reached for the phone, a piece of coal directly behind the wood tool rack on which the phone was mounted fell and struck his elbow. There was no warning of the impending rock fall. The rock that fell was behind the rack and not visible to the employee. Had he arrived 10 seconds later, the rock would have fallen harmlessly to the ground.

Other/miscellaneous was considered the prime factor (86 points) because there was no warning or any way to prevent the accident; it was just bad luck.

The other/miscellaneous factor was implicated as a primary causal factor in only 16 cases (4.7%). This was anticipated because this factor was only implicated when no other factors could be implicated. The underlying causes (more than one underlying cause could be identified for each case) of this factor in the 16 cases in which it was considered primary included:

Unsafe conditions existed, but were undetectable by the worker, often despite complete and thorough inspections for the specific hazard (involved in 50% of the cases in which other/miscellaneous was a primary factor)
Information was available, but the quantity or quality of information was inadequate for the worker to positively identify hazards (43.8%)
All reasonable or mandated safety precautions were properly exercised, but accident happened anyway (32%)
A simple task mysteriously went awry (25%)
A condition was created by a distant and unrelated task or activity which unforeseeably injured an uninvolved worker (18.8%)

Figure 33 displays the mean ratings for the 10 contributing causal factors when "other/miscellaneous" was rated as primary. The lack of any other meaningful ratings, on average, further supports the element of chance (e.g., inability to attribute causality to any other contributing causal factor) in these cases.

Other/Miscellaneous

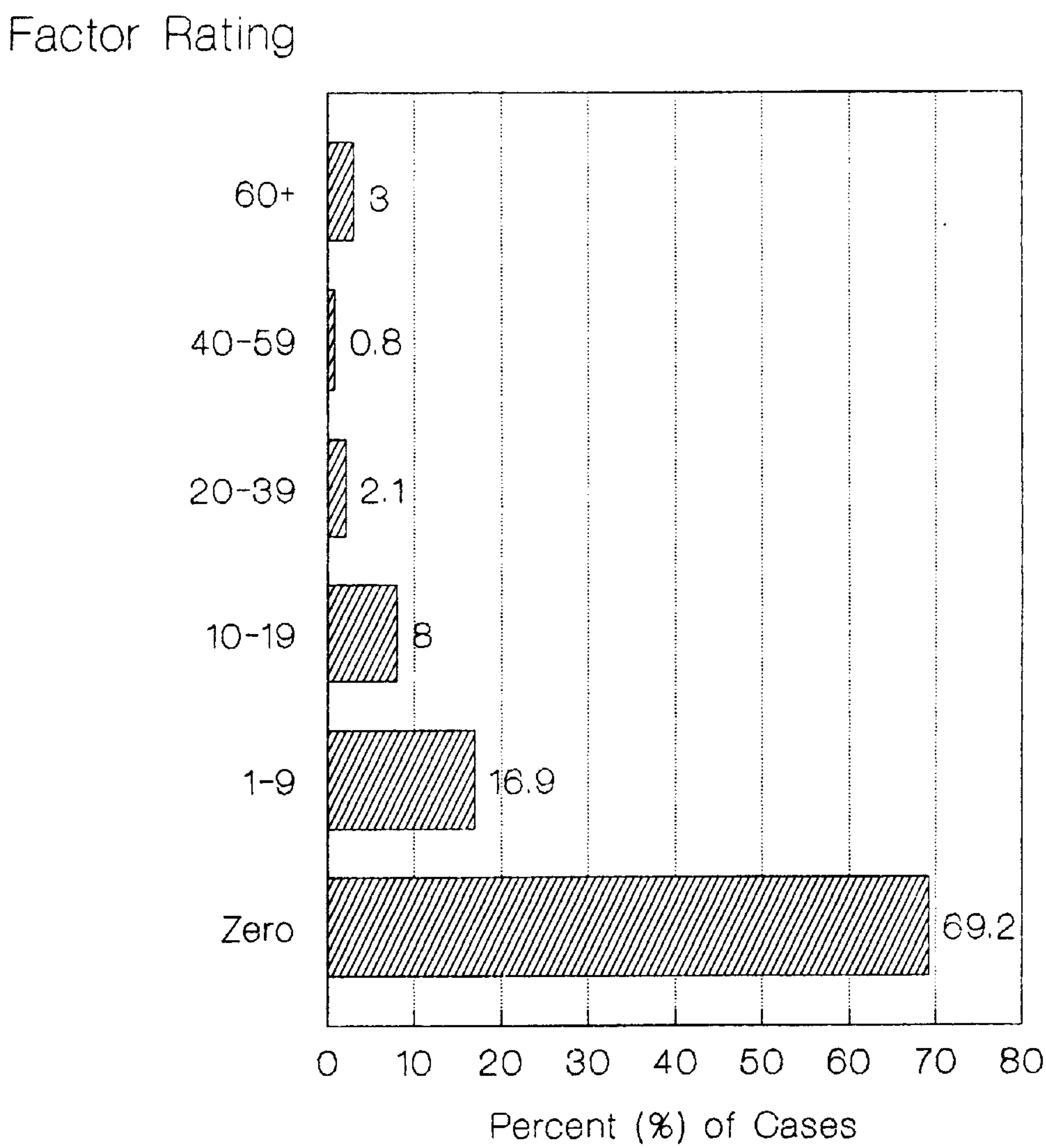

FIGURE 32. - Distribution of mean ratings for Other/Miscellaneous.

Other/Miscellaneous Primary Cases

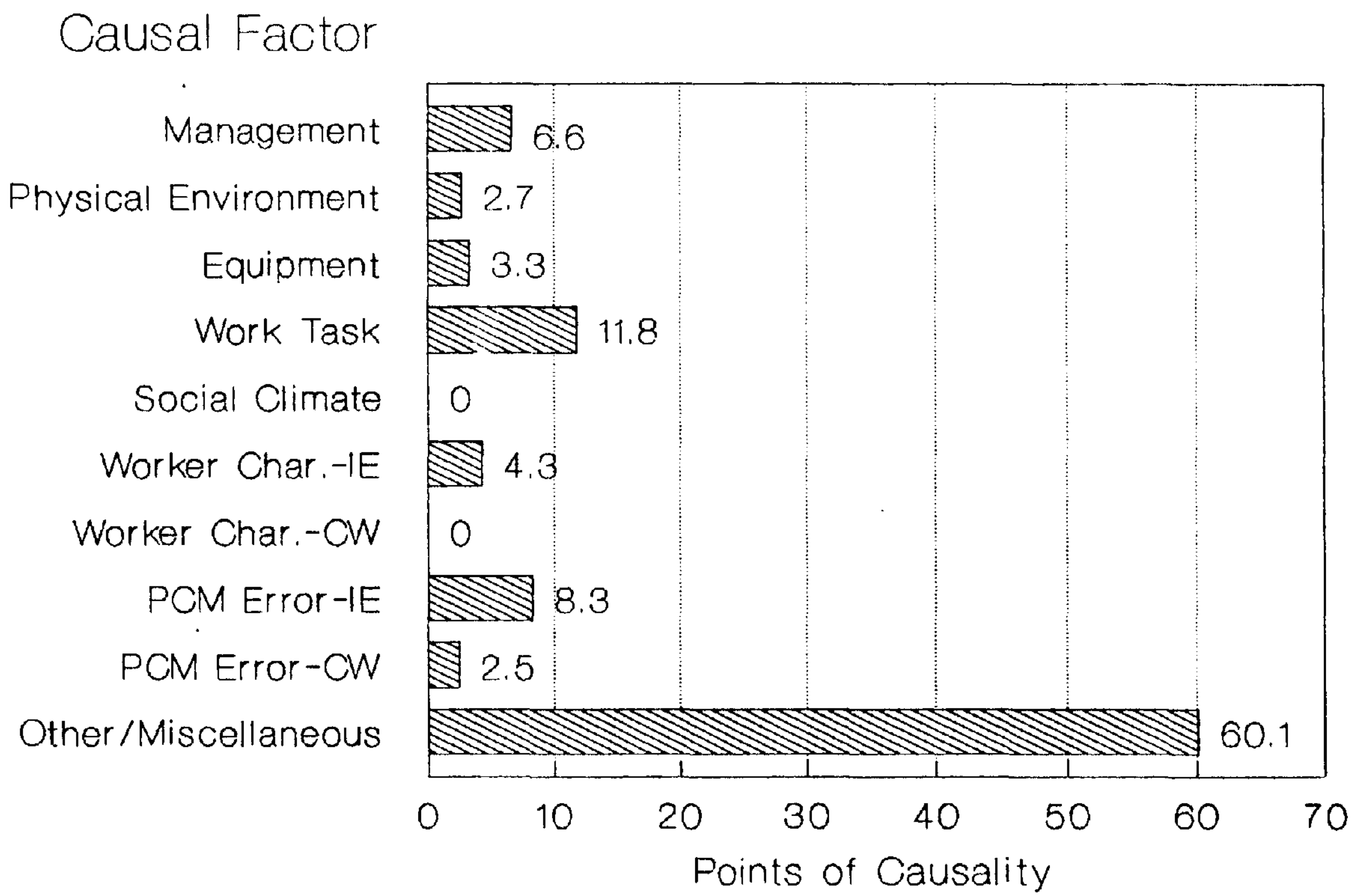

FIGURE 33. - Average causal involvement of each factor for those cases in which Other/Miscellaneous was a primary factor (n=16).

