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Safety Evaluation Methodology for Advanced Coal Extraction Systems

Wayne F. Zimmerman

July 15, 1981

Prepared for
U.S. Department of Energy
Through an agreement with
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ABSTRACT

To be acceptable to the coal industry, an advanced extraction system must provide a significant improvement over conventional systems in cost, safety, environmental impact, and conservation of unmined coal. Qualitative and quantitative evaluation methodologies were developed to assist the designer in determining if a proposed extraction design will be safer than existing systems. The qualitative analysis is a process which tests the new system against regulations and hazards of existing similar systems. The analysis examines the soundness of the design, whether or not the major hazards have been eliminated or reduced, and how the reduction would be accomplished. The quantitative methodology provides the designer with a means of establishing the approximate impact of hazards on injury levels. The results are further weighted by peculiar geological elements, specialized safety training, peculiar mine environmental aspects, and reductions in labor force. The outcome is compared with injury level requirements based on similar, safer industries to get a measure of the new system's success in reducing injuries. This approach provides a more detailed and comprehensive analysis of hazards and their effects than existing safety analyses.

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FOREWORD

This document is one of a series which describes the methodology for evaluating advanced underground coal mining equipment. This methodology is summarized in "Overall Requirements for an Advanced Underground Coal Extraction System," JPL Publication 80-39 by Martin Goldsmith and Milton L. Lavin. Five areas of performance are discussed:

(1) Production cost.

(2) Miner safety.

(3) Miner health.

(4) Environmental impact.

(5) Recovery efficiency.

The report presents the detailed safety methodology used to evaluate advanced designs.

This work is part of an effort to define and develop innovative coal extraction systems suitable for the significant resources remaining in the year 2000. Sponsorship is provided by the Office of Mining, United States Department of Energy, via an interagency agreement with the National Aeronautics and Space Administration. William B. Schmidt, Director of the Office of Mining, is the project officer.

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It is with great pleasure that I acknowledge the assistance received from Milt Lavin, Martin Goldsmith, and Kent Frewing, who provided essential guidance in the development of the safety assessment methodologies. I would also like to acknowledge the help of Leonard Larsen of the Mining Health and Safety Administration, who provided essential data.

DEFINITION OF SYMBOLS

B_j	The historical aggregate number of yearly body injuries for a given accident class j, associated with a conventional design used as a comparison against a protective feature of a new design.
b_j	The aggregate projected yearly body injuries in a given accident class j, for a new design.
d_j	The fractional adjustment in injuries of a given accident class j, based on the consensus of a group of experts pertaining to a new protective device.
f_i	The fractional change in the labor force for a given task; between a new design and an analogous conventional comparison.
g_i	The fractional adjustment in injuries for a given task i, based on the consensus of a group of experts pertaining to a new design.
N_i	The historical yearly injuries associated with a given task, of an analogous conventional system used as a comparison against a new design.
n_i	The projected yearly injuries for a given task i, of a new design.
R_i	The ratio of serious injuries to all injuries for a given task i, for a conventional system used as a comparison against a new design.
S_i	The projected number of yearly serious injuries for a given task i, of a new design.
t_i	The time (hours) exposed to a given hazard for a task i, as performed in a new design.
T_i	The time (hours) exposed to a given hazard for a task i, as performed in a conventional system used as a comparison against a new design.

CONTENTS

APPENDIX

<u>Figures</u>

Tables

SECTION I

INTRODUCTION AND SUMMARY

A. OBJECTIVES

Coal mining has experienced rates of temporary and permanently disabling injuries and fatalities two to three times greater than other occupations. Table 1-1 presents a summary of injury statistics compiled by the Mining Safety and Health Administration (MSHA) and the U. S. Department of Labor for the period 1972 through 1978, for underground coal mining and four similar industries.

The growing need to supplement diminishing oil reserves has suggested a greater commitment to the use of coal, and a requirement for increased coal production through the development of advanced coal extraction systems. To meet this commitment, advanced systems should provide a number of improvements over existing systems. Among the desired improvements is a reduction in underground coal mining disabling injuries and fatalities from those shown in Table 1-1. One of the primary objectives of the Jet Propulsion Laboratory (JPL) Advanced Coal Extraction Systems Definition Project is the reduction of miner injuries and fatalities to levels comparable to other heavy industries

Table 1-1. Average Injury Rates in Selected Industries for the Period 1972 Through 1978

Industry	Aggregate Injuries Per Million Man-Hours	Fatalities Per Million Man-Hours	Disabling Injuries Per Million Man-Hours
Underground Coal Mining (for Central Appalachia)	105.3	0.4	58.2
Construction	84.6	0.2	29.2
Primary Metals	90.5	--	32.0
Non-Metal/ Metal Mining	30.7 - 37.7	0.3	18.0 - 23.3
Petroleum	63.4	0.3	28.5

Sources: MSHA Injury Statistics (1971-1979) Occupational Safety and Health Administration (OSHA) Injury Statistics (1972-1978) such as the ones shown in Table 1-1. This requirement was published as part of Goldsmith's and Lavin's Overall Requirements for an Advanced Underground Coal Extraction System (1980)(1).

The purpose of this safety evaluation methodology is to provide a procedure which can be used to determine if proposed new mining systems will satisfy the safety requirements. The procedure compares proposed advanced systems with conventional equipment, and with other industries, to assess the likelihood of reducing miner disabling injury and fatality rates by 50%.

B. SAFETY REQUIREMENT SUMMARY

The safety requirements, published in the Overall Requirements document, were formulated so that advanced underground coal mining would match the safety performance of comparable industries, and so that the hazards contributing the largest number of fatalities and disabling injuries would be reduced. The concept of injury frequency was approached using the four industries listed in Table 1-1, because of their similarity to coal mining in terms of both the types of hazards encountered and the severity of accidents which occur. Although the aggregate injury rate for coal mining is already within the range of two of the four industries, the fatality and disabling injury rates for coal mining are approximately two times higher than the four similar industries. It was concluded that the safety requirement should stimulate a reduction in deaths and disabling injuries. Also, the requirement should be stated in a way to allow for changes in the injury and fatality rates in both coal mining and the comparable industries during the ten- to twenty-year period required for the development of new technology. These conclusions resulted in the following statement of the requirement:

> AT THE ANTICIPATED TIME OF FIRST COMMERCIAL USE, ANY ADVANCED UNDERGROUND COAL MINING SYSTEM MUST HAVE RATES FOR FATALITIES, DISABLING INJURIES, AND TOTAL INJURIES WHICH FALL WITHIN THE RANGES OF RATES EXPERIENCED BY INDUSTRIES WHICH ARE JUDGED TO HAVE COMPARABLE HAZARDS.

The requirement requires a projection into the future of all three categories of injuries; however, examination of the fatality and disabling injury rates revealed no particular trend for coal mining or for any one of the comparison industries. Therefore, the fatality and disabling injury requirement was projected by extrapolating the industry experience of the seven-year period, 1972 through 1978. The total injuries were projected using the industry experience and by assuming that the ratio of severe and disabling injuries to total injuries would remain constant based on the most recent eight-year injury history from MSHA. This yielded the following target rates:

(1) Total injuries: 40-45/million man-hours

(2) Disabling injuries: 30/million man-hours

(3) Fatalities: 0.2/million man-hours

These targets are based upon projections which may prove to be pessimistic as technology evolves.

Both frequency and severity were also addressed by identifying which hazards contribute most to serious injuries. Examination of fatality and disabling injury rates for Central Appalachia (currently the major source of underground production) indicated a consistently high contribution from roof and face falls, haulage accidents (mostly in the form of pinch and squeeze injuries), other machinery-related accidents, and injuries sustained while handling material. Table 1-2 indicates that these four hazards have continually accounted for more than 75% of all serious injuries during the period 1972 through 1978.

The safety methodology for evaluating new concepts was established after the performance goals were determined. The following sections summarize the current studies used to develop the foundation for the safety methodology, and also provide a description of the methodology. Flow diagrams are provided to show how the MSHA injury data and other pertinent information are used to assess new concepts and determine whether they meet the prescribed safety requirements.

C. CURRENT PRACTICE AS RELATED TO THE SAFETY METHODOLOGY

The framework of the methodology for evaluating advanced coal extraction systems against the requirements was developed around the existing MSHA injury reporting format, using recent studies pertinent to the evaluation of system safety. The MSHA injury reporting format most useful for this study was the tabulation of fatalities, disabling and nondisabling injuries as a function of

Table 1-2. Average Percent Contribution to Serious Injuries from the Major Accident Causal Categories

Accident Causal Category	Avg % Contribution to Fatalities (F) and Disabling Injuries (DI)	
	F	DI
Roof/Face/Rib Falls	47	15
Haulage	23	16
Machinery	14	15
Handling Material	0	32
*Subtotal	84	78

*NOTE: This list does not include remaining accident classes which make up the total injuries.

Source - MSHA Injury Statistics (1972-1978) major accident cause (such as machinery or electrical), and the activity at the time of the accident. This information formed the data base for the detailed comparison between new and conventional systems.

The safety methodology examines new designs through two stages of development: the "conceptual design" and "preliminary design." In organizing the methodology, it became clear that at a conceptual stage, where only the basic architecture is known, it sufficed to identify new system hazards and potential advantages of the new design (qualitative analysis). Several ideas from the system safety literature were drawn upon to design this part of the evaluation. One hazard evaluation technique is "fault tree analysis," which links together events, or combinations of events, that must occur to result in a hazardous condition. This is a powerful tool for identifying hazards and determining their impact. Chugh, et al., used the technique in their paper, "Metallic and Nonmetallic Mining in the United States - A Hazard Analysis" (1974)(2). The fault-tree analysis is also useful for evaluating hazard and task relationships. In "Risk Assessment Methodologies: An Application to Underground Mine Systems" (1978), Denny, et al., used fault-tree analysis to examine cause and effects in the 1972 Sunshine Mine fire disaster (3).

Since the conceptual design stage contains little detailed information on worker interaction with particularly hazardous events or components, it is more useful to identify general worker-subsystem relationships that have historically resulted in many injuries. A checklist showing these generally known relationships allows an easy examination of new designs to assess their basic merits. There are many kinds of checklists for displaying the main hazard-event or hazard-subsystem relationships. "Layered" or "cross-tabulation" accident-injury structures provide cause and effect information for hazard assessment. The advantage of this approach is that an evaluator can easily go from a particular hazard to a characteristic injury and accident situation, or vice versa. Such an approach is discussed by Blumenthal in "An Alternative Approach to Measurement of Industrial Safety Performance Based on Structural Conception of Accident Causation" (1970)(4); and by Ramsey in "Identification of Contributory Factors in Occupational Injury" (1973)(5).

The more detailed cause and effect type information which can be developed during preliminary design allows better definition of how and to what degree workers are exposed to hazards (quantitative analysis). Workers experience exposure to hazards by the nature of the tasks they perform, their proximity to sources of hazards (such as unsupported roof or operating machinery), the amount of time spent doing tasks, and the amount of protection afforded. This type of information provides the basis for making projections about new system safety performance as compared to the safety of existing systems.

One way of handling the concept of "exposure" and its relationship to the adverse effects of various hazards has been to develop "exposure indices." For example, in "Development of Health and Safety Indices for the Evaluation of Underground Coal Mining Systems" (1973), Pfleider and Krug developed subjective hazard indices for noise and dust (6). Indices reflecting hazard severity were based principally upon the amount of time a worker is exposed, and the noise or dust rating (for a given machine or work area) in accordance with OSHA and MSHA standards. Frantz and King used the concept of exposure indices to project the safety impacts from remotely operated continuous miners in their paper, "A Study of Human Factors Aspects of an Automated Continuous Mining Section" (1977) (7). These indices, based on the percent change in number of workers, or worker man-hours, were used to measure the reduction in exposure to various hazards. In addition, there have been several industrial engineering studies of the specific mining tasks (and task times) that expose workers to hazardous situations. A good example of this work is the study done by Theodore Barry and Associates in "Operating Practice Changes and Control Modifications to Improve the Safety of Coal Augering Operations" (1975) (8).

The references cited above, as well as many others (9,10), represent well conceived approaches to assessing hazards, defining exposure, and identifying ways of reducing risk. The concepts developed in this paper draw on these approaches and suggest some refinements that may provide a more comprehensive, quantifiable assessment of hazards.

D. SUMMARY OF SAFETY EVALUATION METHODOLOGY

The strength of this methodology stems mainly from (1) a complete analysis of potentially hazardous system failures, (2) an analysis of the human interfaces with hazardous system and geological failures, (3) consideration of the variation in exposure to hazards during the performance of various tasks, and (4) consideration of ways to reduce both exposure and hazard severity so as to bring injuries down to a level commensurate with the requirements.

Since advanced systems may not resemble existing architectures at all, it is extremely important to examine each design by itself to understand how workers are exposed to both existing and new hazards. The following general steps indicate the normal process for evaluating system safety:

(1) Assess areas of potential hazard.

(2) Identify areas of adverse effect.

(3) Relate exposure with effect.

(4) Estimate the safety impacts.

(5) Determine whether the impact is sizeable.

The methodology presented here follows this basic process, and also accounts for the uncertainty involved with completely new architectures. For example, in order to assess areas of potential hazards, the system and environment are broken down into their respective components. Each component is examined by itself, and as it interacts with other components, with the purpose of understanding how they may fail and cause a hazardous situation. This is important because new systems may introduce new hazards which cannot be assessed until the detailed failure modes are understood. The identification of possible adverse effects follows directly from understanding how workers interact with system failures. Human factors analysis, which examines the interface problems between users and hardware, provides the basis for understanding these interactions. The results of both of these steps then provide the potential hazards that could be present and comprise the actual hazard analysis.

At the conceptual design stage, the basic architecture is known, along with some additional information on how the system will operate, and in particular, the structure of essential worker tasks. If there are several new systems to be evaluated, it is important to choose the most promising systems before further development costs are incurred. This can be done by performing a system hazard analysis, as described above, and then comparing the new systems against similar, existing systems to identify improvements. This methodology can be used to perform this initial elimination process before performing a more detailed analysis on those designs considered most promising. This initial analysis is also important because it directs the evaluator toward the strong areas of the design that should be evaluated more closely later on. A flow chart of the conceptual stage analysis is presented in Figure 1-1.

Figure 1-1 shows that the actual system comparison process requires both an examination of general conformance with safety regulations and hazards. From the hazard analysis, it is relatively clear as to how the system will interact with workers. Using a similar, existing system as a basis of comparison, the new system is tested to see if it meets the intent of the safety regulations designed to protect workers. If it does, then the system is examined to determine what hazards are potentially removed or added as compared to existing systems. Finally, the results of the system failure and human factor analyses are used to determine where the new system streamlines equipment or operations so as to reduce exposure time, or if it provides more worker protection. If a new system potentially offers either of these advantages, then it is considered promising and worth investigating further.

The next stage in the methodology is to gather preliminary design data and examine new designs more closely. These data include task times and descriptions, production rates, crew sizes, protective devices, and machinery redesign possibilities. The same data pertaining to task times, production rates, crew size, etc., are collected for the contemporary equipment selected for comparison. Also tabulated are historical injury experiences related to the major hazards associated with the various conventional tasks. As shown in Figure 1-2, the analysis process at the preliminary design stage is more detailed than the conceptual stage evaluation.