Contributing Causal Factors and Worker Experience

Age and worker experience variables (total mining experience, at mine experience, and in job experience) were correlated with the ratings given the 10 contributing causal factors across all cases. The purpose of this was to determine if there was any relationship between the two sets of variables. For example, did PCM error-IE tend to be rated higher in cases in which younger or less experienced workers were involved? The intercorrelation matrix is shown in table 25. All correlations were small (<0.15) and not statistically significant (p>.05). It does not appear that any of the contributing factors were related to age or experience in any systematic fashion.

TABLE 25. - Causal factors and worker experience variables: Correlation matrix

Factor	Total experience	At mine experience	Job class experience	Age of injured
MGT	-0.060	-0.001	-0.043	0.007
PE	-0.009	-0.093	0.027	0.002
EQ	0.056	0.034	-0.049	0.095
WT	-0.108	-0.127	-0.019	-0.075
SC	0.044	-0.001	0.133	0.015
WC/IE	-0.001	0.002	0.042	0.003
WC/CW	-0.053	-0.051	-0.073	-0.070
PCM/IE	0.053	0.054	-0.004	-0.010
PCM/CW	0.016	0.058	-0.014	0.028
OTHER	0.047	0.054	0.062	-0.033

Key:
- MGT - Management
- PE - Physical Environment
- EQ - Equipment
- WT - Work Task
- SC - Social Climate
- WC/IE - Worker Characteristics-Injured Employee
- WC/CW - Worker Characteristics-Co-Worker
- PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
- PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
- OTHER - Other/Miscellaneous

Contributing Causal Factors and Work-Related Variables

One-way Analyses of Variance (ANOVAs) were performed to compare the contributing causal factor ratings across various categories of work-related variables. The following work-related variables were analyzed: mining companies, mining method used, accident location, job classification of injured employee, and shift at time of accident. For each variable, only those values associated with sufficient numbers of cases to justify inclusion were examined for differences in mean ratings for each of the causal factors. By not including values with small numbers of cases, the results would be more stable and easier to interpret. ANOVAs yielding differences significant at the 0.05 level are discussed. Using the 0.05 level and performing a large number of analyses (10 factors x 5 variables) inflates the chances of making a Type I error (i.e., rejecting the null hypothesis when it is true). Given that this project and its results are predominantly exploratory in nature, it was felt that in the interests of uncovering potentially illuminating findings, the 0.05 level of significance would be considered acceptable rather than a more conservative level.

Table 26 presents the analyses that were performed, identifies those with statistically significant results, and indicates the percentage of variance in the causal factor ratings that is accounted for by each of the significant effects. Each of the significant effects is discussed below.

TABLE 26. - Causal factors and aspects of work: Summary of statistically significant analyses of variance and (in parentheses) percentage of variance accounted for

Factor	Mining company	Accident location	Job class of injured	Shift at time of accident
MGT	(3%) *	(4%) **	NS	NS
PE	(12%) **	(2%) *	(8%) *	NS
EQ	NS	NS	(8%) *	NS
WT	(3%) *	(5%) **	NS	NS
SC	NS	NS	NS	NS
WC/IE	NS	NS	NS	NS
WC/CW	NS	NS	NS	NS
PCM/IE	NS	NS	NS	NS
PCM/CW	NS	NS	(8%) *	NS
OTHER	NS	NS	NS	NS

NS Not significant.
*Significant at p<.05.
**Significant at p<.01.

Key:
- MGT - Management
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- EQ - Equipment
- WT - Work Task
- SC - Social Climate
- WC/IE - Worker Characteristics-Injured Employee
- WC/CW - Worker Characteristics-Co-Worker
- PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
- PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
- OTHER - Other/Miscellaneous

Mining Companies

The cases from 4 of the 5 mining companies were analyzed. A small metal/nonmetal room-and-pillar mining company was omitted due to an extremely small number of accidents (n=3) during the study period. The mean factor ratings are presented in table 27.

TABLE 27. - Mean rating factor as function of mine

	Mining company (number of cases)			
Factor	Metal/nonmetal Conventional stoping (n=75)	Coal (high) (n=78)	Coal (high) (n=161)	Coal (low) (n=21)
MGT *	17.9	18.7	13.6	6.9
PE **	3.8	5.9	7.2	21.7
EQ	13.2	8.3	8.2	8.1
WT *	16.6	12.8	16.3	27.1
SC	1.0	0.6	1.0	1.7
WC/IE	8.5	8.2	8.8	1.6
WC/CW	0.1	0.1	0.3	0.0
PCM/IE	29.5	31.1	33.1	23.8
PCM/CW	6.1	8.5	6.9	5.1
OTHER	3.5	6.0	5.0	4.6

*Significant at p<.05.
**Significant at p<.01.

Key:
- MGT - Management
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- WT - Work Task
- SC - Social Climate
- WC/IE - Worker Characteristics-Injured Employee
- WC/CW - Worker Characteristics-Co-Worker
- PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
- PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
- OTHER - Other/Miscellaneous

The management, physical environment, and work task factors were rated significantly different for incidents at the low-seam coal mine than for incidents observed at the other three mines. There are only small differences between the metal/nonmetal and the two high-seam coal mines.

The unique environmental influence of low-seam coal on accidents and tasks performed in such conditions resulted in significantly higher ratings on physical environment ($F(3,331) = 14.66$; $p<.01$) and work task ($F(3,331) = 3.55$; $p<.05$). The low-seam coal average ratings for both of those factors were more than 10% greater than the ratings on those factors for the other mining companies. This is directly attributable to the confined environmental conditions and the degrading effect of the low roof on task performance in low-seam mines.

Management was rated as a significantly lower source of accident causality in the low-seam mine ($F(3,331) = 3.42$; $p<.05$) than observed at the other mines. This may be, in part, an artifact of the ipsitive nature of the ratings and the fact that physical environment and work task were more highly involved in low-seam accidents.

Ideally, no significant differences should have been found between mining companies, the assumption being that all causal factors were equally operative across all of the sampled mine sites. Although statistically significant, the differences observed in the management and work task factor accounted for only 3% of the variance. The physical environment effect, on the other hand, accounted for 11% of the variance, but this finding is easily understood. All other causal factors showed a high degree of similarity in mean ratings across the sample.

Accident Location

The 338 accidents were categorized into four generic accident locations: maintenance areas, working sections, haulageways/travelways, and miscellaneous areas. Maintenance areas included underground shops, warehouses, battery/charging areas, and on-section maintenance areas. The working sections included stope/heading areas, faces/muckpiles, crosscuts/drifts, and power centers. Haulageways/travelways included all rubber-tire and rail roadways, conveyor lines, raise/dump/feeder areas, as well as ramp and shaft entries. Miscellaneous areas consisted of abandon/inactive sites, lunch/lavatory areas, underground parking/construction areas, and "unknown" locations. Since only 24 cases (7.1%) occurred in miscellaneous areas, that location was deleted from the analysis. Table 28 shows the mean causal ratings for the remaining three locations within the mines: maintenance areas, working sections, and haulageways/ travelways.

A significant difference in management ratings was found between accident locations ($F(2,311) = 6.395$; $p<.01$). Management was implicated to a greater extent in accidents occurring in both maintenance areas and haulageways than for accidents in the working sections. There was no significant difference between maintenance areas and haulageways. This reflects the attitude that management is more responsible for the design and maintenance of "fixed facilities," as well as work procedures occurring in them, than they are for evolving areas such as the working sections. Although management often plays a role in accidents occurring in the working sections, the ratings generally reflect a greater contribution of the work task to such accidents.

Physical environment was found to differentially contribute to accident causality ($F(2,311) = 3.065$; $p<.05$) across the three accident locations. Environmental factors were involved in working section and haulageway incidents (production areas) at more than twice the level than in maintenance facility accidents. Since maintenance facilities are fixed long-term sites, they pose few uncontrollable environmental hazards.

TABLE 28. - Mean rating factor as function of accident location

Factor	Maintenance areas (n=42)	Working sections (n=147)	Haulageways/travelways (n=125)
MGT **	16.5	12.0	19.9
PE *	2.6	7.8	7.9
EQ	10.2	9.1	10.5
WT **	11.2	20.3	13.0
SC	1.4	0.8	0.9
WC/IE	12.5	7.1	7.5
WC/CW	0.1	0.1	0.2
PCM/IE	34.5	31.8	28.3
PCM/CW	7.5	5.3	8.4
OTHER	3.1	5.9	3.6

*Significant at $p<.05$.
**Significant at $p<.01$.

Key:
- MGT - Management
- PE - Physical Environment
- EQ - Equipment
- WT - Work Task
- SC - Social Climate
- WC/IE - Worker Characteristics-Injured Employee
- WC/CW - Worker Characteristics-Co-Worker
- PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
- PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
- OTHER - Other/Miscellaneous

The inherent nature of the work task warranted significantly higher ratings ($F(2,311) = 7.607$; $p<.001$) in working section incidents than for either maintenance area or haulageway incidents. These findings acknowledge the inherently hazardous nature of work tasks and hazardous exposures involved in the mining and ground support activities in these areas. There was no statistically significant difference found between work task ratings in maintenance areas and haulageways.

Although statistically significant differences were found across accident location for management, physical environment, and work task, the differences were small and the accident location accounted for no more than 5% of the variance of any of the causal factors.

Job Class of Injured Worker

Ten job classifications had enough cases to be included in the analysis: Belt/ conveyorman, electrician, mechanic-repairman, stoping mason, laborer, faceman, continuous miner operator, roofbolter operator, shuttlecar operator, and shiftboss/ foreman. Table 29 shows the mean ratings for the causal factors for each of these job classifications.

TABLE 29. - Mean rating factor as function of job title of the injured employee

	MGT	PE*	EQ*	WT	SC	WC/ IE	WC/ CW	PCM/ IE	PCM/ CW*	OTHER
Belt/ conveyorman (n=14)	18.1	7.5	7.9	15.4	0.4	12.0	0.1	32.1	5.3	1.7
Electrician (n=10)	11.6	15.3	2.2	20.0	0.2	11.7	0.0	24.9	13.8	0.6
Mechanic-repairman (n=35)	13.2	7.5	7.2	12.5	1.4	11.7	0.0	36.1	3.7	6.9
Stoping mason (n=14)	16.5	3.6	1.8	14.3	0.8	13.9	1.1	39.5	8.7	0.3
Laborer (n=37)	20.6	6.4	12.4	14.4	0.6	5.9	0.4	25.2	11.6	2.6
Faceman (n=14)	7.5	3.4	18.3	15.1	1.4	11.1	0.4	33.1	4.9	4.8
Continuous miner operator (n=24)	10.0	5.1	6.4	18.4	0.2	7.5	0.1	39.3	6.0	3.3
Roofbolter operator (n=56)	14.3	11.9	7.9	17.8	2.0	7.6	0.1	31.4	2.7	4.8
Shuttlecar operator (n=21)	13.8	8.3	17.1	13.5	0.2	4.5	0.0	27.1	9.2	6.5
Shiftboss/ foreman (n=21)	4.7	1.3	3.7	14.6	0.7	9.1	0.6	45.8	12.7	7.1

*Significant at $p<.05$.

Key:
- MGT - Management
- PE - Physical Environment
- EQ - Equipment
- WT - Work Task
- SC - Social Climate
- WC/IE - Worker Characteristics-Injured Employee
- WC/CW - Worker Characteristics-Co-Worker
- PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
- PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
- OTHER - Other/Miscellaneous

The reader must be cautioned regarding the rather arbitrary nature of job titles. Although efforts were made to translate mine-specific titles into these generic categories based on task similarities, much overlap still exists between similar titles such as electrician and mechanic-repairman, as well as laborer and faceman. The present job classification taxonomy, also, primarily represents the coal industry since many metal/nonmetal mining job classes failed to meet the criteria (>5% of total cases) for inclusion in the analysis.

Physical environment, on average, tended to play a greater role in the accidents of electricians and roofbolters. Electricians are often called upon to perform repair work in confined spaces which would involve a physical environment factor. Roofbolters must contend with inherently unsafe roof conditions in which small rocks fall unexpectedly while bolting. Equipment tended to be implicated to a greater degree for incidents involving laborers, facemen, and shuttlecar operators. It is not readily apparent why laborer and facemen incidents tended to have higher involvement of equipment; however, in the case of shuttlecar operators, lack of adequate seating, operator cab design features, and lack of visibility (all equipment-related factors) contributed to most of the incidents involving this class of worker. PCM error-CW tended to be implicated to a greater extent when the incidence involved electricians, laborers, and shiftbosses/foremen. The reason is that these job classifications involve working closely with co-workers where an error on the part of the co-worker is more likely to cause an injury.

Differences between job classes tended to be small, with job classes accounting for only 8% of the variance of the significant factors (physical environment, equipment, and PCM error-CW).

Shift at Time of Accident

A comparison was made between day (n=129), swing (n=124), and night shifts (n=83). Two cases were deleted from the analysis due to missing shift data. There were no statistically significant differences between the three shifts for any of the causal factor categories. This indicates that the causal factors were probably equally operative in all shifts, despite the fact that the night shift in the sample mines was always a non-production maintenance shift.

Contributing Causal Factors and Accident/Injury Characteristics

The following variables were analyzed to assess whether differences in the rating factors existed between various features of the accident/injury: accident classification, nature of injury, part of body injured, and severity level of injury. Only selected values of these variables could be analyzed because other values had an insufficient number of cases to be included.

Table 30 presents the analyses which were performed, identifies those with significant results, and presents the percent of variance accounted for. Only the significant results will be discussed.

TABLE 30. - Causal factors and accident characteristics: Summary of analyses of variance

Factor	Accident classification (MSHA)	Nature of injury	Part of body involved	Severity of injury
MGT	(5%) *	(5%) **	NS	NS
PE	(14%) **	NS	(7%) **	NS
EQ	(7%) **	NS	NS	NS
WT	(11%) **	NS	(5%) *	(1%) *
SC	NS	NS	NS	NS
WC/IE	(19%) **	(16%) **	(14%) **	(5%) **
WC/CW	NS	NS	NS	NS
PCM/IE	NS	NS	(4%) *	NS
PCM/CW	(6%) *	(5%) **	NS	NS
OTHER	NS	NS	NS	NS

NS Not significant.
*Significant at p<.05.
**Significant at p<.01.

Key: MGT - Management
PE - Physical Environment
EQ - Equipment
WT - Work Task
SC - Social Climate
WC/IE - Worker Characteristics-Injured Employee
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PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
OTHER - Other/Miscellaneous

Accident Classification (MSHA Categorization)

Of the 36 categories of accident descriptors in the MSHA accident classification scheme, only seven were observed in sufficient quantity to warrant inclusion in this analysis. The mean rating for each category is presented in table 31. Significant differences were found on six rating variables: management, physical environment, equipment, work task, worker characteristics-IE, and PCM error-CW.

Management was found to differentially contribute ($F(6,323) = 2.20$; $p<.05$) to the various classes of accidents. The ratings were highest in situations where the worker was either struck by a flying object or caught between a moving and stationary object. A review of these cases indicated that these incidents tended to involve activities such as equipment operation and maintenance. These have a high requirement for management involvement in terms of job/task/SOP design, control/monitoring, and worker training. The categories receiving smaller average ratings tend to emphasize aspects which are beyond management control.

TABLE 31. - Mean rating factor as function of accident classification (MSHA categorization)

	MGT*	PE**	EQ**	WT**	SC	WC/ IE**	WC/ CW	PCM/ IE	PCM/ CW*	OTHER
Struck by stationary object (n=28)	11.7	7.9	17.7	10.9	0.6	4.9	0.2	32.8	11.1	2.5
Struck by moving object (n=18)	15.1	3.3	6.7	16.6	0.3	5.3	1.3	37.4	10.5	3.6
Struck by falling object (n=75)	15.4	13.9	6.2	22.2	0.2	2.7	0.1	29.7	4.2	5.9
Struck by flying object (n=24)	24.8	3.8	7.9	15.2	0.9	3.6	0.2	25.2	7.7	10.9
Caught between moving & stationary objects (n=39)	20.7	2.0	7.9	10.3	1.8	2.4	0.3	38.5	13.8	2.6
Bodily reaction (n=24)	11.7	6.8	15.6	10.2	0.6	16.4	0.2	29.5	6.0	3.2
Overexertion from lifting (n=31)	11.9	4.6	4.9	26.1	1.6	20.0	0.0	23.3	3.1	4.7

*Significant at $p<.05$.
**Significant at $p<.01$.

Key: MGT - Management
PE - Physical Environment
EQ - Equipment
WT - Work Task
SC - Social Climate
WC/IE - Worker Characteristics-Injured Employee
WC/CW - Worker Characteristics-Co-Worker
PCM/IE - Perceptual/Cognitive/Motor Error-Injured Employee
PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
OTHER - Other/Miscellaneous

Physical environment was implicated to a significantly higher degree ($F(6,232) = 6.35$; $p<.01$) for struck-by-falling-object incidents than for the other accident types. The struck-by-falling-object category consists almost entirely of fall-of-ground incidents, where the physical environment represents uncontrollable geological contributions to the causality of the accident.