The two systems are compared from the standpoint of hazards, fractional reduction (or increase) in exposure times, number of people exposed, and body protection afforded. For each task, man-hours at risk are multiplied by the injury rates observed for similar equipment, and then total system safety performance is estimated by aggregating rates for various tasks and hazards. This projection of injuries per million man-hours of exposure represents a logically structured estimate of whether or not the new system can meet the stated system safety requirements; therefore, it provides a relative measure of the potential safety impact of using this new technology. Expert judgment is included to understand the potential risk more clearly by considering that the degree of exposure to hazards and the resultant injuries are not necessarily directly proportional, and that some hazards interact with each other to increase exposure. A group of experts familiar with coal mining safety are

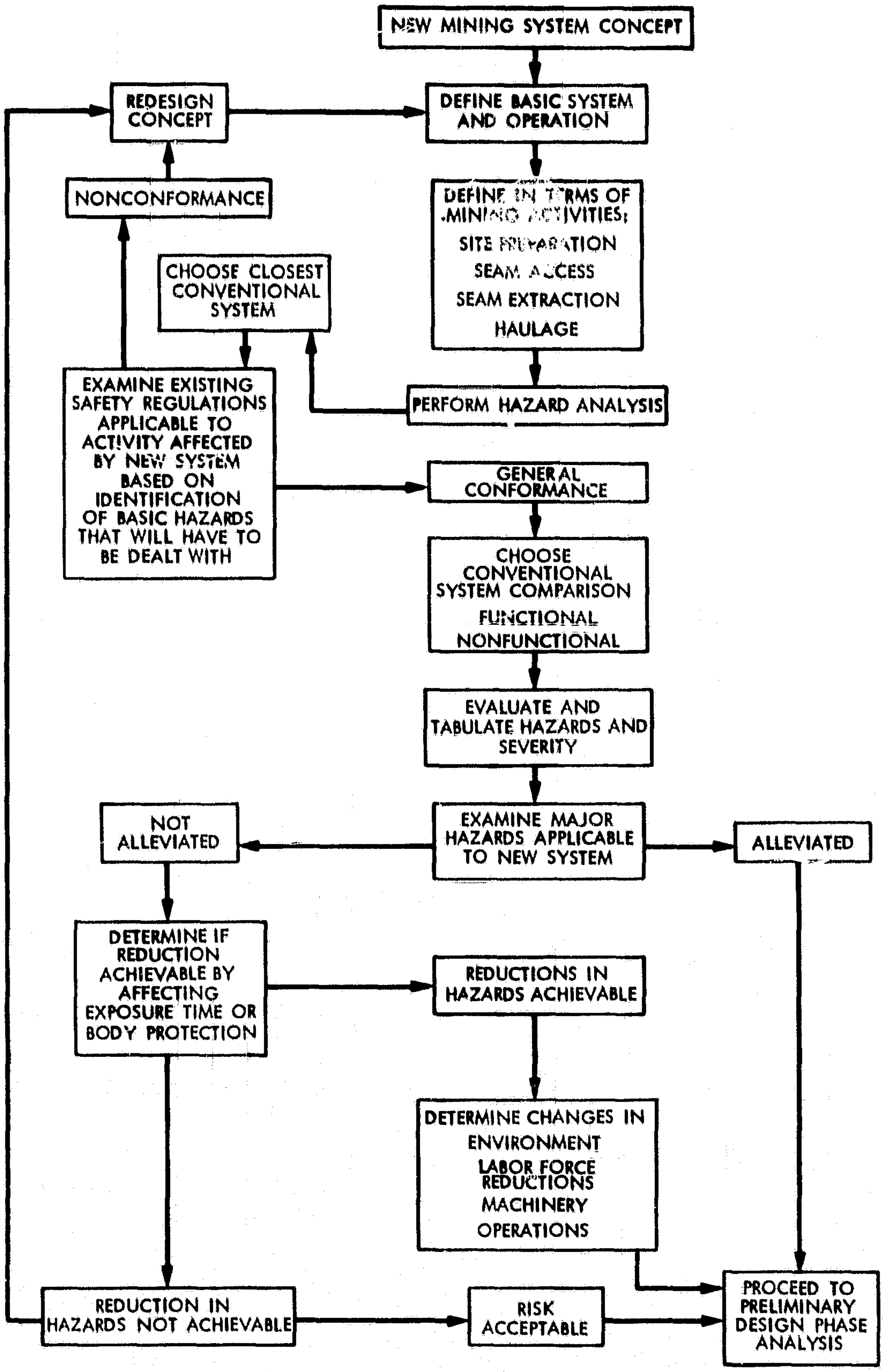

Figure 1-1. Flow Chart of the Conceptual Design Stage Safety Evaluation

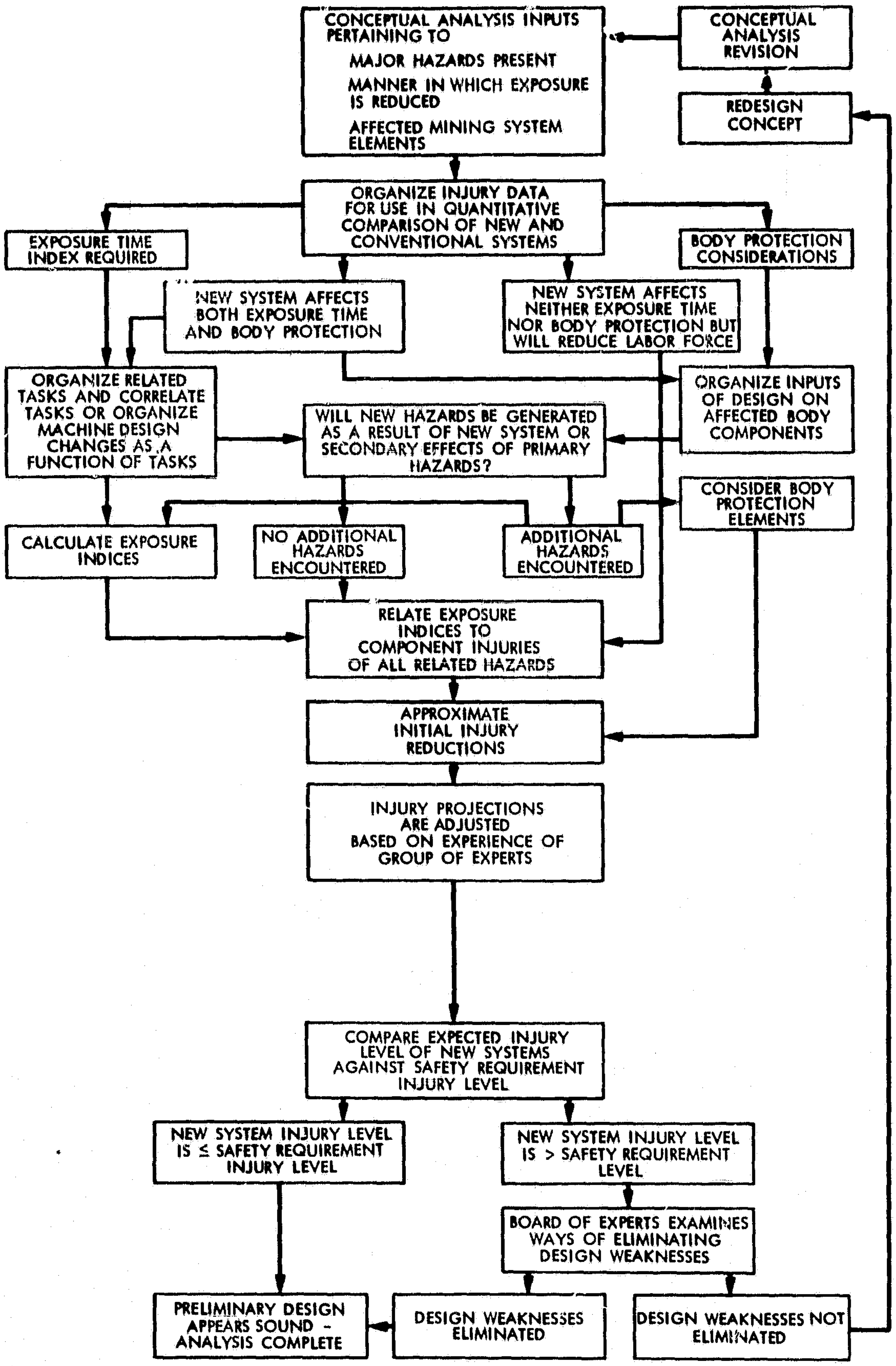

Figure 1-2. Flow Chart of the Preliminary Design Stage Safety Evaluation

given both the historical and initial estimate of the injury rates expected for the new system by considering (1) the new system design, (2) a hazard comparison between the two systems, and (3) present injury levels. The experts are then asked to modify the original estimates until a final range of injuries is reached. If more detailed design data are available on site conditions which may aggravate hazards (e.g., there are more slips and falls in a wet mine environment than a dry environment), then the experts are asked to also consider this information in the injury forecast. The final consensus on expected system performance is compared against the requirement to measure compliance.

In conclusion, the methodology presented in this paper contributes several refinements to existing safety analyses: (1) advanced systems, which may be completely different from existing systems, are examined on their own merits and shortcomings, with special attention given to hazards unique to the new equipment; (2) systems are broken down into the detailed components and associated worker interfaces to understand the exposure to various hazards (e.g., assuming that injuries would be alleviated for a given hazard by providing protection for a task area that only contributes a small fraction to the actual injuries would result in an incorrect conclusion about system safety); (3) both aspects of injury frequency and severity are considered through the use of exposure time and body protection parameters; (4) the analysis provides a means of identifying weak design areas by indicating where exposure time is increased or where protection is ineffectual; and (5) practical guidelines in the form of requirements based on safety experience in similar industries are provided for measuring safety improvements.

The structure of this document is such that the hazard analysis, which forms the foundation of the safety methodology, is developed first and is discussed in Section II. The safety regulations are also important to the development of safe advanced coal extraction systems and are summarized in Section III so the reader has an understanding of the overall intent of the regulations and how they should be used in evaluating designs. The safety methodology to be used for the conceptual design stage safety evaluation is described in Section IV. A step-by-step procedure is presented in Section IV which qualitatively evaluates whether a new conceptual design improves safety by a sufficient margin as to warrant further development of the design. The safety methodology for the preliminary design stage evaluation is described in Section V. This section presents a procedure, and supporting examples, that can be used to quantitatively determine whether an advanced coal extraction system has the potential for meeting the improved safety requirements stipulated for new coal mining systems. Exposure time data for conventional mining equipment are provided in the Appendix as a convenience for the evaluator in comparing the time workers are exposed to hazards for both the advanced system and conventional equipment.

SECTION II

HAZARD ANALYSIS

A. OVERVIEW OF THE HAZARD ANALYSIS

The key purpose of any safety evaluation is to understand what hazards might be present in a particular design, and what the sources of those hazards are. The approach taken in this paper is to (1) understand failure mechanisms of the system which can prevent the system from operating as it should (e.g., component failure due to age or improper design, geological failures which are natural occurrences but may still damage equipment), and human error which often contributes to component failures; (2) examine whether or not workers are interacting with the system at the time of failure, since the consequences of these failures may be of such magnitude as to injure workers; and (3) use the historical evidence present in the form of fault tree analysis and injury statistics to understand what kinds of interactions result in hazardous situations and injuries. A comprehensive list of hazards and an indication of the more hazardous situations surrounding existing equipment are provided as a general guide to hazard identification. An important objective of the analysis is the discovery of new hazards by examining all unique elements of a design and how they may impact workers in such a way as to cause a hazardous situation. Some brief examples are provided to clarify the nature of a hazard analysis.

B. ELEMENTS OF THE HAZARD ANALYSIS

1. System Failure Analysis

There are many ways in which a mining system may suffer major breakdowns which can expose workers to hazardous situations. By definition, the mining system includes all equipment used, the environment in which the equipment operates, and the labor force. In the process of mining, the machinery is stressed while cutting coal and rock or transporting heavy loads. The geologic environment is stressed by removing coal and rock and leaving semi-supported cavities. The labor force is stressed by having to deal with the uncertainty of both machinery and environmental variables, confounded by a working area that is poorly lit and often wet. Studying how all these elements of the mining system break down provides the first clue to understanding how hazardous situations arise.

a. Machinery Failures. Machine components fail by three basic mechanisms. The first is age-reliability degradation. Components subjected to thermal cycles (such as motors), cyclic loading (bearings or booms), or constant abrasion (bearings and cutters) are examples of this failure mode. The second is improper design. This essentially means that a component fails because the actual loads it experiences exceed the loads it was designed to withstand. In the third mechanism an undamped input forces the component to its failure threshold (such as the inrush current to electrical switches and motors causing burnout), or the component responds in an undamped manner which causes it to become uncontrollable and impact another component or object.

When analyzing potential machine failures the system is first separated into its major components (cutter components, booms, pumps and hydraulic lines, motors, brake systems, gearboxes, electric cables, etc.). The next step is to systematically identify all the different conditions under which each component can fail. This includes second order interactions such as components interacting with each other (i.e., a cutter breaking and severing adjacent hydraulic lines). The data from these analyses are then systematically classified.

b. Failures of the Geologic Environment Around Equipment. This is important to define because, in a sense, the environment is not actually failing. As the coal and rock are extracted, roof and rib loads are redistributed toward an equilibrium. Under some conditions, caving is the means by which that equilibrium is achieved. Though this is a perfectly normal process and not a failure in the true sense of the word, the strata would not cave if the seam was not extracted. Therefore this paper considers the extraction process as a means through which the strata is induced to fail under abnormal conditions (i.e., unsupported roof). A similar definition applies to the release of gas into the working area. Though the gas would normally be contained, the extraction process induces the strata to release gas which can ignite and cause both caving as well as equipment damage.

When evaluating new systems operating in underground environments, these failures should be recognized as everpresent problems which can also cause major breakdowns.

c. Human Error. Human error is often reported as carelessness. However, the mine environment in which workers operate machinery and perform support tasks is far from ideal. For example, vision can be obscured by large machinery, operating in close quarters, under poor lighting conditions. This is aggravated by having to perform tasks in a constrained, wet environment, which contributes to unstable ground conditions and fatigue. The degree to which workers are trained to perform support tasks also contributes to their ability to deal with these conditions and avoid making mistakes. Insufficient training can result in improper use of equipment or workers not recognizing hazardous situations.

When evaluating new systems it is important to understand that all of the above factors affect the way workers can make mistakes. Human error can be categorized into three broad areas (11,12,13):

(1) Workers are inexperienced and/are not sufficiently trained to recognize hazardous situations.

(2) Workers recognize hazardous situations but still choose to accept the risk of exposing themselves, and possibly others, to injury.

(3) Worker's perception and reaction to hazards are dulled by fatigue.

In designing new systems, the effort toward eliminating human failures should be directed toward removing the requirement for the human to decide whether a situation is hazardous or not, or designing the system to prevent a worker from risking the safety of others (e.g., prevent careless equipment operation by using component stress sensors and controls, obstacle sensors, speed controls, etc.).