Equipment design factors played a more significant role ($F(6,232) = 3.09$; $p<.01$) in struck-by-stationary-object and bodily-reaction incidents than all other classifications of accidents. Issues such as canopy design (adjustability limitations) and operator compartment design (ingress/egress issues) appear to have influenced these findings.

The work task factor was also significant ($F(6,232) = 4.9$; $p<.01$) with struck by falling objects (roof falls), and overexertion from lifting receiving significantly higher average ratings than the other accident classes. These types of accidents are often associated with inherently hazardous tasks such as repetitive lifting of heavy objects or being exposed to unstable roof conditions while bolting.

Characteristics of the injured worker played a role in bodily reaction and overexertion from lifting accidents, whereas it played essentially no role in any other accident classification. This typically represented some prior injury or weakness that predisposed the worker to injury in these cases.

PCM error-CW was differentially involved in the accident classifications compared ($F(6,232) = 2.63$; $p<.05$). The categories where PCM error-CW involvement was at its lowest were the categories where the behavior of individuals contributed least to the accident (struck by flying or falling objects) and where co-workers were usually not involved (bodily reaction, overexertion from lifting).

Nature of Injury

The following nature of injury categories were included in the analysis: contusion, laceration, fracture, dust in eye, sprain/strain, and multiple injuries. Multiple injuries were typically major contusions in conjunction with other injury types. Table 32 presents the means for the causal rating factors and each of these injury types.

Management was found to contribute differentially ($F(5,290) = 3.057$; $p<.01$) to the six major injury types. Accidents resulting in lacerations and multiple injuries had a higher average rating for management involvement than either sprain/strain or contusion injury accidents. A major source of lacerations was minor fall of roof during roofbolting. In these cases, management was rated as being causal because of an equipment selection tradeoff which favored ATRS-equipped roofbolters without canopies.

Injured employee worker characteristics was found to be significantly different ($F(3,290) = 11.30$; $p<.01$) across the types of injury categories. About half of the sprain/strain injuries were back injuries from overexertion and were determined to involve a predisposition to such injuries.

Involvement of PCM error-CW also displayed significant differences ($F(3,290) = 3.07$; $p<.01$). PCM error-CW was rated lower in dust-in-eye or sprain/strain cases than in the other categories. Both of these types of injuries almost always involved the injured worker with little involvement of a co-worker. There was no significant difference between the other injury types.

TABLE 32. - Mean rating factor as function of nature of injury

Factor	Contusion (n=70)	Laceration (n=56)	Fracture (n=37)	Dust in eye (n=13)	Sprain/ strain (n=108)	Multiple injury (n=12)
MGT *	13.6	22.0	18.2	18.4	11.7	22.1
PE	7.3	6.1	5.5	6.5	8.8	3.0
EQ	10.2	8.8	12.3	3.4	8.9	10.0
WT	16.3	18.5	12.1	21.9	16.7	9.4
SC	0.2	1.1	1.4	1.2	1.2	2.6
WC/IE *	3.7	1.6	5.0	0.5	16.2	2.8
WC/CW	0.5	0.2	0.0	0.0	0.1	0.7
PCM/IE	33.3	30.1	37.8	39.6	27.6	29.1
PCM/CW *	10.4	8.1	8.4	0.0	3.8	13.7
OTHER	4.9	3.9	2.4	8.7	5.3	6.9

*Significant at p<.01.

Key:
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- OTHER - Other/Miscellaneous

Part of Body

The part of body injured was collapsed into the following major body part categories for this analysis: face, head (excluding face), arm (excluding hand), hand, trunk (including chest and back), leg (excluding foot), and foot. All categories were observed in sufficient quantities for inclusion. The mean causal factor ratings are displayed in table 33. Significant differences were found in the physical environment, work task, worker characteristics-IE, and PCM error-IE factors.

Physical environment was rated significantly higher ($F(6,315) = 3.80$; $p<.01$) when there was a head or arm injury than for other injured parts of body. Head and arm injuries were most frequently caused by falls of roof during ground support activities. Ground support accidents have a high degree of causation due to physical environment; hence, these parts of body stand out as different from the remainder.

TABLE 33. - Mean rating factor as function of part of body

Factor	Face (n=31)	Head (n=25)	Arm (n=16)	Hand (n=89)	Trunk (n=90)	Leg (n=42)	Foot (n=29)
MGT	17.7	24.2	16.6	16.6	11.6	12.4	16.0
PE **	6.7	13.7	12.5	3.7	8.0	4.8	9.0
EQ	8.8	10.3	4.3	10.7	7.9	9.0	9.8
WT *	16.3	12.0	28.3	15.4	19.1	10.7	15.1
SC	0.9	0.9	0.2	0.9	1.0	0.7	1.5
WC/IE **	2.0	5.0	1.9	3.5	16.6	14.0	3.6
WC/CW	0.3	0.2	0.0	0.4	0.1	0.2	0.0
PCM/IE *	32.8	29.6	23.3	35.2	25.3	37.0	36.6
PCM/CW	6.8	3.9	1.3	9.5	5.7	6.0	6.5
OTHER	7.9	0.6	12.1	4.4	4.8	5.5	2.2

*Significant at $p<.05$.
**Significant at $p<.01$.

Key:
- MGT - Management
- PE - Physical Environment
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- WT - Work Task
- SC - Social Climate
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- OTHER - Other/Miscellaneous

The work task factor showed significantly higher ratings ($F(6,315) = 2.51$; $p<.05$) for arm and trunk injuries than for other body injuries. The higher arm injury ratings on work task are related to the high number of arm injuries sustained during ground support activities. Exposure to inherently hazardous environments, as well as exposure to inherently hazardous tasks, are associated with ground support tasks. These attributes have been identified as the principal underlying causes for implication of the work task factor. The high average work task rating for trunk injuries is driven by the preponderance of back injuries in this category. Although back injuries share a high component of worker characteristics or PCM error, most tasks which caused back injuries were noted as being inherently hazardous in nature due to requirements for repetitive motions and heavy lifting.

For the worker characteristics-IE factor, trunk and leg injuries were found to be significantly higher ($F(6,315) = 8.25$; $p<.01$) than all other injured body parts. Although the high rating on the trunk category is easy to explain (predisposition to back injuries in the majority of back injury cases), the peak in ratings, which is observed in leg injuries, cannot be easily explained.

PCM error-IE was rated lowest for arm and trunk injuries (F(6,315) = 2.32; p<.05). As explained above, the principal accident types for both of these categories share a high percentage of their causality with both physical environment and work task; therefore, the percentages for other factors are less. Part of body only accounted for 4% of the variance in PCM error-IE ratings.

Severity of Injury

The mean causal factor ratings were compared as a function of the severity of injury using only days-lost and doctor-visit-only (no days lost) incidents. The mean causal factor ratings are shown in table 34. Significant differences were found for the work task factor (t(303) = 2.1; p<.05) and worker characteristics-IE factor (t(303) = 3.8; p<.01). The difference observed in the work task factor is minimal, only 1% of the variance accounted for, and may be the result of Type I error.

TABLE 34. - Mean rating factor as function of severity of injury

Factor	Days lost (n=178)	Doctor visit only (n=127)
MGT	14.5	16.3
PE	7.3	6.9
EQ	9.2	8.5
WT *	14.1	18.5
SC	1.0	1.0
WC/IE **	10.7	3.8
WC/CW	0.2	0.2
PCM/IE	32.0	31.8
PCM/CW	7.4	6.7
OTHER	4.0	6.5

*Significant at p<.05.
**Significant at p<.01.

Key:
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The mean ratings for worker characteristics-IE, however, is more than double for days-lost than for doctor-visit-only incidents. Despite this large difference, severity only accounted for 5% of the variance of worker characteristics. Worker characteristics was implicated, principally, in situations where the worker had a predisposition to injury, such as a weak back or history of back injuries and these injuries tended to result in days lost rather than just a visit to the doctor.

Cluster Analysis of Cases Based on Causal Factor Ratings

The cases (n=333; 5 were excluded) were subjected to a cluster analysis in an effort to determine if unique patterns of causal factor ratings could be identified. Cluster analysis is an iterative process in which each case, initially, is considered a unique cluster, and then cases are combined to form larger and larger clusters. At the final iteration, only one cluster containing all the cases remains. Inspection of the results indicated that a 7-cluster solution might be interpretable. The causal factor ratings of all cases in a cluster were combined to establish the underlying causal pattern that generated that cluster. For the 7-cluster solution, table 35 presents the mean, minimum, and maximum causal ratings for the cases in each cluster. The results were clear-cut. Six of the seven clusters were based on high ratings on a single causal factor. One cluster represented cases with high ratings on work task and/or physical environment. It appeared, therefore, that the 7-cluster solution added little to what was already embodied in the causal factors themselves.

To explore further for potential multiple causal factor patterns, an 11-cluster solution was examined. It was hoped that by forcing more clusters, multiple factor patterns would emerge. The results are shown in table 36. The results were disappointing and difficult to interpret. Ten of the 11 clusters were again defined by a single causal factor. Worker characteristics-CW was involved as the single factor in three different clusters. Other/miscellaneous was involved as the single factor in two clusters. Further, five of the clusters had 11 or fewer cases. It became obvious that higher-order cluster solution would only involve stripping a few cases off the already existing clusters, but not enough to make any meaningful interpretations. Undoubtedly, the independence of the causal factors (see section titled "Factor Analysis of Contributing Causal Factors") contributed to the single factor patterns found in the cluster analysis.

Discussion

As hypothesized, the majority of cases (88%) involved multiple causal factors. The number of primary or secondary contributing causes, however, rarely exceeded three factors. The contributing causal factors were found to contribute to accident causality in varying degrees. The PCM error-IE factor was implicated in nearly all cases and two factors, management and work task, were implicated in about three-quarters of the cases. The social climate and worker characteristics-CW factors were found to be seldom implicated and, when implicated, contributed only a small portion of the causality.

The prevalence of PCM error-IE, implicated in almost all cases (averaging 33 points of causality), appears to be due to the high degree of responsibility accorded to individual miners. Individual miners are responsible for maintaining a safe workplace and performing their tasks in a safe manner. By law, mine workers are trained in the methods of assuring safety in the workplace. Since conditions are highly variable, always evolving, and working sections are typically spread over a wide area, close

TABLE 35. - Summary of causal factor scores for cluster analysis: 7 cluster solution

Cluster	No. of cases	MGT	PE	EQ	WT	WC/ SC	WC/ IE	PCM/ CW	PCM/ IE	CW	OTHER	
		9	4	4	11	1	7	0	61	2	1	Mean
PCM/IE	102	0	0	0	0	0	0	0	31	0	0	Min.
		39	29	36	40	24	38	4	98	17	14	Max.
		11	2	4	7	1	2	1	28	43	2	Mean
PCM/CW	35	0	0	0	0	0	0	0	0	21	0	Min.
		36	16	23	30	6	10	15	63	75	31	Max.
		50	6	7	9	1	2	0	18	6	1	Mean
MGT	54	30	0	0	0	0	0	0	0	0	0	Min.
		80	30	28	31	32	20	3	46	40	22	Max.
		8	19	6	41	0	1	0	17	3	5	Mean
WT & PE	67	0	0	0	0	0	0	0	0	0	0	Min.
		36	65	43	80	10	21	8	41	27	24	Max.
		5	4	2	13	2	53	0	18	1	2	Mean
WC/IE	32	0	0	0	0	0	33	0	0	0	0	Min.
		19	28	25	50	16	95	5	35	15	40	Max.
		8	3	4	13	0	1	0	8	0	65	Mean
OTHER	14	0	0	0	0	0	0	0	0	0	37	Min.
		35	12	19	35	0	10	0	31	2	90	Max.
		12	2	56	5	1	3	0	16	4	2	Mean
EQ	29	0	0	22	0	0	0	0	0	0	0	Min.
		36	10	96	18	29	29	0	40	30	15	Max.

Key:
MGT - Management
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PCM/CW - Perceptual/Cognitive/Motor Error-Co-Worker
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TABLE 36. - Summary of causal factor scores for cluster analysis: 11 cluster solution

Cluster	No. of cases	MGT	PE	EQ	WT	WC/ SC	WC/ IE	PCM/ CW	PCM/ IE	CW	OTHER	
		9	4	4	11	1	7	0	61	2	1	Mean
PCM/IE	102	0	0	0	0	0	0	0	31	0	0	Min.
		39	29	36	40	24	38	4	98	17	14	Max.
		11	2	4	7	1	2	1	28	43	2	Mean
PCM/CW	35	0	0	0	0	0	0	0	0	21	0	Min.
		36	16	23	30	6	10	15	63	75	31	Max.
		50	6	7	9	1	2	0	18	6	1	Mean
MGT	54	30	0	0	0	0	0	0	0	0	0	Min.
		80	30	28	31	32	20	3	46	40	22	Max.
		6	13	7	47	0	2	0	18	2	4	Mean
WT	56	0	0	0	13	0	0	0	0	0	0	Min.
		31	50	43	80	10	21	8	41	27	24	Max.
		6	4	2	14	3	50	0	20	1	0	Mean
WC/IE	29	0	0	0	0	0	33	0	0	0	0	Min.
		19	28	25	50	16	73	5	35	15	3	Max.
		3	2	4	11	0	1	0	6	0	74	Mean
OTHER	10	0	0	0	0	0	0	0	0	0	63	Min.
		12	7	19	35	0	10	0	20	0	90	Max.
		12	2	56	5	1	3	0	16	4	2	Mean
EQ	29	0	0	22	0	0	0	0	0	0	0	Min.
		36	10	96	18	29	29	0	40	30	15	Max.
WC/IE		0	0	0	0	0	59	0	1	0	40	Mean
&	1	0	0	0	0	0	59	0	1	0	40	Min.
OTHER		0	0	0	0	0	59	0	1	0	40	Max.
		20	5	4	20	0	0	0	12	1	40	Mean
?	4	3	0	0	0	0	0	0	4	0	37	Min.
		35	12	12	32	0	0	0	31	2	44	Max.
		16	48	4	20	0	0	0	10	5	7	Mean
PE	11	0	33	0	0	0	0	0	0	0	0	Min.
		36	65	25	27	0	0	0	20	21	22	Max.
Pure		0	0	0	2	0	02	0	7	0	0	Mean
WC/IE	2	0	0	0	0	0	88	0	2	0	0	Min.
		0	0	0	3	0	95	0	12	0	0	Max.

Key:
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supervision is almost impossible. When a mine worker was involved in a accident while performing a task in which he or she had been trained to perform, it was assumed that the worker was fully cognizant of the hazards. Therefore, when an accident occurred, the individual worker was almost always viewed as a contributor because he or she always had the last say regarding the manner in which the task was performed.

Two factors, management and work task, were implicated in about three-quarters of the cases, contributing an average of 20 points each. These represent two factors commonly associated with PCM error-IE. Management was often implicated in conjunction with PCM error-IE because of management's responsibility to develop safe operating procedures, enforce existing operating procedures, and provide proper equipment. These items constitute a large portion of the "basic knowledge- and tool-set" which the workers should have for making good decisions; without them, human errors are more likely to occur. Work task was implicated when it could be clearly identified that there was no conceivable or practical means of making the task or environment less hazardous. In short, some aspects of mining are simply hazardous by nature.

Equipment, including classical human factors design issues, was involved in half of the cases, averaging about 20 points of the causality. It appears that a significant number of accidents involve equipment design and that improvements in equipment design might reduce the frequency or severity of accidents.

Although generalities such as these can be drawn from the data, it is important to remember that the assessment of causality cannot be determined by formula. By virtue of the large individual differences in the mine workers, equipment, environment, and unique task demands of accident situations, each accident must be viewed as somewhat unique, and the unique features must be fully investigated before meaningful assessment of capability and countermeasures can be developed or successfully implemented.

RESULTS: COUNTERMEASURES

Overview

Raters supplied countermeasures for each case in which they thought a countermeasure would reduce the probability or severity of the accident or injury. These countermeasures were consolidated and content analyzed. The most commonly mentioned countermeasures dealt with management-related issues, principally providing proper equipment and enforcing standard operating procedures. Equipment design and training-related countermeasures were the next most common categories mentioned. Where possible, specific examples of generic countermeasures are presented.

Analysis of Data

As part of the rating process, the raters provided countermeasures they thought would reduce the probability or severity of the accident or the injury. Raters were not required to provide countermeasures for each case, and could provide more than one if they so chose. A total of 2,198 countermeasures were provided for the 338 cases rated by the members of the rating team. On average, the team supplied 6.5 countermeasures per case.

Because the ratings were carried out independently, it was common for several raters to suggest the same countermeasure on a case. The countermeasures for each case were reviewed and duplicates were consolidated into a single countermeasure for that case. This process yielded 743 countermeasures, an average of 2.2 unique countermeasures per case.

The countermeasures were then content analyzed, and grouped for discussion. The groupings are somewhat arbitrary, but an attempt was made to match the accident causation model adopted for this project. In many cases, a countermeasure dealt with more than one class of contributing factor. For example, providing proper equipment deals with equipment and management (not providing proper equipment). In such cases, a determination was made as to the most appropriate grouping for discussion. (In the above example, providing proper equipment was considered along with other management-related countermeasures.)

Countermeasures

Table 37 presents the generic types of countermeasures grouped into the following categories: Management, Job Assignment/Scheduling, Standard Operating Procedures, Equipment Design, Employee Training, Maintenance/Housekeeping, Supplies, Environment, and Other. Each of these categories will be discussed in turn.