2. Human Involvement with System Failures

The most important component of any hazard analysis is determining whether a worker is directly involved in the system failure (14). This part of the analysis requires a basic understanding of what kinds of tasks workers will be required to perform when operating a new system. This information would have to be available at the conceptual design stage and would include (1) knowing how much and what kind of equipment will be required, (2) how many people will be required to operate the equipment, and (3) where workers will be stationed during the operation and maintenance of the equipment. All of these information elements will be explained in greater detail later in the methodology. Next, the evaluator systematically examines the interaction of major potential failures with workers. In some cases a system component may fail catastrophically but not interact with workers (e.g., an internal gear box failure, or failure of a remotely controlled component). In these cases the failure is considered benign because a hazard is not presumed to exist unless a worker is present. This does not mean that workers are totally safe from these kinds of failures. Even though a component has already failed, workers may still be exposed to after effects such as, (1) latent failures of other components during maintenance (i.e., hydraulic lines), (2) environmental and human errors associated with doing maintenance on a unit located in a poorly illuminated and cramped workspace, or (3) manual replacement of heavy, cumbersome machine components. It is important to evaluate each major system failure and worker interaction through both the operational and maintenance phases of operation. This total list of major failures and possible human interactions, coupled with existing accident and injury experience leads to the identification of hazardous situations.

3. Hazard Identification

Matching each major system failure with its respective interaction with workers provides both the hazard and major potential accident causal factors (e.g., roof falls, machinery, handling material). This procedure can be made clearer by considering the extensive historical data available on accidents and injuries. The detailed accident and injury causes from MSHA combined with the results of fault tree analysis reveals the various hazards and resultant injuries for existing equipment, and provides insight into system failures, human interactions, and the overall process of hazard identification (2,3,12,15). The major accident causes generally recognized by MSHA are roof/rib and face falls, slips and falls, handling material, tools, pinches and squeezes associated with haulage, electricity, machinery, explosions due to gas, dust or explosives, and suffocation. These causes can further be broken down by fault tree analysis into the following list of contributing hazards:

(1) **Roof/Rib/Face Fall**

Support is adequate, but is disturbed or insufficient due to:

(a) Being struck by a vehicle.

- Vehicle out of control due to mechanical failure (brakes, steering, etc.).

- Vehicle out of control due to an operator failure (carelessness, poor training, bad environment such as wetness, poor visibility or traffic congestion).

(b) Being struck by a tool in the hands of a worker.

(c) Being struck by material being handled by workers.

(d) Being improperly placed or set, and works loose or does not provide support in the right locations.

(e) Support is inadequate for protection because:

- Unusual geologic conditions are encountered (air/gas/water pockets under high pressure).

- Insufficient data are available on roof and rib conditions, causing insufficient placement of reinforcements.

- Openings and entries are improperly designed or improperly executed in accordance with the design.

- Workers are careless, lack experience or are improperly trained on how and where to set reinforcements.

(f) Protection provided workers is adequate, but:

- Workers are permitted to work outside protection during performance of tasks, or have to move from underneath protection in order to see.

- Workers are not trained properly or are careless and do not observe when they are outside of the protection.

- Unusual geologic condition encountered (e.g., rock blast).

(g) Protection is inadequate as a result of:

- Protection not being designed to withstand the force of rock falls, or prevent debris intrusion into the operating or working area.

(2) Slip and Fall

(a) Worker in a position to be caught off balance due to:

- Tool or object being worked on breaking.
- Worker not properly trained or careless, choosing to use tool not suited for task resulting in it breaking or slipping.
- Workers escaping another hazard such as an explosion or out of control vehicle.
- Workers being on loose or slippery footing and, or, handling cumbersome material in a bad environment (such as low coal).
- Improper placement/lack of adequate guards on machines or elevated structures to prevent falls.
- Guards or equipment failing when stressed in normal working conditions (i.e., defective scaffolding, railings, ladders, etc.).
- Workers being careless on machines or elevated structures.

(b) Worker in a position to be struck:

- By tool or material being handled by another worker.
- By machinery.
- By sliding material such as loose rock or mud.

(c) Worker receives an electrical shock.

(3) Handling Material

(a) Worker in a position to be struck by material as a result of:

- Materials being stored in an unstable position and falling.

- Materials being defective and failing (breaking) when being handled (e.g., props, machine parts).
- Other workers not handling material properly or being improperly trained.
- Handling a heavy machine component while replacing it.

(a) Physical capabilities exceeded as a result of:

- Material weight too heavy for worker.
- Material size too cumbersome for worker to handle comfortably.

(4) Tool Injury

(a) Worker in a position to strike or be struck by a tool as a result of:

- Tool being defective and slipping or breaking.
- Object being worked on has difficult configuration or is defective, causing tool to slip, jam or break (i.e., crowbars/bars, picks, axes, sledge hammers, shovels).
- Handling tool carelessly, causing it to slip or break.
- Being close to coworkers using tools.
- Dropping tool on self, or having tool dropped from above.

(b) Worker in a position to be struck by objects being worked on by tools as related to:

- Flying particles from objects worked on (e.g., object fragments such as rock chips).

(5) Pinch or Squeeze as Typically Related to Haulage Type Activities

(a) Worker in a position to be struck by machine due to vehicle going out of control:

- Mechanical malfunction.
- Poor environment obstructing vision or causing skidding.

- Striking an object (e.g., rock, building material).
- Operator carelessness.

(b) Worker in-between objects which can move:

- Poor lighting and blind corners causing vehicles to collide, or causing vehicle to impact rib.
- Worker pinched in cab following collision of two vehicles.
- Machine or system design requires worker to be in a cramped area between an operating vehicle and rib due to poor layout of maintenance areas.
- Exposed to being struck or to pinch points on moving or rotating machinery (e.g., conveyors):
  - Poor layout of maintenance and operating areas around machinery.
  - Bad lighting.
  - Carelessness.

(6) Electrical Shock/Burns

(a) Worker in a position to be in contact with a conductor as a result of:

- Tool or machine coming in contact with a bare energized conductor (e.g., frayed cable) causing shock or arc.
- Worker forced to handle energized electrical components or do electrical maintenance (cable splicing/handling, switch/junction box checks, etc.) in a damp or wet environment.

(7) Machinery

(a) Worker is struck by machine as result of:

- Tramming and moving machinery in close quarters.
- Bad lighting or obscured vision which prevents operator detecting other workers in area.

- Insufficient guards.
- Machine components breaking due to:
  - Normal material fatigue.
  - Being operated past stress limits (carelessness, improper training).
  - Being improperly designed.
- Noise obscuring presence of other machinery.

(b) Worker in a position to be caught in machinery due to:

- Wearing loose clothing which gets ingested.
- Carelessness.
- Insufficient lighting to avoid contact with catch points.

(8) Explosion/Burns

(a) Workers in area of methane release and:

- Poor ventilation causes gas buildup at face where mining operations generate sparks (e.g., striking rock with cutter picks).
- Inadequate monitoring of gas allows gas buildup and ignition (worker carelessness or equipment failure).
- Ignition source present due to short on equipment or power source.

(b) Workers are working with, or in proximity to, explosives and:

- Explosive materials are improperly handled, causing detonation.
- Explosive materials detonate prematurely due to effect of age on material instability, or improper design of detonating device (detonation by outside electrical noise).
- Explosives detonated and workers are in line of blast or given insufficient warning, or workers are exposed to the shock wave generated by the blast.

(9) High Pressure Release

(a) Workers exposed to high pressure release due to natural geologic occurrences such as:

- Intersecting a pocket of air, gas or water under pressure (i.e., natural gas well, artesian well, underground spring) and system does not provide adequate warning.

(b) Workers exposed to high pressure releases from machinery such as:

- Impact by high pressure stream of hydraulic fluid from severed line (resulting from overstress, natural fatigue, or being struck).

- Impact by whipping hose resulting from severed hydraulic line.

(10) Welding and Chemical Burns

(a) Worker in contact with electrical equipment and worker burnt by flash or flying particles from electric/gas welding.

(b) Worker using chemicals comes in contact with highly corrosive agents (battery fluids, cleaning agents).

(11) Suffocation

(a) Workers exposed to natural elements such as:

- Mud/dirt slides.

- Inrush of water when intersecting natural pocket.

- Roof or rib fall.

- Gas seepage into working area.

(b) Workers exposed to work-induced elements:

- Smoke or other toxic gas from mine fire or explosives.

C. HAZARD ANALYSIS

Given a new design, it might be argued that the regulations address all the hazards associated with equipment. This is not always true for the following reasons, (1) new designs may introduce new sources of familiar hazards as well as totally new hazards, and (2) even though regulations exist and are enforced, injury data show that workers continue to be seriously hurt at a greater frequency than other relatively similar industries (1); this suggests that we are not fully aware or in control of the more serious hazards. For these reasons a systematic approach to isolating key hazards and designing new systems accordingly is necessary.

The results of the hazard identification analysis are of immediate use in finding where <u>major problems</u> in the design exist. Identifying the major problem areas tells the evaluator if a new design offers major improvements over existing systems. As many new designs may have hazards similar to existing systems, a good first step is to describe these major hazards as a function of their percentage contribution to serious injuries. Tables 2-1 through 2-10 display the relative ranking of the nine most prominent accident classes of the eleven accident types listed in Section II-B, above.

1. Major Accident Causes

In Table 2-1, the list of major accident causes clearly indicates that roof, rib and face falls, haulage, machinery, and handling materials contribute the largest portion to fatalities and disabling injuries. The

Table 2-1. Breakdown of Major Accident Causes by Fatalities and Nonfatal Disabling Injuries

Accident Causal Category (in order of severity)	Avg % Contribution to Serious Injuries Fatalities (F) Nonfatal Disabling (NFD)	
	F	NFD
Roof/Face/Rib Falls	47	15
Haulage	23	16
Machinery	14	15
Handling Material	0	32
Subtotal	84	78
Explosion/Fire	9	1
Electricity	7	3
Slips/Falls	0	8
Handtools	0	7
Suffocation	0	3
Total	100	100

Source - MSHA Injury Statistics (1972-1978) remaining accidents contribute less than one fourth of the total serious injuries. Each of the nine accident causes are broken down into their respective contributing hazards (taken from the list shown in Section II-B-3) in the remainder of this section. The percent contributions of detail hazards to the total injuries associated with each accident category are provided where data were available. The discussion of each table further illuminates the causes with emphasis given to the worst hazards.

2. Hazards Related to Roof, Face, and Rib Falls

Table 2-2 indicates that the hazards which far outweigh all other hazards deal with roof support being adequate (but unable to provide support in the proper place at the right time), or inadequate due to worker inexperience, or carelessness, during the installation process. The term "adequacy" implies that if the support had been placed in the right location and at the proper time, it would have prevented the rock fall. For example, machinery geometry and volume often prevent temporary and permanent support from being placed as close to the face as preferred. Similarly, machinery geometry and volume, and floor conditions, often prevent temporary support being placed in a solid position to hold up the roof. The variable nature of stress release in strata is also a factor since this is not predictable and can occur at the time support is placed. In all of these examples the support is adequate to protect workers from rock falls but fails because it cannot be installed under the conditions for which it was designed. The problem of "inadequate" support is basically due to an insufficient amount of temporary or permanent support being installed. The source of this problem becomes apparent when it is recognized that most of the serious injuries involve workers with less than five years of experience in their task area (see aggravating factors). The complicated nature of strata mechanics demands considerable experience in knowing where, and how many supports should be placed.

Venturing under unsupported roof to install temporary support, or moving away from the protection of a cab to inspect a possible equipment failure under unsupported roof, seem to be inherent in most conventional mining systems. Though it appears that workers accept this as a job-related risk, it seems that considerable effort should be expended to reduce this inherent problem in these task areas.

3. Hazards Related to Haulage

Table 2-3 shows that the major contributor to haulage type injuries (pinches and squeezes) is the necessity for miners to work in proximity to the haulage equipment. For example, workers perform cleanup tasks during the loading process in the immediate vicinity of shuttle cars and bridge conveyors. These machines can pinch workers between the machine and rib. Workers couple and uncouple rail cars as part of normal haulage operations and are required to be in between the cars during the performance of this task. Understanding that many haulage type tasks are performed in a poorly lighted environment where machine operators may not see other workers, further clarifies why these tasks are extremely hazardous.

Table 2-2. Major Contributing Hazards to Roof, Face and Rib Falls

Roof/Face/Rib Fall Hazards as Related to Ground Control	% Contribution to Fatalities
Support adequate but is not placed close enough to the face, is improperly placed, or is not placed in sufficient time to prevent strata overstress (i.e., roof fails at time support is being placed or moved)	54 - 60
Support inadequate because workers are careless, inexperienced, or improperly trained on how and where to set support (i.e., failure to recognize bad roof and use adequate support)	23
Unusual geologic conditions met (kettle bottom, fault, rock burst, etc.)	8
Total mine system improperly designed (openings and entries improperly designed or executed)	3
Inadequate roof support plan (insufficient or inaccurate data available on roof/rib conditions)	2
Other hazards which contribute to accidents in lesser degrees:	
- Inadequate supervision	3 - 11
- Support material has quality flaw and fails	
- Support is adequate but fails as a result of being struck by a vehicle (mechanical failure or operator failure)	
- Support is adequate but fails as a result of being struck by a tool or material being handled by workers	
Total	100

Aggravating factors - largest majority of serious injuries occur within 25 ft of face; low coal does not provide room to escape hazards; most serious injuries involve workers with less than 5 years experience in their task area

Roof/Face/Rib Fall Hazards as Related to Equipment Protection	Contribution to Fatalities
Protection built into equipment is adequate but workers are still required to move outside of protection in order to perform certain tasks or to have better visibility of operations	MSHA experience indicates this is largest source of serious injuries related to equipment (discussion with MSHA personnel in the Safety and Injury Statistics Branch)

Aggravating factors - low coal less than 30 in. does not require canopy protection

References:

"Tables for Falls of Roof, Face, and Rib Fatalities in Underground Bituminous Coal Mines," MSHA, Gadash, C., 1977 to 1978.
"Nonfatal Injuries from Falls of Roof, Face, and Rib (Includes Pressure Bumps or Bursts) in Underground Coal Mines," MSHA, Gadash, C., 1977 and 1978.
"Analysis of Fall of Rib, Roof and Face Accidents in Underground Coal Mines," MSHA, Heim, M., 1978.
"Comparison of Injury Hazards in Different Coal Seam Heights," MSHA, Hudson, S., 1976.