Management

The main category of management-related countermeasure was to provide proper equipment to do the job or task. An analysis of the 88 "provide proper equipment" countermeasures showed a wide range of specific items mentioned by the raters. The largest single category mentioned was lifting aids (14 cases), followed by ladders (7), mechanical scalers (7), proper length scaling bars (4), and carousel roofbolter machines (4).

TABLE 37. - Countermeasures suggested

Countermeasure category	Number of cases
Management:	
Provide proper equipment	88
Enforce SOP	52
Enforce use of personal equipment	38
Provide better supervision	11
Discipline problem employees	6
Perform better safety analysis	6
Management/supervisor training	5
Other	3
Job assignment/scheduling:	
Job reassignment for injured employee	21
Schedule work/rest cycles for physically demanding tasks	5
Other	5
Standard operating procedures:	
Develop new SOP	60
Modify SOP	23
Other	4
Equipment design:	
Modify existing equipment	126
Develop new equipment	3
Employee training:	
Job performance training	90
Physical training and/or back injury control	40
Hazard recognition training	22
Counseling problem employees	11
Other	1
Maintenance/housekeeping:	
Better maintenance	31
Better housekeeping	22
Better inspection procedures	7
Supplies:	
Palletize bulk materials	9
Better logistical supply procedures	8
Environment:	
Modify environment	28
Provide warning	15
Other	3

The category of enforcement of standard operating procedures (SOPs) was mentioned in 52 cases. The largest single category of SOPs that was mentioned was related to roof control: inspecting roof and barring down (12 cases), and working near unsupported roof (3). Other SOPs mentioned more than once were de-energizing equipment and lock-out procedures (4), inspection of travelways (5), and manual materials handling (3).

Countermeasures dealing with enforcing the use of personal protective equipment specifically called out boots (ankle support, 3 cases; metatarsal protection, 5 cases; boot soles, 1 case), eye protection (12 cases), gloves (14 cases), and other or not specified (3 cases).

Six cases involved suggestions related to better safety analyses. Half of those dealt with reviewing the roof control plan to determine if it could be improved.

Job Assignment/Scheduling

In 21 cases, the raters suggested that injured employees should be reassigned to jobs that are less likely to cause a recurrence of the injury. In almost all cases, back injury was involved and the worker was placed on a job that required heavy and/or repetitive lifting. Unfortunately, union regulations often prohibit reassignment of a worker who has been injured if a doctor certifies the individual as fit for return to work. Back specialists often do not really know when a person is fit for work, and they often have no idea of what work the patient will perform when he or she returns to the job.

Related to reassignment of injured workers is the suggestion that work-rest cycles should be developed for physically demanding work (mentioned in 5 cases). Workers do not realize the need for a rest until they are very fatigued. Regulated work-rest cycles for specific jobs, it was felt, would reduce the likelihood of injury.

Standard Operating Procedures

Raters felt that new operating procedures were needed in 60 cases and that SOPs should be modified in 23 cases. Again, the specific items mentioned covered the full range of procedures from washing down floors, to removing a gear from a shaft. Some procedures were very specific, such as using a gripping tool to hold materials to be hammered, driving slow at low spots, lubing conveyor rollers while the belt is idle, and carrying a scaling bar on a grader. Some procedures were very general, such as freeing jammed ore cars, installing drive shafts on scoops, radio and visual signaling protocols, and stacking of stored materials.

Equipment Design

In 126 of the cases, raters felt that modifications of equipment would reduce the probability or severity of the accident or injury. Raters often suggested countermeasures related to equipment modification, but did not consider equipment design to be a major contributing factor to the injury case. The equipment was considered adequate or state-of-the-art, but the raters saw ways to improve it further. For example, in 21 cases, raters suggested the addition of lightweight canopies on roofbolters to prevent injury from small pieces of rock. The roofbolters were equipped with ATRS systems, and by law were not required to have additional canopies over the operator. The ATRS is designed to protect against fatal roof falls, but it is not very effective in protecting an operator from small pieces of rock that often fall and strike the operator's hands, head, and legs.

Several equipment design countermeasures pertained to reducing the amount of buffeting experienced by operators of mobile equipment, or the extent of injury resulting from hitting one's head on the underside of the canopy while tramming. The following were the specific recommendations (one case often resulted in several countermeasures): provide seat belts (12 cases), provide padded or suspension seats (8), pad the underside of the canopy (5), raise the height of the canopy to take advantage of the higher seam heights available (9).

The need to modify the egress features on equipment (handholds, footholds, ladders) was cited in eight cases. Other equipment design suggestions that showed up in several cases included: use of automatic air doors rather than manual (3 cases), better couplers (5), guarding of moving parts (5), and improved design for maintainability (12).

Employee Training

Improved job performance training was cited in 90 cases; hazard recognition training was cited in 22 cases. Physical training and/or a comprehensive back injury control program was cited in 40 cases. The following were the jobs or tasks mentioned for improved training in more than one case: roof inspection and sounding (15 cases), barring down or scaling roof (11), lifting (11), general training for inexperienced workers (9), conveyor belt-related tasks (4), crew communications (4), moving or hanging cable (3), walking to avoid tripping (3), shoveling (3), use of hand tools (3), changing tires (2), and detecting bad ribs (2).

Maintenance/Housekeeping

Recommendations regarding better housekeeping (22 cases) emphasized clearing debris, loose coal, and rock; repair of chuck holes in roadways; clean-up of spilled oil; wetting down to suppress dust; and removing water accumulations. Recommendations for better maintenance pertained to specific maintenance problems in individual cases. Recurring maintenance themes included: maintaining brakes on various types of equipment (4 cases), track (railway) maintenance (3), and maintenance of trolley wires and poles (4).

Supplies

Recommendations pertaining to palletizing movement of bulk materials was mentioned in nine cases. Items suggested for palletizing included timbers, concrete blocks, and oil drums.

Environment

Countermeasures dealing with modifying the environment were mentioned in 28 cases. Modifications to the roadway were the most common modifications suggested. The purpose was often aimed at reducing slipping hazards. Specific modifications included: grooving the floors (3 cases), reducing grade or slope (3), and providing drainage systems (2). Roof and rib support modifications were also suggested, including use of cross bar supports (1 case), mesh screen support (2), and timbers for ribs (1). Other modifications mentioned in more than one case were: more space to park vehicles on the track (3), improved lighting (3), lifting aids in supply and storage areas (2), increase roof height (2), and modifications of shop areas (2).

Recommendations for providing warnings were made in 15 cases. The warnings were principally directed toward unsafe track conditions (3 cases), and low-clearance areas (8).

Discussion

The countermeasures could be grouped into global categories (e.g., Management, Equipment Design), but beyond that, the suggestions were very case-specific and clear patterns were hard to discern. The three major categories of countermeasures were Management, Training, and Equipment Design, which is not really surprising. Recurring themes included countermeasures aimed at reducing injuries from rock falls (e.g., training in roof inspection techniques, enforcement of SOPs related to roof inspection and barring down loose rock/coal, and provision of canopies for roofbolters), back exertion (e.g., supplying lifting aids, reassignment of injured workers, and back control programs), and slips/trips/falls (e.g., better housekeeping and modifications of the roadways). These results are not surprising and probably represent fairly standard countermeasures addressing the typical types of injuries found in underground mining.

It is always easier to suggest a countermeasure after-the-fact, then to do it before an injury occurs. Providing warnings of low-roof area could, in some mines, result in a litter of warning signs. Posting a warning at an area where bumping one's head is common is a more reasonable suggestion. This, however, requires a history of accidents to determine where such a warning should be posted, i.e., an after-the-fact solution. In many cases, countermeasures would have to be applied to every piece of equipment because it would not be possible to predict which piece would be involved in the accident. In some cases, the cost would be prohibitive to apply the countermeasure across-the-board to all potential accident situations.

DISCUSSION AND RECOMMENDATIONS

This section discusses recommendations derived from this study. These recommendations are organized around four areas: The model of contributing causal factors (CFAC), the project methodology, specific findings based on the research conducted during the project, and observations of industry trends. Each will be discussed in turn.

Model of Contributing Causal Factors (CFAC)

The model of the 10 contributing causal factors (CFAC) developed for this study were rated by the multi-disciplinary rating committee, with a high degree of interrater reliability. The contributing causal factors, themselves, were found to be relatively independent and not amenable to further reduction by factor-analytic or cluster-analytic approaches. Factor analysis identified five factors; these factors exhibited high negative loadings and were difficult to meaningfully interpret. Cluster analysis identified clusters; however, the clusters tended to closely mimic a subset of the original 10 contributing causal factors.

Only one contributing causal factor in the model represented a loosely defined concept. The "other/miscellaneous" factor was defined as a catch-all category to explain the essentially unexplainable (i.e., chance or totally random events). Few cases implicated the other/miscellaneous category, and these cases involved an obviously high degree of chance or total unpredictability.

The combination of high statistical independence, low reliance on the other/ miscellaneous factor, and high interrater reliabilities on the averaged ratings provides a high degree of assurance that the contributing factors of the model can be reliably identified and rated by trained accident analysts. The 10-factor CFAC model, therefore, can be considered a valid tool for the evaluation of accident causality.

Methodology

Accident Investigation

The success of the project's methodology hinged on complete accident investigations and a trained group of expert raters. The use of a systems-approach investigation style enabled identification of valuable evidence that may have been overlooked by the more typical mine- or MSHA-investigation style approaches.

Access to information at the mines was also crucial to the conduct of thorough investigations. In typical investigations conducted by mining companies, the injured employee is the principal focus, often the sole focus of the investigation. This leads to limited data which is often biased by the injured worker to limit any implication of culpability. To identify contributing causal factors, various sources beyond the injured employee have to be consulted. A comprehensive investigation <u>must</u> include access to the "on-the-spot" supervisor's investigation notes, follow-up investigation notes and records, training records, and records of previous accidents, as well as interview access to co-workers, supervisors, mine managers, and mine safety personnel. These sources should be interrogated, and discrepancies in the information obtained should be resolved or explained.

The execution of a systems-approach to accident investigation proved to be practical in real-world situations. The in-depth investigations require about the same amount of time as most "typical" mine-conducted accident investigations. The average investigation took approximately 1 to 1-1/2 hours to perform. Most participating mines were willing to commit this amount of time in order to achieve a better understanding of an accident's causality.

Rater's Training

Prior to conducting the actual assessment of causality, a common understanding of the definitions and implications of each causal factor category was needed. In this project, the rating committee was brought together for a one-day group training session. Training involved the rating of several accident cases and a group discussion of the rationale that each rater used to evaluate a case. Some differences in ratings between various raters were expected due to differences in disciplines and background. Large amounts of unexplained variance in the ratings, however, were reduced by the training process.

Comments from Participating Mines on Methodology

Management personnel from participating mines commented that they learned about the importance of various contributing factors to accident causation from participating in this study. Many of them commented that their own investigations often failed to uncover some of the data that the project's systems-approach investigation uncovered. Specifically, some of the interactions between working groups have not come to light because the focus of a typical mine investigation is on the accident/injury event rather than on all factors influencing the event.

Many comments from mine management were directed toward the depth and breadth of the project's accident reports, in comparison to the reports made by mining companies and those provided to MSHA. Every mine that participated in the study commented on the large differences between the project's accident reports and their own reports. The typical accident report tends to directly address only the issues of the typical investigation, i.e., culpability, documentation of the accident/injury, and documentation of losses/compensation. This project demonstrated to the participating mines that it is possible to generate a report that fulfills MSHA and compensation requirements of accident and injury documentation, as well as identify sources of corrective actions for accident prevention using a systems approach to the investigation.

One of the participating mines performed an abbreviated version of the rater's training at an annual supervisors' training session. The session included members of the UMWA safety committee and mine management personnel, from shift supervisors to superintendents. The objective was to identify the breadth of contributing factors, and to conduct exercises to encourage more inclusive accident investigations and causality assessment. Although the full methodology was not implemented, the key elements of the systems approach and non-culpability-based accident investigations were promoted. The training session was reported to have generated considerable audience participation regarding the types of contributing factors that should be considered in determining the contributing factors of accident causality. In part, this resulted from the taxonomy of factors that was reported to be more structured and inclusive than the supervisors had ever experienced. Since the taxonomy was somewhat foreign, acceptance and understanding required interactive discussion and several structured exercises. Two hours were allocated for the training session.

As a result of the training, a significant change of perspective with regards to the basic causes, and the multiplicity of causes, of accidents was noted. The participants agreed that the procedure was interesting and beneficial to their understanding of the true causes of accidents.

Recommendations Based on Methodology

The participating mines' managers expressed the feeling that they were enlightened to a new perspective that they firmly believed to be of significant value for increasing overall safety awareness and promoting a proactive accident prevention program. This, however, should not be a one-time application of the methodology, but rather an on-going process based on an understanding of the various considerations of the systems approach. It is recommended, therefore, that technology transfer seminars be developed specifically for purposes of educating mining safety and production managers on the accident investigation and analysis procedures developed for this study. Furthermore, it is suggested that these seminars be extended to include MSHA inspection personnel so that MSHA's efforts can further benefit from the application of the systems approach to accident investigation and analysis used in this project.

Specific Project Findings

Assumption of Multi-Causality

The assumption of multi-causality of accidents, which was made at the outset of this project, was found to be true. Few accidents were found to be "purely" caused by a single causal factor; the majority of accidents involved more than one contributing causal factor. The number of contributing causal factors, however, were generally limited to three or fewer factors.

Factor Involvement

There was, as anticipated, a high incidence of human error involvement in accident causality. The majority of accidents involved some degree of human error, and most involved human error as one of the primary or secondary causal factors. The human errors that were identified involved assessment of risk by workers, including both risk-taking and misjudgment of risks. Other human errors involved the workers forgetting to do things they knew should have been done. The majority of the work tasks in the mining industry involved a great deal of individual worker autonomy and decision-making. When considered in isolation, many of the mining tasks in which workers are injured involve rather simple tasks or rote performance. Mining conditions, however, vary from situation to situation, and are often rather dynamic during the performance of a single task. This places a heavy burden on workers to be adaptive and analytic in their approach to performing mining tasks. Timesharing is also a factor in mine work, because workers must simultaneously monitor conditions for changes while performing other tasks.

The implication of management in accident causality tended to focus on more global issues, such as SOPs, training, and equipment selection/provision, rather than on direct involvement in the execution, or monitoring, of the mining tasks. Management's role was commonly viewed as providing basic knowledge of equipment operation and mining safety, machines and tools, and overall mine safety assurance. Management was implicated when these items were assessed to be missing, incomplete, or inaccurate. Perceptual-cognitive-motor error, either IE or CW, was implicated when the basic knowledge or tools were provided, but were not used or were not used properly.

For some time, there has been the notion that a company or the industry could achieve the goal of "zero accidents." The data from the present project, however, indicate that this is not likely. Accidents that were attributed to the other/ miscellaneous factor were so chance-based that there is likely to be no possible way of ever completely predicting or controlling them. The physical environment and work task factors also represent relatively uncontrollable accident causation factors, in the sense that these factors represent the inherently hazardous aspects of underground mining. Although zero accidents is an admirable but perhaps unachievable goal, it does seem that serious accidents can be eliminated by careful application of preventative countermeasures. Minor accidents will probably always be with us as long as mining involves humans and the use of heavy equipment in a hostile environment.

Recommendations Based on Specific Project Findings

The present study has produced a large amount of descriptive and causal assessment data on a broad-based sample of mining accidents. Although the data may be subject to some bias due to limited sampling of mining companies, these data represent a full consideration of all aspects of each individual case. Numerous types of analyses were conducted during the present project to extract as many meaningful findings as possible. Other researchers, however, may have different analytic approaches and questions. The data, therefore, should be assembled into a unified data base that would provide a valuable data source for future accident/injury causality research.

In addition to the current curriculum of general mine safety and specific job/task performance and safety training, consideration should be given to issues of information processing, risk-taking, and "adaptability" of the workers to novel situations. Because mining conditions are seldom static, workers must continually reassess situations to detect changes in conditions. As conditions change, the workers must adapt their behaviors to accommodate the current situation and cannot necessarily blindly rely on an SOP. This type of decision-making appears to be difficult for many mine workers, in part, because it is not facilitated by current miner training concepts.

A specific training issue that should be addressed is the development of performance strategies based on timely and accurate risk assessment of hazards and mining conditions by individual mine workers. The goal of such training must be to enhance the abilities of underground mine workers to make more accurate risk assessments, hence, reducing accident potential. One approach would be the development of an interactive training system where the workers are presented with realistic simulations of dynamic situations. Hazardous conditions and specific safety hazards would be identified and assessed for accident/injury potential. Interactions with other team members, both proximal and distal, can also be simulated for better indoctrination in the systems approach to hazard identification and evaluation. With immediate interactive feedback from the training system, and post-training debriefing from safety/training personnel, the hazard identification skills of workers could be modified for improved breadth and accuracy of hazard evaluation.

One media that exhibits potential promise for this type of training is the interactive video disk (IVD). In a dynamic training media like IVD, the evolution of hazards could be displayed, and the consequences of hazard-reduction activities, as well as the consequences of no activities, could be visually and/or auditorially simulated. Virtually all current miner training, except for OJT and "training-face" training, are static representations of dynamic tasks and environments. When dynamic, as in slide-tape, film, or videotape presentations, the sequencing of events is restricted to a fixed serial presentation. IVD offers the capability to dynamically adapt the training scenario to the unique interactions of each trainee. Trainee errors can be identified in a safe and non-destructive setting while graphically displaying the dangerous results of such errors. Furthermore, the training system can adapt the presentation of information in accordance with predefined measures of mastery rather than relying on the hope that the concept was mastered when first presented. There are numerous examples of successful implementation of this media for task performance and safety training that Essex Corporation (and others) has developed for the U.S. military and other non-military industries.