Table 2-3. Major Contributing Hazards to Haulage Injuries

Pinch or Squeeze as Typically Related to Haulage Type Activities	% Contribution to Fatalities and Disabling Injuries
Worker struck by machine or is in between objects which can move as part of normal operations	50
Worker struck by machine out of control as a result of mechanical malfunction, obstructed vision, machine striking an object, or carelessness	12
Worker is in between vehicle and roof or rib while operating machine	6
Collision of vehicles pins operator in cab	4
Workers are exposed to pinch points on moving or rotating machinery	
- Poor design of maintenance and operating areas around machinery	3 - largest source of injuries is due to performing maintenance on moving machinery
- Bad lighting	
- Carelessness	
Workers fall while jumping in or from cars (mostly a surface related hazard)	5
Workers pinched while rerailing haulage vehicles (rail car related)	3
Undefined causes (miscellaneous)	17
Total	100

Aggravating factors - low coal constrains space, workers have to escape hazards and also decreases space available to perform maintenance

References:

"Nonfatal Injuries Caused by Haulage Related Accidents in Underground Coal Mines," MSHA, Gadash, C., 1977.
"Analysis of Injuries Involving Conveyors in Metal and Nonmetal Mines," MSHA, Stahl, R., 1976.
"Comparison of Injury Hazards in Different Coal Seam Heights," MSHA, Hudson, S., 1976.

4. Hazards Related to Machinery

The major problem demonstrated by Table 2-4 and often encountered with tramming or moving equipment in underground mines, is negotiating the narrow entries. Large, slow moving equipment, such as longwall systems, allows workers time to move out of the way. Other types of lighter, less stationary equipment, such as face drills, cutters, loaders or roof bolters, move more quickly and are subject to rapid, unstable movement when traveling over an uneven floor. This same unstable movement also occurs when these machines are operating. For example, a face drill or cutter which encounters a very hard parting in the coal may bind and impart a torque large enough to displace the machine sideways. Workers in the vicinity may not be expecting this kind of movement, or may not see the machinery if lighting is poor or their vision obstructed. Inexperience is also a major contributor to these hazards because workers may not have the awareness necessary to always position themselves safely while equipment is operating.

5. Hazards Related to Handling Material

The problem of workers' physical capabilities being exceeded composes almost three fourths of the disabling injuries in Table 2-5, below. Since most of these injuries occur during lifting or pulling various materials, it appears that weight, size, and the physical mechanics a worker employs during lifting or pulling, work together to cause injuries. For example, an extremely strong individual can be injured if he attempts to lift a cumbersome component without using the proper technique (i.e., not using the leg muscles in conjunction with the back muscles). It is also understandable that numerous injuries are caused by dropping material since many supplies and machine components are not easily grasped. It is important to note that existing data indicate low coal operations considerably increase the chance of handling material injuries because the restricted space requires awkward physical positions.

6. Hazards Related to Explosions and Burns

Gas and dust explosions are a considerable problem because of the many ignition sources present in the mining environment. Cutting machines generate sparks when striking rock. Sparks are also generated when pounding spikes into brattice cloth, by the static discharge between closely operating machines, or due to shorts on equipment or power cables. Table 2-6 confirms that the difficulty with controlling spark generation, coupled with monitoring gas at the right time and in all the right locations, contribute to making the explosion hazard unpredictable and difficult to control.

Injuries caused by explosives, suffer the same degree of variability in controlling the causes. Variability in coal and rock strata effect the direction and degree to which fracturing occurs from explosive forces. For example, the explosive shot could be directed out of the charge hole if the surrounding strata is extremely hard. Workers supposedly out of the line of the blast could experience a higher exposure to deflected, flying debris as a

Table 2-4. Major Contributing Hazards to Machinery Injuries

Machinery	% Contribution to Fatalities and Disabling Injuries
Workers are struck by machinery in the process of tramming and moving machinery in close quarters at the face. (Non-stationary equipment such as roof support and loading type machinery are major contributors to this hazard)	
Workers are struck or caught by machinery during maintenance, clean-up, or support operations	59
- Insufficient guards	
- Bad lighting and obscured vision prevents operators seeing other workers in vicinity	
- Non-stationary equipment is difficult to control as a result of forces imparted on machinery during cutting or roof support operations	
Other contributing hazards are:	
- Inexperience/carelessness	41
- Machinery fails as a result of being overstressed	
Total	100

Aggravating factors - low coal restricts the movement of workers close to machinery and prevents workers from being able to escape hazards.

References:

"Industrial Engineering Study of Hazards Associated with Underground Coal Mine Production," Vol. I and II, Theodore Barry & Associates, December 10, 1971.
"Study of Fatal Accidents Involving Underground Coal Loading Machines," MSHA, 1978.
"Comparison of Injury Hazards in Different Coal Seam Heights," MSHA, Hudson, S., 1976.
"MSHA Detail Injury Summary," Report #CM341L2, 1976-1979.
"Accident Analysis by Functional Classification for Bituminous Coal Mines in 4 ft. to 8 ft. Seam Heights," FMC Corp., December 1972.

Table 2-5. Major Contributing Hazards to Handling Material Injuries

Handling Material Hazards	% Contribution to Disabling Injuries
Worker's physical capabilities are exceeded because objects are too heavy or cumbersome to handle. Tasks which act as the major sources of this hazard are:	
- Handling supplies (such as timber, tools, and equipment (fans, pumps, conveyors, etc.)	39
- Performing machine maintenance and handling machine components	15
- Handling power cables or cable reeling	6
- Handling coal, rock, and other waste	8
- Coupling, blocking or chocking mine cars	3
Workers are struck by material as a result of material being stored in an unstable position (mostly roof support materials)	6
Other miscellaneous or not otherwise classified causes	23
Total	100

Aggravating factors - low coal displays a statistically significant larger number of injuries because workers are constrained by restricted space in which to handle materials, and are usually in awkward positions when handling material.

References:

"Comparison of Injury Hazards in Different Coal Seam Heights," MSHA, Hudson, S., 1976.
"MSHA Detail Injury Summary," Report #CM341L2, 1976-1979.

Table 2-6. Major Contributing Hazards to Explosion/Burn Injuries

Explosion/Burn Hazards	% Contribution to Fatalities and Disabling Injuries
Workers in area of methane release, and	
- Poor ventilation causes gas and dust build up in presence of an ignition source	38
- Inadequate monitoring of gas allows gas build up and ignition	
Workers are in-line of explosive blast	28
Explosive materials are detonated prematurely due to age, or improper design of detonating device (stray signals)	1
Workers exposed to high pressure releases from hoses on machinery while performing maintenance	8
Miscellaneous or not otherwise classified causes	25
Total	100

References:

"Analysis of Injuries Associated with Explosives in Coal Mines," MSHA, Tierney, M. P., 1976.
"MSHA Detailed Injury Summary," Report #CM341L2, 1976-1979.

result of the denser outburst. Similarly, strata conditions could direct the blast through a weak rib into a working area in another entry. Worker inexperience or carelessness cannot be overlooked as another contributing hazard in both personal exposure and in exposing other workers because of poor communication at the time of detonation.

7. Hazards Related to Electricity

The underground mining environment contributes significantly to the electrical hazard. For example, power cables experience substantial wear from being run over by machinery, abraded by rough or sharp corners or rock, and corroded by acidic, standing, ground water. The failure rate of cables varies depending on the degree to which they are affected by these variables. This results in workers not knowing if the cable is shorted when they handle it and subsequently exposing themselves to potential electrical shock. The data provided in Table 2-7 confirms this problem. The electrical hazard is further aggravated by poor lighting (such that workers cannot readily see if power switches are activated on machinery, or if cables are abraded), and mine conditions such as standing water, which may hide a shorted cable.

Trolley wires are usually exposed to allow good electrical contact with the trolley pole. These bare high voltage lines are an ever present hazard to those walking or crossing the roadways which contain the lines, as well as those who must pass near a line while boarding, riding, or leaving a railcar. Low coal aggravates this hazard considerably.

8. Hazards Related to Slips and Falls

The greatest contributors to slip and fall injuries (Table 2-8) are (1) loss of footing, (2) being caught off balance or struck when operating or working around equipment, and (3) handling material. Though carelessness is sometimes a factor in these injuries, it is equally important to recognize that poor lighting, obstacles (such as fallen rock, stored materials, etc.), machinery operating in close quarters, and wet floors are aggravating factors. For example, a worker handling heavy timber in a wet environment may more easily slip and fall or strike another worker causing him to fall. Sometimes the chain of events leading to an injury is complex. For example, in cases of machine-related incidents a worker not injured when bumped by a machine may be knocked off balance and suffer a severe injury as a result of the fall.

Table 2-7. Major Contributing Hazards to Electrically Related Injuries

Electrical Hazards	% Contribution to Fatalities and Disabling Injuries
Worker must handle energized electrical components and contacts conductor with tool (major component is handling/splicing cable, 25.0)	57
Workers handling rail-car related electrical components (trolley wire or pole)	20
Miscellaneous or not otherwise classified causes	23
Total	100

Reference:

"Analysis of Electrical Injuries in the Coal Mining Industry," MSHA, Mason, W. and Seale, E., 1980.

Table 2-8. Major Contributing Hazards to Slip and Fall Injuries

Slip/Fall Hazards	% Contribution to Disabling Injuries
Worker in a position to be caught off balance due to:	
- Loose or slippery footing	31
- Loss of footing due to carelessness	
Worker in a position to be caught off balance or struck by machinery due to:	
- Improper placement/lack of adequate guards on machines or elevated structures to prevent falls	19
- Being careless getting on or off elevated structures	
- Guards or equipment failing when stressed in normal working conditions (i.e., defective scaffolding, railings, ladders, etc.)	
- Being careless getting on or off machines	
- Not observing machinery operating in proximity	
Worker in a position to be caught off balance or struck as a result of:	
- Tool or materials handled by another worker	15
- Handling cumbersome material	
Worker in a position to be caught off balance due to:	
- Tool or object being worked on breaking	3
- Worker not properly trained or careless, choosing to use tool not suited for task resulting in it breaking or slipping	
- Sliding material such as loose rock or mud	1
Worker receives an electrical shock	1
Worker in a position to be caught off balance due to:	
- Escaping another hazard such as an explosion or out of control vehicle	1
Miscellaneous or not otherwise classified causes	29
Total	100

Reference:

"MSHA Detail Injury Summary," Report #CM341L2, 1976-1979.

9. Hazards Related to Handtools

The source of the major handtool hazards (Table 2-9) is often the type of tool chosen for a job and the manner in which the tool is used. For example, an incorrectly sized wrench used to loosen or tighten bolts could very easily slip. Similarly, a crowbar (which is usually applied to bar down loose rock) used as a jack to install a machine component could very easily slip or be overstressed and break. Another problem experienced is the application of too much force on a tool which results in the tool breaking. A secondary consequence of the incorrect use of tools is workers often being struck by the broken tool or chips from the object worked on. It should be noted that this hazard category considers other sources besides carelessness. For example, tools used for breaking rock (such as sledge hammers) often expose workers to injury from fragments even though the tools are being handled properly.

10. Hazards Related to Suffocation

In the underground environment it is important to note that mine refuse such as dirt, rock or mud must be stored and periodically transported out of the mine. Refuse stored in overhead bins often clog in the process of filling rail cars. One of the major hazards shown in Table 2-10, related to refuse, occurs when workers try to unclog the bin from underneath or the top and are entrapped in the rapid slide of material when the bin is freed of the obstruction.

Table 2-9. Major Contributing Hazards to Handtool Injuries

Handtool Hazards	% Contribution to Non-Disabling Injuries
Tools handled carelessly causing them to slip or break	68
Workers struck by chips of objects being worked on, or broken tools	18
Workers struck by tools in the hands of coworkers	2
Tool is defective and slips or breaks	2
Tool is dropped on self or dropped from above	1
Other miscellaneous or not otherwise classified	9
Total	100

Reference:

"Handtool Injuries in Coal Mines," MSHA, Seale, E., 1979.

Table 2-10. Major Contributing Hazards to Suffocation Injuries

Suffocation Hazards	% Contribution to Fatalities
Workers exposed to refuse slides in normal operations	26
Inrush of Water	26
Gas seepage into working area as a result of insufficient or inoperative sensing systems	14
Surface-related fatalities	34
Total	100

Reference:

"Suffocation, Drowning and Asphyxia Fatalities in Coal and Metal/Nonmetal Mining," MSHA, Mason, W., 1979.

The presence of water and gas in underground mines is a natural occurrence. Occasionally, large pockets of water (such as artesian wells or underground springs) are intersected, resulting in a rapid inrush of water which engulfs workers. The gas seepage hazard usually occurs in sections that have already been worked. Workers, unaware of the seepage, suffocate due to lack of oxygen.

The consistent theme throughout the above tables and discussion is that workers are exposed to hazards because of (1) inexperience or lack of training, (2) working in an extremely dangerous environment, and (3) the nature of the tasks they perform. It appears that equipment design is also strongly related to hazard exposure as a function of task. This was especially clear in injuries associated with rock falls, machinery, and haulage. Examination of equipment and how it is used reveals existing designs require workers to install temporary support under unsupported roof, perform support tasks close to operating machinery, or work in between moving machinery. Also coupled with task exposure is the requirement for workers to handle heavy, cumbersome materials and machine components. Although some of these hazards are somewhat mitigated by regulation, it appears accidents could be substantially reduced via designs that are more sensitive to built-in hazards, with particular attention to the unforgiving mine environment, and worker error.

After identifying familiar hazards and determining which will be major problems in a new design, it is then necessary to isolate new hazards. Because operating data are not available, it is necessary to use the system failure and human interaction method to identify new hazards. A brief example, to provide the reader with the sort of analysis intended, is the rapid variation of temperature to fracture coal. The ways in which this process could go out of control through sudden release of heat or coolant, would represent unique failures compared to existing technology. Identifying the tasks that would bring workers into contact with these failures completes the description of the unique hazards associated with this system.

The system may be envisioned as having a reservoir to contain the gas or liquid used as the injection medium, a temperature inverter to add or remove heat, a pressurizer to build up injection pressure, and an injector which vents the medium into drill holes in the face. Workers monitoring the temperature inverter and pressurizer components could be exposed to severe burns due to high or low temperature release if valves or piping failed. Similarly, injector operators could be exposed to the same hazard if injector nozzles or valves failed. Inhaling or touching the injection medium could also be hazardous. This would not only be a hazard to system operators and helpers in the event of pressure release, but also to workers performing routine maintenance and handling refill containers.

Though there would probably be no information available to determine the degree of exposure of workers to new hazards, the hazard analysis at least indicates that workers could be injured by these hazards. Whether or not workers will be injured is a function of how well the design reduces their exposure. This will be addressed when the remainder of the methodology is developed.

SECTION III

MINE SAFETY REGULATIONS

A. PURPOSE OF SAFETY REGULATIONS

The Federal Coal Mine Health and Safety Act (Public Law 91-173) and its respective amendments was designed to regulate working conditions in view of historical injury data which shows that the mining industry exposes workers to extremely unsafe and unhealthful working conditions. The safety regulations govern everything from worker sanitation facilities to design standards for controlling the natural environment, and equipment in which workers perform their functions. The intent is to provide a safe working envelope within the total mine environment. Though it is understood that advanced systems may not necessarily resemble or operate the same way as existing technology, it seems reasonable that at a minimum, advanced systems should prove their integrity by meeting the intent of these regulations. Further, it is hoped that they would provide a substantially greater measure of safety through improved design. The following summary of the safety regulations, as a function of their respective major accident classifications, is provided to clarify the intent of existing safety regulations. The health regulations, though equally important, are addressed in a separate document (16). This information will be important for evaluating the design integrity of new concepts.