IVD training systems facilitate collection and reduction of user-response patterns and errors. It is conceivable, therefore, that such a training tool could also be beneficial to mine management, engineering, and safety personnel in the identification of system-wide strategies to use for reducing hazard potential. This type of unique training approach could be readily prototyped for a specific task, or class of tasks, and validated (quantitatively and qualitatively) in the mining industry. Expansion to additional tasks, after the initial system is developed, becomes a matter of the development of additional task-specific IVD modules.

The involvement of PCM error in a group of accidents was attributed to the worker "doing something the worker knew shouldn't be done." Many of these accidents included tasks that are so simple they are apparently taken for granted in current miner training. These tasks include walking through mining environments, manual materials handling, and basic shop safety practices. Although mine safety personnel consider these tasks to be as critical to mine safety as are specific production-related tasks, they often receive much less consideration in miner training. A lot of attention is given to the reduction of low-incidence, potentially high-cost accidents, and little attention is given to the reduction of high-incidence, lower-cost accidents. The situation, which is often not considered, is that despite the relatively small cost of accidents resulting from these incidents, they occur in sufficient quantities to equal (and maybe exceed) the cost of a single major incident. These "low-cost" but frequently occurring accidents should be recognized by the industry and MSHA as being of equal importance to the more dramatic incidents. Reduction of these accidents should be addressed through awareness/motivational programs, as well as through enforcement and training approaches.

Field Observations and Recommendations

This section will discuss several specific trends that were drawn from either the data or observations made during the data collection period. These include: ATRS versus canopy; mining equipment design "recommended practices;" unique accident causality patterns; involvement of co-workers in accident causality; and the lack of correlations between causal factors and worker experience. Each will be discussed in turn.

ATRS Versus Canopies on Roofbolters

A recurring trend was observed where roofbolter operators received minor lacerations/contusions from small pieces of falling roof. These pieces generally fell from areas above the operator station, in roof that had just been supported. The roofbolters involved in these accidents were ATRS equipped, with no supplemental canopy. Although there are numerous factors that contributed to these incidents, most of these injuries could have been averted had a canopy also been in place.

Roofbolter operators consider these incidents to be minor inconveniences, an integral part of the job, and part of the reason why that job classification is so well paid. The federal law currently requires an ATRS or a canopy, but not both devices. ATRS systems are being encouraged because of the improved protection from catastrophic roof failure. Supplemental canopies are often not desired because there are problems associated with the older style "elephant ear" canopies. Specifically, the boom cannot be positioned directly adjacent to the rib when installing the rib row of bolts.

The majority of these incidents involved no lost time, but the cost of these repeated incidents can add up to a significant annual cash outlay. There is, however, little incentive to reduce these incidents because MSHA regulations and criteria for roofbolting safety are currently being met. Furthermore, the bureaucratic headaches associated with certification of safety equipment modifications contributes to the tendency to accept the repetitive incidents of minor accidents while protecting against the single incident of major consequence.

Continued efforts should be directed toward a solution to situations such as this, especially with the increased requirements for ATRS-equipped roofbolters. Two approaches are advisable. First, efforts should be continued towards the development of innovative designs of lightweight roofbolter canopies to work efficiently in conjunction with ATRS systems. Second, attempts should continue to impact the decision-making processes of MSHA, legislators, and unions to improve awareness of situations such as this. Major catastrophes can be averted by the ATRS regulation, but additional injuries can be prevented if lightweight canopies are used in conjunction with ATRS systems.

Mining Equipment Design "Recommended Practices"

The equipment factor was involved in half of the cases. The equipment factor was very conservatively defined to include primarily human factors issues in terms of design and maintainability. This indicates a need for improved incorporation of human factors principles in mining equipment design.

In recent years, human factoring of mining equipment has been given considerable advertising exposure by several manufacturers. This equipment, however, does not yet exist in large numbers in the field. Most miners are operating older models/styles of equipment. As hardware attrition dictates replacement of equipment, the newer equipment will slowly be introduced.

Assuring that human factors principles are being fully and accurately considered is an effort that should be implemented in OEM design as a way of increasing safety and productivity. Currently, there are governmental efforts, via R&D contracts, to impact the design of mining equipment. Another approach that should be considered is the development of design guidelines such as the "recommended practices series" that the Society of Automotive Engineers provides for automobile and truck designers. Such an effort would provide, albeit indirectly, human factors expertise that may not currently be available in the OEM's design staff. Recommended practices should focus on both crew station design and design-for-maintainability issues.

Unique Accident Causality Patterns

During the data analysis, it was noted that back injuries from manual materials handling accidents/injuries were attributable to a consistent set of contributing causal factors. Most other accident/injury types displayed a much more varied pattern of contributing causal factors.

Back injuries resulting from materials lifting tasks were attributed, in great part, to the worker characteristics-IE and work task factors. The underlying causes of back injuries involving materials handling were predispositions to back injuries due to physiological weaknesses resulting from prior injuries of a similar nature, and the inherent hazards associated with manually lifting heavy objects.

Back injuries are currently being addressed by industry and industry-support organizations through a variety of means. Miner safety training and specialized "back schools" focus on basic education techniques of presenting miners with information that will allow them to perform manual materials handling lifting tasks in a "safe" manner. Once the training is presented, the responsibility for utilization of such knowledge is transferred to the individual workers. Mine management personnel encourage knowledge retention through regularly scheduled retraining presentations, informal OJT, and post-incident counseling.

Once a back injury occurs, it is often difficult to determine a worker's actual state of readiness to return to work. Workers often return to the same job in which the accident occurred. The high involvement of the worker characteristics causal factor suggests that there may be a continuing cycle of recurring back injuries. The minerals market has created a job market in which mobility between job classifications has become difficult. Workers who suffer back injuries may desire to change to a less physically strenuous classification, but openings may not be available. Mine operators are generally restricted by union contract from reassigning workers to other job classifications, even when such reassignments are in the best interest of the workers, the mine, and co-workers.

Back injuries associated with manual materials lifting are tightly defined in terms of contributing causal factors, so they are amenable to research efforts directed at accident reduction strategies. It is, therefore, recommended that the Bureau continue the inclusion of these back injury issues in upcoming research efforts. Ideas based on mechanical aiding, job redesign, training, and motivational techniques should all be further investigated in the quest for an effective solution.

Union, mine management/safety, and legislative representatives must be brought into some form of cooperative understanding to affect a solution to the problem of recurring back injuries. Involvement of the medical community is also warranted. Even in regions where mining is the dominant industry, there may be a deficit of knowledge about mining and mining tasks on the part of health care workers.

Involvement of Co-Workers in Accident Causality

Current accident investigation and causality assessment techniques focus directly, if not solely, on the actions of the injured workers. The present study has found that when a co-worker is involved, the level of involvement is typically quite significant. This finding must be disseminated to industry and mining enforcement personnel, along with the other considerations of a systems approach to accident investigation and causality assessment.

Miner training and refresher sessions should include the topic of teamwork and team interactions. Emphasis must be placed on both the immediate team interactions and communications, as well as the more distal implications of teamwork (e.g., inter-shift and inter-work group cooperation and planning). Motivational techniques could also be explored to foster a greater sense of mine-wide team spirit and cooperation.

Lack of Correlations Between Causal Factors and Worker Experience

There were no statistically significant correlations between causal factor involvement and any measure of worker experience. This indicates that the causal factors are equally operative across the entire range of mine worker experience. This may appear to run counter to common opinion, which seems to believe that more experienced workers are less prone to the commission of human errors. The present study could not look at the propensity of workers toward making human errors in terms of probability. It was found, however, that when miners have accidents, human error is equally involved across the entire range of worker experience.

Closing Comments

Success was achieved in this project by developing an effective systems approach to mining accident investigation, validating a reliable causality assessment methodology, defining a taxonomy of contributing causal factors, and identifying the frequency and causes of mining accidents. Due to the large individual differences between mines, mining companies, mining technologies, etc., the development of countermeasures for the reduction of mining accidents was not fully satisfying. This type of effort is more amenable to small-scale (mine-level) studies rather than industry-wide overview research.

Numerous recommendations were developed based on the data analyses and observations that were made during the data collection efforts. These ideas must be further investigated and evaluated in terms of potential accident reduction and cost-benefit tradeoffs. It is clear from the project findings that mining accident investigation and analysis must be encouraged to evolve toward the full breadth of causal considerations that are included in this present study. This appears to be both achievable and within the desires of many industry people. Expansion of these considerations to federal and state mining enforcement people should be encouraged in order to form a more consistent approach toward mining accident reduction. It is apparent that mining accidents cannot be totally eradicated, but there is a high probability that mining accidents can be further reduced through the implementation of some of the recommendations developed from this study.

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