B. SUMMARY OF THE SAFETY REGULATIONS

The following summary of safety regulations is organized by major accident cause. This information is provided as an adjunct to the accident and hazard relationships developed in Section II, and provides the evaluator with a sound basis for making a qualitative assessment of new concepts.

1. Injuries Due to Roof, Rib, or Face Falls

The intent of regulations in the area of ground control is to protect workers from potential falls or bursts of rock caused by high pressures exerted on the roof and ribs by the overburden. These regulations also try to prevent situations that could jar the strata loose, such as explosions of gas. The general regulations call for an approved roof control plan which specifies where roof support devices (such as timber or roof bolts) will be located, and what the entry and pillar dimensions must be. Variations in strata conditions permit some flexibility in the content of an approved plan. The regulations also address the periodic testing of roof support devices to insure their structural and holding integrity. Detailed procedures for using temporary support when recovering roof support devices are also set forth. To prevent strata disturbance in the event of explosion, ventilation is required to keep gas buildup at non-explosive levels. The ventilation regulations are developed in greater detail when the hazard of explosion is discussed later in this section.

2. Injuries Resulting from Haulage-Related Equipment

As indicated by the hazard analysis of Section II, the basic hazard associated with haulage equipment is workers getting squeezed between objects or machinery. The intent of regulations in this area is to provide a means of warning workers of the hazard. For example, audible warning signals are required on all haulage vehicles. Reflectors are also required to assist workers in identifying approaching vehicles. Vehicle headlamps are required to improve operator visibility and also warn other approaching vehicles. Jacks and other lifting devices are required to assist workers in moving debris out of the way, performing equipment maintenance, or moving equipment which may be stuck. To insure better operator control of haulage vehicles, two independent brake systems are required. Additional requirements for guards on haulage equipment address the hazard of entrapment in rotating or moving components. Finally, vehicle traction and controllability are regulated by requiring sanding devices for slippery areas and specifying that haulage ways be kept clear of debris.

3. Injuries Related to Machinery

The object of these requirements is to prevent workers from being struck or entrapped by machinery and components, which may catastrophically fail under load, or may be difficult to control in the course of performing maintenance or making machine adjustments. For these reasons, guards are required in conjunction with easily accessible "panic bars" or shut-off switches. Automatic shut-off switches are required on hand-held power equipment. All face machinery is required to have falling object protection (FOP) to protect operators from falls of rock and other material. All machinery, and areas around machinery, are required to have illumination to allow workers reasonable vision of activities. The requirements also address safe operating and maintenance procedures such as operators communicating warnings to other workers that a particular activity associated with machinery is starting; or, in the case of performing inspections or maintenance, insuring that precautions are taken to set brakes and completely shut systems down.

4. Injuries Associated with Handling Material

Many of the materials handling activities in mining are done manually, thus, it is difficult to set standards for how these tasks should be done, and as a result, very few regulations exist. As many of the tasks requiring handling heavy or cumbersome material are support tasks for ground control or machinery, safe practices associated with the operation and maintenance of this equipment include the material handling aspects as well. As this is a major contributor to serious injuries, it appears that this area is in need of system improvement.

5. Injuries Resulting from Explosion and Fire

Regulations related to these accident causes address both the hazards associated with using explosives as well as hazards associated with the possible buildup and ignition of gas. Regulations associated with using explosives can be divided between (1) controls over the design of explosive devices, and (2) controls over the use of explosives. Explosives are examined for their ingredients so that the amount of poisonous gases given off after detonation are kept to acceptable levels, and so that the detonation force is sufficient to fracture coal but not result in catastrophic damage to the entries. The ingredients are also tested for their ability to not detonate other substances such as gas and dust, and for their sensitivity to outside influence such as stray electrical signals or being dropped when handled. Handling precautions are further stressed by requiring proper storage and labeling of explosives.

Regulations addressing safe user practices relate to maintaining control over the depth of the drill hole and rib thickness to minimize the amount of debris that may leave the face at detonation and travel down entries or penetrate ribs. The size of the charge is regulated since this also affects the travel distance of debris. To prevent premature detonation of charges, ignition cables and switches must be designed as fail safe as possible.

Explosions and fires may also result from the ignition of gas and dust released from coal. Regulations in this area first define what is meant by "gaseous" and then address flammable mixtures of air, gas, and dust under various mine conditions. Stringent specifications are set forth for all face equipment (i.e., cutting and loading machines, and haulage equipment) since much of the gas is released during the cutting process. These specifications include periodic methane checks, ventilation of battery enclosures, flame and spark arrestors on all electrical connections, and fail safe cable design. In addition, flame tests are required on all equipment where there is a potential for heat buildup due to friction (such as on conveyors). Gas may seep into enclosures containing electrical connections. Therefore, as an additional precaution against possible failure of spark arresting systems, the regulations require explosion proof enclosures around major electrical components and connections. The regulations also try to exert a certain amount of control over the mine environment in the event explosion and fire does occur by requiring installation of sprinkler systems, fire fighting equipment, escape ways (two ways out), and use of non-flammable materials for stoppings.

6. Injuries Associated with Electrical Components

The intent of regulations in this area is to minimize the possibilities of workers coming into contact with energized electrical components. These regulations overlap with those associated with reducing the possible ignition of gas by sparking. The regulations require that high voltage cables and circuits be deenergized prior to performing repairs. Training and protective equipment such as rubber gloves, guards, and insulated tools are also called for to provide additional protection when performing maintenance. All electrical equipment must be grounded in order to protect operators and workers who may contact equipment when it is operating. Additional requirements also call for periodic testing of circuit breakers to insure power is cut off under overload conditions.

7. Injuries Resulting from Slips and Falls

A worker being injured from a slip or fall is often the result of carelessness or the difficult working environment (such as cramped working areas, poor lighting, and slippery floor conditions). As these variables are hard to control, there are no regulations in this area. The only regulations that might assist in mitigating this problem are those related to haulage (i.e., sanding slippery areas and keeping haulage ways free of obstacles).

8. Injuries Resulting from the Use of Handtools

Handtools designed for use in mining are also used in other industries as well. Consequently, there are no regulations governing the design or use of tools. The only regulation which remotely applies is the machinery requirement which addresses the use of automatic shut-off switches on hand held power tools. This is confined primarily to power drills. The safe use of handtools overlaps safe operating and maintenance practices spelled out in the regulations for ground control and machinery.

9. Suffocation-Related Injuries

Regulations in this area are intended to prevent workers from being suffocated by gas or smothered by refuse. The regulations governing ventilation apply to the problem of working in methane environments. Labeling certain areas in a mine as "gassy" is an additional precaution taken to appraise workers of the hazard. Refuse piles are required to be placed in designated storage areas away from work areas to prevent workers from being caught in rushes or slides of material.

C. THE EFFECT OF NEW CONCEPTS ON ENHANCING SAFETY REGULATIONS

The safety regulations provide workers protection from a variety of hazards. However, workers continue to be seriously injured at markedly high rates. Occasionally injuries may be traced to a failure to comply with the regulations; however, an equally important factor is the failure to control circumstances under which a component in the mining system fails to perform the safety function for which it was designed. A component designed in accordance with regulations could fail but not reveal the failure until it is called upon to perform its function. Breaker switches, methane monitors, or fire suppressant systems are examples of components which may experience hidden failures. Some mine environments are more severe than others and, therefore, stress certain components more than others. Insulation breakdown on cables and corrosion of electrical terminals occur at faster rates in extremely damp environments or highly acidic ground water conditions. In addition to these kinds of variables, poorly illuminated areas and standing ground water make it difficult to both observe problems and repair them. Though the severe accident causes such as rock falls and machinery are closely regulated, it is obvious that variables such as these cause gaps in the regulations. Furthermore, tightening regulations does not necessarily ensure fail safe operation. Subsequently, the thrust of this paper is to assist in designing new concepts that meet the spirit of the regulations and, more importantly, display a potential to offset the gaps in the regulations. This is discussed in greater detail in the methodology of Sections IV and V, where examples are provided to help define how advanced systems should perform in the key hazard areas.

SECTION IV

SAFETY EVALUATION OF NEW SYSTEMS AT THE CONCEPTUAL DESIGN STAGE

A. OVERVIEW OF THE EVALUATION

The overall aim of the conceptual level safety evaluation is to identify conceptual designs that offer major improvements over existing systems by substantially reducing exposure to hazards. It is imperative that fatalities and disabling injuries be reduced for all hazards, with emphasis placed on the major hazards. As stressed in the previous section, it is anticipated that new designs will reduce serious injuries by meeting the intent of existing regulations and strengthening safety performance in areas where the regulations do not suffice. The evaluation first requires that a hazard analysis be performed, and then tests the basic integrity of the design by checking its general conformance with the regulations using an analogous existing system as a point of reference. The evaluation examines other design strengths by first providing the means by which serious injuries can be reduced; namely, by reducing exposure to hazards, or reducing the severity of injuries resulting from hazards. This may be accomplished by (1) reducing the time workers are exposed to hazards, (2) reducing the number of people exposed, (3) redesigning machinery to provide more protection, (4) streamlining operations to remove particularly hazardous equipment and tasks, and (5) monitoring the development of potentially hazardous situations so that workers can be removed before injuries result. The evaluator is asked to indicate which of these general accident reduction schemes is incorporated in the new design to offset both new hazards and the hazards which exist in analagous conventional systems. The result of the analysis is a subjective hazard comparison of the new system against similar existing systems, with reasons why each hazard is reduced (emphasis being particularly placed on the major hazards related to roof and face falls, haulage, machinery, and handling materials). Basic design requirements are provided as guidance for determining the kinds of detailed hazard reduction schemes considered important in improving the safety performance of new systems.

B. CONCEPTUAL LEVEL SAFETY EVALUATION

The conceptual level safety evaluation is qualitative since it serves only as an initial examination of new concepts to identify those which show merit. At the completion of this safety evaluation, the regulatory integrity will have been tested, the strong points of the design identified, and the potential impacts of improving safety will have been determined.

1. Definition of the New Systems

Before a new concept can be evaluated, the basic system and its operations must be defined in sufficient detail to permit both a detailed hazard analysis and a comparison with existing equipment. The kinds of descriptive information required to adequately define the new system are as follows:

(1) A description of basic system operation which includes the means by which the system gains access to the seam, the manner in which coal is extracted, and the means by which coal is conveyed from the face to the outby loading point for shipping.

(2) A description of the various system components and how they interact in the process of gaining seam access, extracting coal, and transporting coal.

(3) A description of the kinds of tasks workers perform and approximate number of workers exposed to various levels of risk.

(4) A description of additional equipment required to support system operation which may include components such as generators, transformers, hoists, material for ground support, skids, etc.

2. The Hazard Analysis

The next step is to perform a hazard analysis by drawing on the previously assembled design information. The analysis is conducted as indicated in Section II with a detailed breakdown of major system failures and worker interaction with them. The evaluator should go beyond the historical hazard data provided and identify both new ways in which the old hazards can occur, as well as ways in which new hazards can arise. The evaluator should be careful not to automatically discount hazards just because the new system offers protection in those areas. Those aspects of the design that reduce hazard exposure are taken into consideration later in the analysis.

3. Selection of an Analogous System

In order to assess whether a new concept meets the intent of existing regulations, and test its integrity, the evaluator must select, for comparison, a conventional system which is similar to the new concept. The chosen comparison can have either "functional similarity" or "nonfunctional similarity." The distinction is as follows:

(1) Functionally similar systems operate in exactly the same environment, in essentially the same fashion, and have similar architectures. For example, both employ rotary drilling technology of about the same scale to extract coal from a surface environment. Another example would be two longwall systems; one a shearer, and the other a plow.

(2) Nonfunctionally similar systems have only one thing in common; they both may either extract or haul coal. Nonfunctional comparisons have totally different architectures and are chosen if the new technology is so different that a functional comparison is unavailable, or if the new system is intended to replace a conventional system for which it is generally agreed that the conventional system is inherently

more hazardous. A good example of a nonfunctional comparison would be the choice of a tunnel boring concept (which is totally integrated with the roof support system and has its own life support system) in place of a conventional room and pillar operation in order to provide a complete protective envelope around workers. This would serve the purpose of sealing workers from the inherently unsafe underground environment. Though these systems would only be similar to the extent that they both extracted coal, the comparison would be made with the intent of replacing the room and pillar system with a tunnel borer.

Note that it would be impractical to use a nonfunctional comparison to test regulatory compliance when the new system is intended to replace an inherently unsafe conventional system. In this case it is appropriate to select two comparison systems: a functionally similar system for evaluation of regulatory conformance, and a nonfunctionally similar system for identifying and assessing hazard reductions.

For example, though it may be intended to replace a room and pillar system with the tunnel borer for safety purposes, it would be more practical to check the borer's general regulatory conformance by comparing it to tunneling equipment use in road building (i.e., OSHA regulations). This comparison would essentially tell the designer if the tunnel borer conformed to basic safety practices employed on tunneling type equipment. Any additional MSHA regulations peculiar to the coal mining environment would also be considered.

4. Test of Regulatory Conformance

The results of the hazard analysis indicate hazards to which workers will be exposed. Knowing these hazards and relating them to their generic accident classification allows the evaluator to check general regulatory compliance of the new concept, with emphasis on the intent rather than the letter of the regulations. If a new concept is at variance with the intent of the basic regulations, the design can be altered accordingly while the concept is still in the drawing board stage. While general regulatory conformance does not ensure that the new concept will be safer than existing systems, it does indicate that there is no inherent flaw in the design and that is it reasonable reasonable to proceed with the evaluation. Table 4-1 summarizes the regulatory information provided in Section III and is displayed in a checklist format to assist the regulatory test procedure. If a new design meets the intent of the regulations but not the letter it is important to note how the concept achieves this. An example of this would be a new single entry concept (as opposed to the required multiple entry design,) which allows automatic sealing and ventilation of the working areas in the event of fire or major roof fall. The regulation is designed to provide additional escapeways for workers in the event of these occurrences. However, a single entry system such as this would provide the same degree of protection, and therefore meet the intent of the regulation (which is to separate workers from these hazards).

In the event a new hazard is identified for which there is no applicable MSHA regulation, the evaluator may choose to reference other appropriate regulations (such as OSHA) which may apply. These should also be noted.

Table 4-1. Summary of Safety Regulations

General Regulations	Conformance		Manner in which New Design Meets Intent of Regulations
	Yes	No	
Machinery and Electrical Regulations			
Exercise safe design practices for both standard fuel and electric vehicles that are in general conformance with or meet the intent of related MSHA regulations as applied to the mining environment (e.g., safe load capacity, warning devices, spark arrest, canopies, cable and electrical connections).			
Ground and Environmental Control Regulations			
Exercise safe design practices that are in conformance with or meet the intent of related MSHA regulations as applied to mine development and construction (e.g., control of site subsidence, identification of hazard areas, power line installation, ventilation, roof control plan, use of high pressure lines and vessels, fire controls, designated refuse areas, mine entry design).			
Operations and Maintenance Regulations			
Exercise safe design practices with consideration to applicable MSHA regulations related to human interfaces with equipment and associated material (e.g., handling spare components, timber, ducting, casings, electrical and machinery operation and maintenance).			

Table 4-1. Summary of Safety Regulations (Continuation 1)

General Regulations	Conformance		Manner in which New Design Meets Intent of Regulations
	Yes	No	
Explosives, Dust and Gas Control Regulations			
Exercise safe design practices that are in conformance with or meet the intent of MSHA regulations related to control of dust and gas. Exercise safe design practices that are in conformance with or meet the intent of regulations related to the use and storage of explosive, combustible, corrosive, or toxic substances.			
Worker Protection Regulations			
Exercise safe design practices that that are in conformance with or meet the intent of regulations related to protective covering of the body against the mine environment.			
Other regulations applicable to mitigating new hazards (such as OSHA).			

Note: Please refer to Section III for a more detailed summary of each group of regulations.

5. Evaluation of Safety Improvements

New concepts can reduce exposure to hazards by either reducing the time workers are exposed to the hazards, or by providing more protection (6). These factors can mitigate hazards through several different approaches as indicated by Figure 4-1. Figure 4-1 shows that there are four basic ways one can effect a reduction in exposure. Two ways involve machinery redesign to provide operators and helpers more protection, or decreased exposure time. For example, one of the major roof fall hazards discussed in Section II is injury at the time temporary support is installed. A system that could cut and install permanent support as it advanced would reduce the time for roof

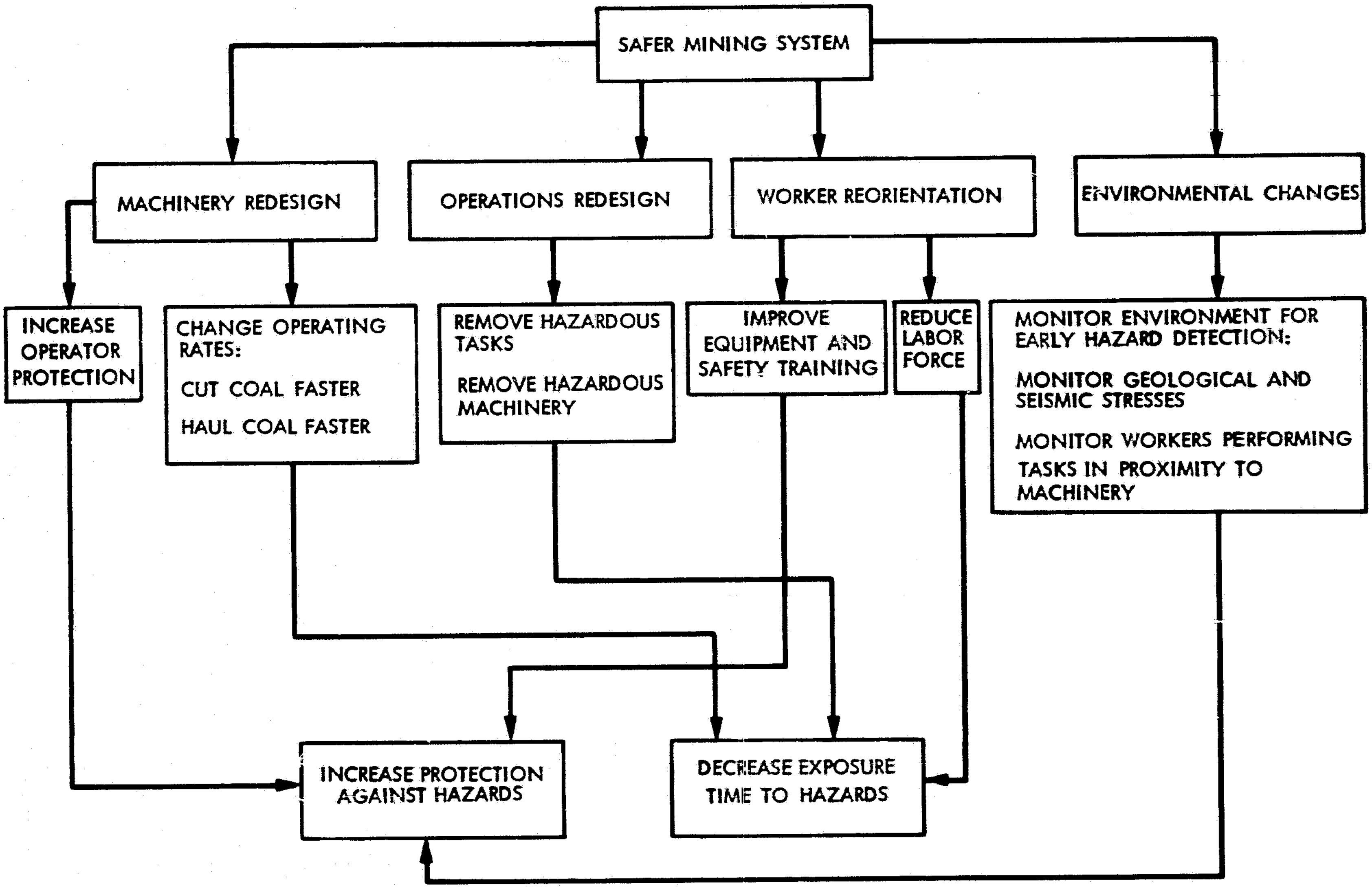

Figure 4-1. Relation of Hazard Reduction to Exposure Time or Protection

stresses to build up to dangerous levels. This same example could be applied to the next hazard reduction factor, operations redesign. This means that a new system could streamline operations and also achieve a reduction in exposure time. The above example would allow the extremely hazardous task of setting temporary roof support to be eliminated.

Two other ways that exposure may be reduced are through reductions in the number of workers exposed in high risk task areas (coupled with intensive training), and through hazard monitoring devices (such as seismic ground control devices, machine proximity sensors and warning devices, etc.). The data in Section II-C provided a detailed breakdown of all the major hazard areas as a function of their respective contributions to the total number of injuries. Using the approaches for reducing hazards outlined in Figure 4-1, and coupling these ideas with the major hazard areas, it is possible to derive some detailed design guidelines for hazard reduction. The evaluator is provided the following guidelines to illustrate the kinds of design criteria advanced systems should meet to effect major reductions in hazards. These guidelines should also stimulate the designer's imagination toward means of controlling new hazards which may be introduced by a proposed design:

(1) Improving Ground Control and Equipment Protection

(a) System should provide permanent support at the face (to the extent cutter geometry allows) as part of systematic support plan as the system cuts and advances, and should not allow workers to be under unsupported roof at any time (particularly within the distance from the face to the last permanent support). Systems should test the roof and establish support positions as well as supplemental support without requiring workers to be exposed to unstable geologic conditions.

(b) System should not require workers to perform tasks outside of equipment protection when in unsupported roof areas.

(c) System should provide dynamic feedback on ground control conditions, and also monitor unusual geologic conditions (i.e., faults, potential rock bumps). Systems should also provide alternative actions (such as stress data feedback via computer) to allow immediate changes in the systematic ground support plan.

(d) Workers should be trained and certified for major tasks.

(e) System should incorporate quality control programs to monitor degradation in ground control components (such as designing scheduled and unscheduled maintenance programs based on the severity of the mine environment; this would consider a variability in dampness and degree of groundwater acidity which effect corrosion rates of components).

(f) System should utilize permanent and temporary ground control components designed such that they cannot be dislodged by impact resulting from machinery or other objects.

(2) Reducing Pinch and Squeeze as Typically Related to Haulage

(a) Maintenance and operating areas in and around equipment should be illuminated to allow good machine component visibility and should generally place workers in areas where equipment or equipment components are not traveling or subject to rapid movement.

(b) Moving equipment should monitor obstructions and provide dynamic feedback to vehicle controls to prevent collision with other vehicles, people, or rib.

(3) Machinery Improvements

(a) Equipment and lighting should be designed to allow unobscured vision of all operations; and equipment should monitor the presence of workers in areas that may expose workers to impact or being caught. Guards against catch points should be provided and equipment should incorporate devices which allow operation only when guards are in place. If visual confirmation of a repair is required, positive "system up" signals should be provided without requiring workers to adjust system when it is operating.

(b) Equipment should be stable under all operating conditions so as to prevent undamped, uncontrollable system responses which can cause impact with other equipment or workers in the area. Equipment should have feedback control systems that levelize power input when components are overstressed.

(c) Workers should be trained and certified for major tasks. Training aids (including simulators) should be an integral part of the system.

(4) Reducing Handling Material Hazards

(a) Workers should have appropriate support equipment that provides automated handling and positioning of heavy, cumbersome materials (e.g., ground control materials).

(b) Work areas should be designed to incorporate appropriate space and support equipment to allow for stable storage of equipment components and material as part of the total mine design.

(5) Reducing Explosion/Burns

(a) Ventilation system should continuously monitor gas and dust buildup and should alter ventilation to maintain established MSHA safe levels, and should provide warning simultaneously to all workers (e.g., unsafe areas where gas is building up at a faster rate than ventilation system can handle). Ventilation system should fault isolate areas where fire initiates, and activate control systems to seal off area and provide ventilation to areas where workers may be forced to remain until the fire is extinguished.

(b) Shot setting and blast systems should not expose workers to premature blast or flying debri resulting from blast (e.g. remotely controlled drill and shot setting system).

(6) Reducing Electrical Hazards

Workers should not be exposed to handling electrically energized components through design incorporation of electrical diagnostics and fault identification systems, and by automatic disconnect systems that cut off power at the sources.

(7) Reducing Slips and Falls

Work areas should be systematically designed to allow room for materials and debris to be stored outside the work area.

(8) Improving Handtool Design

Handtools should be configured for specific tasks and incorporate positive locking devices to prevent slippage. Where possible, fasteners that can allow the removal or installation of components without the use of large or heavy tools should be employed.

(9) Reducing Suffocation Hazards

(a) Work and storage areas should be designed to prevent intrusion of stored material into areas where workers are present as part of the mine system design. Where necessary to store refuse in bins or hoppers, worker interface in the process of unclogging should be eliminated through the use of vibrators or pre-crushing treatment.

(b) Control of gas buildups as it contributes to suffocation coincides with the proposed ventilation criteria related to explosions and fires.

6. Comparison of Hazards Associated with New Designs Against the Conventional Comparison

The last step in the conceptual level analysis is to examine the previously developed information on hazards and features designed to offset these hazards, and then determine whether the new design offers a substantial improvement in comparison with an analogous conventional system. The first step in this process is to identify the general hazards associated with the comparison system. Figure 4-2 assists in this task by relating generic classes of mining activities and conventional equipment to their associated accident categories. The evaluator simply selects the desired comparison activity and equipment from the left hand column and notes which major accident categories

DESCRIPTION OF CONVENTIONAL SYSTEMS BY MINING ACTIVITIES		HAZARDS	SLIPS/FALLS	ELECTRICAL (ARC/FLASH)	EXPLOSION/IGNITION	FIRE BURNS, CHEMICAL BURNS/ IRRITATION	STRUCK BY MACHINES	PINCHED/SEQUEEZED BY MACHINERY (RELATED TO HAULAGE)	PRESSURE BUMPS/ROCK BURSTS	ROOF FALL/OR FALL OF FACE/RIB	PRESSURE VESSEL/LINE FAILURE	SUFFOCATION	HANDLING MATERIAL
	1)	Construction of access roads	X				X	X					X
SITE PREP	2)	Leveling of site and establishing pad/foundations for surface equipment	X	X			X	X					X
	3)	Remove overburden	X	X			X	X		X			
	4)	Drill borehole for seam access, ventilation, etc.	X	X			X	X					X
SEAM ACCESS	5)	Dig shaft	X	X			X	X		X			X
	6)	Provide external support											
		a) electric power		X		X							X
		b) water										X	
	7)	Move support equipment in place	X				X	X					X
	8)	Extract coal											
		a) Cut/continuous mining	X	X	X		X	X	X	X	X	X	X
		b) Auger	X	X	X		X	X	X	X	X	X	X
		c) Blast	X		X	X			X	X		X	X
SEAM EXTRACTION		d) Saw	X	X	X		X	X	X	X		X	X
		e) Hydraulic/solvent	X			X					X		X
		f) Shovel/dragline	X	X			X	X		X		X	
		g) Manual/hand tools	X		X		X	X		X		X	X
	9)	Haul coal											
		a) Shuttle car	X	X	X		X	X	X	X			X
		b) Conveyor	X	X	X	X	X	X	X	X			X
		c) Slurry/pump	X			X					X		
		d) Rail car/truck	X	X	X		X	X		X			X
		e) Capsule/high pressure air or hydraulics									X		
HAULAGE		f) Auger	X	X	X		X	X	X	X			X
	10)	Support haulage route											
		a) Borehole casing	X				X	X					X
		b) Chocks	X		X		X	X	X	X		X	X
		c) Roof bolt	X	X	X		X	X	X	X	X	X	X
		d) Backfill					X	X	X	X		X	X
		e) Timber			X		X	X	X	X		X	
	11)	Haul material/supplies	X		X	X	X	X	X	X	X		X
SITE CLOSING	12)	Remove equipment							X	X			X

Figure 4-2. Hazard Matrix

the conventional system normally experiences. The detailed hazards follow directly from Section II-3 once the accident classification is found.

At this stage, all the information necessary to compare the two systems is available. Since there is particular concern with fatalities and permanently disabling injuries, a good measure is whether the new system will reduce those serious injuries. A simple judgment of "less than," "equal to," or "greater than" will suffice. If injuries are expected to decrease, then the reason (in terms of the suggested performance criteria outlined in Section IV-4) should also be indicated. Table 4-2 illustrates a simple cross tabulation format useful in making this comparison. The ground rules for using Table 4-2 are as follows:

(1) The evaluator is not constrained to use only one type of conventional comparison.

(2) Depending on the similarity of various accident causes and hazards, the evaluator may choose the depth of the comparison. For example, a remotely operated room and pillar system which replaces a conventional room and pillar system would not expose workers to roof falls. Therefore, it would suffice to make the comparison at the level of whether roof falls will be a major accident class.

(3) An estimate of the potential for disabling injuries must consider both injury frequency (exposure time) and severity (protection). Therefore, a new design which effects either would allow one to register a reduction in serious injuries.

(4) If a new design displays hazards similar to its comparison system and increases exposure through a larger labor force, greater exposure time, or less protection, it must be assumed that the potential for serious injuries will increase, unless it incorporates mitigating design factors.

The last step is to summarize the serious injury potentials of the new system. This summary should emphasize the performance of the new system in the areas of roof falls, haulage, machinery, and handling materials, which comprise more than 75% of serious injuries for conventional systems (see Section II-C). These areas must show a reduction in order for the design to be considered truly viable. Though it is desirable to demonstrate reductions for the remaining hazards, these have little impact on reducing the serious injuries experienced by current-day equipment.

7. Illustrative Example

A simple example can be used to demonstrate the whole procedure. One example of an advanced concept is a borehole hydraulic coal mining system (17). This system was designed to replace a room and pillar operation by establishing a borehole network over the coal seam and operating the hydraulic cutters (placed down the borehole) from the surface. The hydraulic cutters use the jetting force of water to cut the coal and form a cylindrical cavity having a radius equal to the reach of the jet. The loosened coal is pumped out of the

Table 4-2. Hazard Comparison of the New System Against the Conventional Comparison

New System Designation__________________________

Description of Conventional Comparison	Major Hazards Experienced by Conventional System	Major Hazards Experienced by New System	Potential for Disabling Injury			Reasons for Expected Reduction in Injuries
			<	=	>	

cavity in slurry form and vented directly into a settling tank where it is then pumped to the prep plant. A functionally similar system would be the auger since it extracts coal using a boring process and utilizes a rig, drill stems, and support equipment similar to the borehole system. For simplicity we will only examine the process of hauling the coal out of the cavities. The auger accomplishes this task by using an overhead conveyor to move coal to trucks; and the borehole effects coal transport out of the cavity by slurrying the coal into a settling tank.

The system failure and human interaction approach outlined in Section II reveals the basic hazards to which the one or two auger workers are exposed during clean up around the conveyor (see the haulage and machinery hazards):

(1) Workers can be struck by the conveyor chain drive which can fail under load.

(2) Workers can be struck by conveyor fragments resulting from belt failure under load, or can become entrapped in the moving conveyor.

(3) Workers can be struck by debris falling off the conveyor.

(4) Workers can suffer injuries in the process of moving large debris which has fallen off the conveyor.

The borehole system is a closed loop hydraulic circuit which only requires one person to monitor system operation (17). This person monitors the operation from a cab mounted close to the point where water under high pressure is pumped in, and the slurry is pumped out. The major hazard the worker is exposed to is a high pressure burst from either the input or output lines.

Table 4-2 would be filled out as follows. The conventional comparison would be the auger conveyor. The accident class would be haulage and the hazards would be listed as outlined above. The new system hazards are not exactly the same because the borehole eliminates both the need for a conveyor and the subsequent cleanup task. The new hazard introduced is the possible burst of the pressure lines. For this we would compare it to a conventional oil drilling or gas well operation. In both comparisons the expected result is a reduction in serious injuries for the following reasons:

(1) The borehole system reduces the number of workers required for support tasks on augers and drill rigs.

(2) The borehole system provides protection by placing the one exposed worker in a cab and, being a closed hydraulic circuit, does not require the worker to be under a conveyor, close to a drill rig, or handling cumbersome materials. The hazardous cleanup task has been removed and replaced by a monitoring task.

It can be concluded from this analysis that the borehole system looks promising because it offers a sizeable reduction in disabling injuries by effecting one of the more severe accident classes. The next step would be to project what the reduced injury level might be as a result of the removal of a hazardous task and reduction in labor force. This is developed in the following quantitative portion of the methodology.

SECTION V

SAFETY EVALUATION AT THE PRELIMINARY DESIGN STAGE

A. OVERVIEW OF THE EVALUATION

The preliminary design stage safety evaluation is a quantitative projection of the hazard and injury reductions identified in the qualitative analysis. In light of the quantitative nature of this section of the methodology it is appropriate to restate the overall requirements; namely, the overall projected injury rate should not exeed 40-45 injuries per million man hours and the disabling injury and fatality rates should respectively not exceed 30 and 0.2 injuries per million man hours. If a new system meets these requirements it will exhibit a level of safety commensurate with the trends of existing, similar industries which are safer. As with the qualitative analysis, emphasis is placed on projecting the effect of a new design on reducing fatality and disabling injury rates. Injury frequency and severity are equally important and are addressed respectively by reducing hazard exposure time or increasing worker protection. Injury frequency is affected by using exposure time indices which are the fractional changes in task times of the new system as compared to an analogous existing system for similar risk populations. The risk reduction factors which can be reflected in an exposure time index are machinery redesign and operational changes (removing hazardous tasks). This index can be further influenced by labor force reductions and quality of training. The exposure index for a given task is multiplied by the injuries associated with the same hazard and task of the conventional analogous system to project the new system safety performance.

Reductions in severity are measured by subjectively determining the aggregate effect of new protective design measures on the body component injuries associated with the analogous conventional system. The analysis examines how injuries for existing systems might be reduced by employing the protective design measures of the new system. The new system must offer protection for the body areas that are the most exposed and have the most severe injuries in order to be judged as a sound design. The risk reduction factors, which can be grouped as protective measures, are machinery redesign and environmental controls and monitors.

The intent of the projections is to establish the relative difference in the magnitude of injuries between a new design and existing systems. The projection of the magnitude of injuries was considered the only realistic goal because of the necessity to make simplifying assumptions in order to remove some of the complicating aspects of the analysis (such as multiple task and hazard interactions). Realism is incorporated by presenting both the new design and injury projections to a group of experts in mining safety and adjusting the projections in light of their experience. Other aspects which effect injuries such as the possible need for comprehensive training programs and any unusual site characteristics are also incorporated at this time.

B. DISCUSSION OF EXPOSURE REDUCTION VARIABLES AS RELATED TO RISK POPULATIONS, EXPOSURE INDICES, AND SEVERITY INDICATORS

This section discusses the influence the exposure reduction factors have on injury frequency and severity by respectively reducing hazard exposure time or increasing protection. The exposure reduction factors were introduced in Section IV-B, and are summarized as follows:

(1) Reduce exposure time to hazards associated with various tasks.

(2) Remove dangerous tasks completely.

(3) Increase protection against hazards and allow exposure time to remain the same.

(4) Provide hazard warning devices as a means of protection.

The quantitative measure of these possible means of reducing hazards requires a detailed identification of the populations at risk, and development of exposure time and injury severity indicators.

1. Definition of Exposure Reduction Factors

The exposure reduction factors which affect either exposure time or injury severity are: redesigning machinery, streamlining mining operations, reducing the size of the risk population, and providing a better means of monitoring the mining environment and workers. As stated in the conceptual level design evaluation, machinery can be redesigned to reduce exposure time or provide greater protection. For example, exposure to roof falls can be reduced by increasing the cutting rate of a mining machine. If a cutter can be designed to advance quickly, such that permanent support can be installed almost immediately, then the large buildup of stresses which cause caving can be somewhat mitigated. This would reduce the amount of in-place time during which workers are exposed to roof fall hazards. This same approach to reduce the roof fall hazard applies to ground control equipment. Any machinery redesign which reduces the task time for installing temporary or permanent support will assist in reducing the exposure to rock fall injuries. Another approach might be to design machinery which provides positive protection against falls and does not require workers to leave the protection until the task is completed and they have moved to an area under permanently supported roof.

Exposure time can also be reduced by removing particularly hazardous tasks or operations. One example provided in Section IV-B referred to streamlining the roof support process by installing permanent support as the new system advanced. This would alleviate the need to place temporary support (such as timber or chocks) as required with existing room and pillar systems. Another useful example of making operations more efficient is the hydraulic borehole miner and conventional auger comparison discussed in Section IV-B. In this example, the borehole improved the efficiency of the haulage process by removing the need for an overhead conveyor and, therefore, removed the hazardous task of cleanup underneath the conveyor.

Hazard monitoring and alert devices can provide additional measures of protection for workers. This is achievable at a macro level (the total mine environment in which equipment operates) or a micro level (distinct components of the mining system such as machinery). Devices could be employed at the macro level to monitor internal changes in strata stresses and also the transfer of stresses from one location to another (such as the transfer of stress concentrations from the face area to the entry areas). The stress signals could then be transformed into warning signals for workers in the area. An example of exerting hazard control on a micro basis would be the use of obstruction monitors on pinch points in machinery. These would warn workers if their hands or feet were too close to hazardous areas on operating equipment. Similarly, equipment operators could be provided signals in the cab warning them of workers in areas around the equipment which are not visible from the operator's compartment.

All of the above means of reducing hazard exposure have one main thrust; namely, the reduction of injuries to the risk population. The possibility of reducing hazard exposure by reducing the number of workers involved in hazardous tasks cannot be overlooked.

One additional informal element that has been shown to reduce hazard exposure is training. Training studies using injury statistics from known populations (workers with and without formal training) suggest that comprehenhensive instruction in hazard identification and avoidance can contribute to a 10% reduction in injuries in the four major accident categories (i.e., roof falls, haulage, machinery, and handling materials) (9). This methodology assumes that a requisite level of training will accompany any new design, and that this training will be adequate in mitigating hazards caused by operator error. However, if the analysis suggests that normal, on-the-job training may not adequately prevent operator error, then the potential impact this could have on compounding hazards would be addressed during the final design review with the group of experts. The experts would be asked to comment on the impact operator error may have on injuries, and also asked for training suggestions that might resolve operator problems. The following represent examples of additional training aids:

(1) A formal task instruction program which has a well-defined syllabus and includes, where necessary, mockups of real situations (including equipment simulators), and instructor evaluation.

(2) Certification for major task areas such as machinery operation and ground control support tasks.

(3) Periodic testing, reevaluation, and retraining.

All of the above hazard reduction factors must be transformed into comparative measures of exposure time, protection, or change in risk populations before the injury projection for the new system can be completed. These measures are defined in the following sections.

2. Definition of Risk Populations

The risk population is defined as the group of workers exposed to a set of hazards. Identifying the number of workers involved in task areas that are related to major hazards is essential to measuring the impact of improved safety. The quantitative methodology uses the fractional change in the comparable risk populations of a new system and an analogous conventional system as one means of assessing possible design improvements (i.e., if a new concept was similar in every way but increased the risk population in a particularly hazardous task area then this would tend to increase injuries). Hazards associated with slips and falls, handtools, and suffocation are not specific to any given task area, location, or groups of workers and, therefore, do not have any particular worker task category attached to them. However, the remaining accident categories do display a distinct task-severity relationship. The following tables (Tables 5-1 through 5-4) and discussion demonstrate the relationship between task and injury frequency as a function of each accident class and the approximate number of people involved in each task. The evaluator is provided this information to help identify critical tasks and worker locations that largely expose workers to serious injuries.

a. Roof and Face Fall Injuries. The most important aspect of the hazards and tasks shown in Table 5-1 and associated with ground control and working in the face area is the location of workers in relation to the position of the last permanent support. The ground control tasks often require workers to be "inby" the last permanent support (i.e., close to the face under unsupported roof), and the other face tasks (such as operating mining equipment) place workers right at the position of the last permanent support. Other general support tasks place workers "outby" the last permanent support (i.e., away from the face under supported roof). The distribution of serious injuries by task clearly demonstrates that the 10-15 workers inby, or right at the last permanent support, have a much higher chance of being injured. The inferred reverse of this statement would also appear to be true; namely, the chance of being injured could be greatly reduced if the permanent support could be placed as close as possible to the face.

b. Haulage Injuries. Operating haulage equipment is a very hazardous task because drivers are exposed to hazards driving to and from the face as well as at the face. For example, operators must often lean out of the cab in order to back up or observe operations. This can result in being pinched between the machine and rib. Negotiating narrow, unlighted entries, or maneuvering haulage equipment in close quarters with other moving machinery in the face area can also result in operators being pinched or struck. Helpers riding on equipment are exposed to an even greater extent to these hazards because they have no protection. All of these elements contribute to the major hazards shown in Table 5-2.

Performing maintenance in the face area is standard procedure since most equipment is located in this area and repairs are usually done in place. However, the congestion caused by operating equipment (mining machines, loaders, bolters, etc.) in proximity to one another suggests that the face

Table 5-1. Relationship Between Roof and Face Fall Injuries and Worker Task

Major Task Areas	Average Number of Workers Involved in Task	Average Percentage Contribution to Fatalities and Disabling Injuries
Ground Control- provide temporary support, followed by installation of permanent support (i.e., drill roof, insert and torque bolts)	2-4	31
Working in the face area:		
Operating mining equipment	2	6
Scaling the roof	1	6
Setting brattice	2	2
Operating loaders and shuttle cars	2/vehicle	3
Using handtools to break up large pieces of rock and coal	1-2	3
Supervising and observing operations	1-2	2
Subtotal	-	22
General Face area support tasks:		
Cleanup	1-3	2
Machine maintenance	1-2	3
Moving cables	1-2	2
Transport supplies	2	2
Subtotal	-	9
Unclassified or not otherwise specified	-	38
Total		100

Reference:

"Analysis of Fall of Rib, Roof, and Face Accidents in Underground Coal Mines," MSHA, 1976-1978.

Table 5-2. Relationship Between Haulage Injuries and Worker Task

General Task	Average number of Workers Involved in Task	Average Percentage Contribution to Fatalities and Disabling Injuries
Operating haulage equipment such as shuttle cars, loaders or rail cars	1-2	42
Helpers riding on equipment in transit	1	13
Workers performing maintenance on equipment in proximity to moving haulage equipment	1-2	5
Workers spotting or coupling rail cars	1-2	9
Workers rerailing rail cars	3-4	4
Workers performing clean-up in the face area	1-2	2
Workers moving power cables near the face	1-2	2
Workers handling supplies in proximity to moving haulage equipment	1-2	1
Unclassified or not otherwise specified	-	18
Total		100

References:

"Nonfatal Injuries Caused by Haulage Related Accidents in Underground Coal Mines," MSHA, 1977.
"MSHA Detail Injury Summary," Report #CM341L2, 1976-1979.

area is not the safest location to perform this task. This appears evident because the contribution of maintenance to the total serious injuries shown in Table 5-2 is significant. As discussed in Section II, the task of spotting and coupling rail cars is hazardous because workers usually perform this task while the cars are moving. The possibility of being struck or pinched between cars is, therefore, considerably increased.

c. Machinery Injuries. The major task contributors to serious machinery injuries (Table 5-3) involve operating and maintaining machinery in the face area. As with haulage-related injuries, it appears that the amount of equipment in the face area creates a congested work place, which increases the likelihood of being struck by machinery. Conventional roof bolting equipment introduces an additional problem because workers must often manually guide the drill and bolt when installing permanent support. If either the drill or bolt break, the worker can be struck. Another contributor, discussed earlier, is the instability of mining and bolting equipment when cutting or drilling extremely hard rock. This can result in the machine moving abruptly sideways and striking workers in the area. Taken as a whole, these data indicate that there is sizeable room for new designs to reduce machinery related accidents by providing better machine stability, more protection, or streamlining operations to reduce face congestion.

d. Handling Material Injuries and Worker Task. Because the material handling task injury relationships were developed in detail in Section II-C, it will suffice to simply summarize them here. Almost 70% of the total disabling injuries are associated with the following tasks:

(1) Handling supplies (such as props or timber) and equipment (such as fans, pumps, etc.).

(2) Performing machine maintenance and handling machine components.

(3) Handling power cables or cable reeling.

(4) Handling coal, rock, or other debris.

The primary problem experienced in these task areas is the weight and cumbersome nature of these objects. This results in worker's physical capabilities often being exceeded, in which case they may either strain muscles or drop objects on themselves or others. This suggests that new concepts should provide appropriate support equipment to remove some of the tasks that contribute to overexertion.

e. Explosion and Burn Injuries and Worker Task. The largest sources of explosion and fire hazards are gas, coal and dust, and explosives (see Section II-C.). Because these accidents usually involve a large number of workers doing a variety of tasks, it is not meaningful to break explosion and burn injuries down by task. Existing injury data do suggest that the highest risk area for both gas and explosive accidents is the mine face. This

Table 5-3. Relationship Between Machinery Injuries and Worker Task

General Task	Average number of Workers Involved in Task	Average Percentage Contribution to Fatalities and Disabling Injuries
Operating roof bolting equipment	2	34
Performing maintenance on equipment in the face area	1-2	13
Operating mining equipment	2	12
Setting/removing/relocating props in proximity to operating machinery	2	3
Moving cable in proximity to operating machinery	1-2	3
Operating loading machines	2	3
Handling supplies in the face area	1-2	3
Tramming and positioning equipment	2	2
Cleanup in the face area	1-2	2
Undefined or not otherwise classified	-	25
Total		100

Reference:

"MSHA Detail Injury Summary," Report #CM341L2, 1976-1979.

makes sense because the face is the principal area that brings together all the elements required for an explosion; namely, gas released in the winning process, dust, and an ignition source (such as sparks generated by cutting machines striking rock). In the case of explosives the face area is the primary focus of the shooting process. Subsequently, it appears that advanced systems could provide protective measures for workers through continuous environmental monitoring of dust and gas or, for tasks requiring handling of explosives, through replacement of workers with robotic devices.

f. Electrical Injuries. As would be expected, Table 5-4 indicates that electrical and machine repairs are large contributors to serious injuries. Transporting conducting materials, or moving machines that are made

Table 5-4. Relationship Between Electrical Injuries and Worker Task

General Task	Average number of Workers Involved in Task	Average Percentage Contribution to Fatalities and Disabling Injuries
Electrical repair of cables and equipment	1-2	38
Moving materials to and from the face (such as roof bolts, rail, etc.) and moving equipment (such as rerailing cars)	2-4	24
Machine maintenance and repair	1-2	13
Cable handling	1-2	9
Cleanup at the face in proximity to equipment	1-2	8
Operating equipment	2	6
Unclassified or not otherwise specified	-	2
Total		100

Reference:

"MSHA Detail Injury Summary," Report #CM341L2, 1976-1979.

of conducting materials, and allowing them to come in contact with energized components (such as trolley wires), are also major contributors to serious electrical injuries.

The trend that appears throughout the tables and discussion is the high exposure of the face crew to the majority of the hazards in almost all of the accident classes. This is an important finding because it tells the designer where the real safety improvements must be made through labor reductions, or relocation of workers to safer areas. It is clear that the major task areas at the face which should be targeted for improvement are ground control, operating haulage and ground support equipment, equipment maintenance, and handling supplies and machine components. Identification of the most hazardous task areas allows a clearer understanding of the exposure time and protection concepts introduced in the previous section. These concepts are defined in detail in the following sections.

3. Definition of the Exposure Time Index

Studies of individual worker injury histories suggest a strong relationship between the chance of being injured and the cumulative time a worker is exposed to hazards while performing tasks. Though this probability curve varies as a function of hazard and task, the overall implication is that injuries could be reduced if exposure time is decreased.

This concept of an exposure index has been used in studies by Pfleider & Krug (6), and Frantz & King (7). The Pfleider, Krug paper developed health indices for the hazards of dust and noise by first rating various mining equipment in terms of dust and noise levels, and then multiplying the ratings by the number of men and hours exposed. The Franz, King paper developed exposure indices which expressed the expected percent reduction in time exposed to various hazards associated with a remotely operated continuous miner. The quantitative indices developed below reflect the fractional change in task exposure time between the new system and the analogous conventional systems. This analysis is done for each hazard and task in those areas where machine or operational redesign cause a change in task time.

4. Definition of the Measure for Severity

The severity aspect of hazard exposure was handled differently from the exposure time index because it was more difficult to quantify. The reason for this is because variation in injury severity is related to the protection of the body. Early in the design of a new concept it is difficult to identify the degree to which various parts of the body may be exposed to hazards. Therefore, it appeared that the best measure of the effectiveness of machine protection, or hazard monitoring devices would be a general indication of the magnitude of the injury reduction. The methodology determines the magnitude by testing each design element to see if it protects those body components from serious injuries which are historically associated with major hazards.

C. DESCRIPTION OF THE QUANTITATIVE PROCEDURES FOR PROJECTING INJURIES

The following sections demonstrate how the various reduction factors of risk population, exposure time related elements (such as machinery and operational redesign), and protection elements, are used to actually project injuries. The injury projection also requires the use of historical injury data and further definition of both the new system and existing technology from the standpoint of design and task description. The injury data must be broken down by both accident classification and task activity. Certain assumptions were used to simplify the injury projection process. Since these assumptions could materially affect the accuracy of the projection, it was decided to incorporate the judgment of a group of experts in the field of mining safety to improve the reliability. The procedure for incorporating this judgment into the projection is also discussed. Finally, a simple example is provided to demonstrate the complete projection process.

1. Explanation of the Injury Projection Equation Using the Exposure Time Index

Any mathematical modeling process cannot exactly duplicate the actual system. In the area of safety, because of the human element, this process is made even more difficult. Therefore, assumptions must be made which simplify a system enough to make it amenable to solution, but still close enough to the real world so as to retain reasonable accuracy. The following assumptions appear to satisfy these criteria:

(1) Injuries are evenly distributed with time. Over a short time period of perhaps one month, this is not true. However, if a system is observed over a period of years, deviations from an average, constant injury rate are not significant.

(2) Injury occurrence is directly proportional to exposure. Depending on the hazard, this statement may not be exactly correct. For example, the hazard of roof falls is extremely great during the first half hour after a new face is created. Therefore, the chance of injury is very high over a very short time period. However, historical data do indicate an increasing chance of injury as exposure increases. Although a gross simplification, this assumption does permit a first order estimate of the magnitude of the affects of reduced exposure. To offset the problems with this assumption the final results will be adjusted by a review group composed of experts in mining safety.

(3) All health and safety regulations are complied with. For example, the methodology does not consider possible worker reluctance to wear proper clothing, and therefore, increase injuries due to entrapment.

(4) All injury data are representative and accurate.

(5) Changes in system safety design will be completely effective. This is not completely accurate because very few systems operate exactly as they were designed. Thus, the injury projections may be somewhat optimistic. This is another reason why the methodology has incorporated a review group into the final analysis of new design integrity.

A simple injury projection expression was developed employing the above assumptions. This expression incorporates the following factors:

n_i - The projected injuries for a given task i and hazard in the new system (measured in injuries per year).

N_i - The total number of injuries associated with a given task i and hazard of the analogous conventional system, used as the starting baseline for the new system projection (measured in injuries per year).

t_i - The exposure time index, which is a measure of the fractional
T_i change in task exposure time between the new and conventional comparison systems, calculated for each hazard and accident class. The term t_i applies to the new system task time, and T_i refers to the time required to perform the same (or similar) task in the conventional system (dimensionless).

f_i - An additional adjustment factor which encompasses the expected changes in injury rates caused by fractional labor changes for a given task (dimensionless).

g_i - One final judgment factor which represents the general consensus of opinion of the group of experts pertaining to the safety integrity of the new system (expressed as a fractional change in injuries). If additional comprehensive training is required, or representative site data are also available, then the experts are asked to consider the impacts of these elements on the injuries (dimensionless).

It is easy to see that the injury rate for the ith task of the advanced system is the following expression:

$$n_i = N_i \frac{t_i}{T_i} f_i g_i$$

The projection is initially computed with a value of unity assigned to g_i. At the last step in the methodology, the group of experts is provided both the original injury level (N_i) and the initial projection (n_i) so that they have a baseline from which they can judge each new design element and incorporate their experience to further adjust the outcome. This judgment is summarized in the adjustment factor (g_i). The adjustment process is structured and is explained later in the methodology.

The serious injury rate (S_i) is determined by referring to the percentages developed in the hazard analysis section (Section II-C) This is expressed as follows:

$$S_i = n_i R_i$$

where, R_i = the ratio (or percentage) of serious injuries to all injuries for the analogous conventional system, for task i.

An adjustment of the serious injury rate by the group experts is not feasible at the preliminary design stage because there is no experience available on which to base decisions about the seriousness of injuries.

The total serious and non-serious injury rates for the new system are determined by simply summing all the projected yearly injury rates for all tasks and hazards.

2. Explanation of the Method for Projecting Severity of Injuries

If it is decided to reduce severity by providing better personal protection (beyond standard regulatory body protection such as helmets, safety goggles, etc.) then a body component exposure analysis must be conducted. The basic idea behind the analysis is that by providing increased body protection to certain areas of the body, there may be a marked decrease in injuries.

As stated in the Section B-4, the evaluation of personal protection requires a subjective measure of the relative increase in body protection of the new system over existing systems. A subjective approach was taken because at the preliminary design stage, the new system design elements affecting personal protection are not yet firm. For example, the preliminary design of a new system which changes the roof contour to better distribute roof stresses, will not have all of the details worked out pertaining to the exact design controls for maintaining the structural integrity (under all geological conditions) of the support. Prototype testing (detailed design stage) would provide the final statement of design integrity. Therefore, detailed injury reduction calculations indicating the aggregate effect on injuries to the body would not be appropriate at this time. Another reason why a more subjective approach is better at this design stage relates to the problem of multiple injuries. MSHA reports injury data by both frequency and severity. Each incident reported as a fatality or disabling injury in the frequency tables is likewise translated into a body injury in the severity format. Generally, the total frequency and severity counts are the same since MSHA attempts to record the major body component contributing to the fatality or disabling injury. However, in some cases, workers may suffer multiple injuries which result in death or disablement. At the preliminary design stage there would be insufficient data to determine if multiple injuries could result from a given hazard. This implies that the general magnitude of the injuries is the only reasonable conclusion that can be drawn without actually testing and demonstrating the new design. As a result, the approach taken in this methodology is to simply allow some gross statements to be made about personal protection and injury reduction.

Assumptions similar to the exposure time index discussion apply to the assessment of severity; namely, (1) all injury severity data are accurate, and (2) safety improvements in the new design will be effective to the degree intended. The approach to the severity analysis is outlined below:

(1) Identify the major task areas (and from these identify hazards and accident classes) where machinery redesign or hazard monitoring devices may enhance worker protection.

(2) Establish the most severe body areas historically affected by the various hazards and lack of protection for the conventional comparison to determine the magnitude of injuries involved.

(3) Match the appropriate protective design measures with the various hazard and accident classifications and key body areas affected.

(4) Subjectively determine whether the design adequately protects the worker.

(5) Summarize the results to determine if the major hazards have been mitigated.

(6) Apply an adjustment factor which reflects the degree of reduction in serious injuries based on the consensus of a group of experts. The experts are provided the subjective degree of adequacy of the protection based on the analysis and then asked to translate the subjective findings into an expected fractional reduction in injuries. As with the exposure time projection, any labor reductions or representative site characteristics which may influence the quality or completeness of the protection are also included at this time.

The injury projection expression for the protective aspects of a new design is as follows:

$$b_j = B_j d_j$$

where,

b_j = The injury projection considering the incorporation of new protective design measures, for a given accident class j (measured in injuries per year).

B_j = The aggregate number of historical injuries to the body associated with a given accident class j (measured in injuries per year).

d_j = The general consensus of the group of experts pertaining to the integrity of the new protective device (expressed as a fractional change in injuries).

The most hazardous task areas and accident classes were established through the hazard analysis explained in Section II. It was further determined that the workers in the face area represent the risk population in greatest need of protection. It is feasible that a new concept may elect to provide a more protective environment and not reduce exposure time; in which case it is important to identify what areas of the body are in greatest need of protection against the major hazards. Table 5-5 displays the relationship between hazards and various body components. The relative contribution of each body component to the total disabling injuries is defined as follows:

(1) Small - 0 - 10% of the total disabling injuries.

(2) Medium - 10 - 30% of the total disabling injuries.

(3) Large - greater than 30% of the total disabling injuries.

The above percentage ranges were defined by examining the percentage contribution of each body component (by accident class) to the total disabling injuries resulting from the use of conventional mining equipment. This was done by analyzing the six most recent years of MSHA body component injury data

Table 5-5. Historical Effect of Hazards on Body Components

Body Component and Relative Frequency of Disabling Injuries / Hazards	Head			Eyes			Trunk			Arms/Hands			Legs/Ankle/ Feet		
	Large	Medium	Small	Large	Medium	Small	Large	Medium	Small	Large	Medium	Small	Large	Medium	Small
Roof/Face Falls		X				X		X			X		X		
Haulage (Pinched/Squeezed)		X				X	X				X			X	
Machinery			X			X		X		X				X	
Handling/Material			X			X	X			X				X	
Bumps/Bursts		X		X				X				X		X	
Electrical			X	X					X	X					X
Slips/Falls			X			X	X				X		X		
Explosion/Ignition	X					X		X			X			X	
Fire/Chemical Burns or Irritation		X				X	X				X				X
Other															

and calculating the mean number of injuries for each component and hazard (15). The relative ratings of small, medium and large were selected after examining the general number of injuries out of the total yearly occurrence associated with each component. This was done to give the evaluator a simple, subjective indication of the critical areas affected by hazards.

Table 5-5 indicates that serious injuries related to rock falls largely involve the lower extremities and trunk. Because these components comprise the bulk of an individual, it appears that some type of total protection would be the only adequate solution. This applies similarly to the hazards associated with haulage and machinery. In the case of haulage and other machinery hazards, the tasks of operating equipment and performing maintenance in proximity to operating equipment expose most of the body to impact. Conseqently, new protective concepts should strive to provide a total safety envelope around face personnel that is independent of the variable mine environment as well as the actions of other workers. This is a good example of the need to consider the aggregate impact on bodily components a new design may have.

As suggested earlier by some examples in Section V-1, protection can be provided through machinery design or hazard monitoring devices. Some additional examples are provided here to provide further direction to the designer. System redundancies are often useful protective measures. For example, redundant hydraulic circuits which include sensors for isolating major pressure leaks, accompanied by automatic shut-down and switch to a back-up system would allow continued component operation without exposing workers to the pressure release hazard. Another possibility is to accept the presence of hazards but provide a barrier between the worker and hazard. For example, a cab and boom arrangement used for roof inspection and support installation could establish a barrier against roof and face falls, and gas ignition, by isolating the operators inside a cab equipped with a self-contained life support system.

The relative effect design changes have on reducing severity is the next element that must be determined. The following ratings reflect the worth of varying degrees of protection and are provided to assist in placing subjective values on design changes:

(1) If a new design incorporates protective measures which establish a complete protective envelope for workers, then it is highly probable that the major hazards will be mitigated.

(2) If a new design incorporates protective measures that are fairly complete (i.e., they protect those exposed body areas that contribute the largest proportion of serious injuries to a given accident class), then it is fairly likely that the major hazards will be mitigated.

(3) If a new design incorporates protective measures which are incomplete (i.e., the measures employed still leave opportunities for workers to expose those areas of the body which contribute substantially to serious injuries), then major hazards will be only marginally mitigated.

(4) If a new design offers protective measures no different from existing systems, and experiences the same hazard potentials, the hazards will not be mitigated and the injuries would most likely remain the same.

(5) If a new design offers few protective measures, has a new (or the same) potential hazard in comparison to an analogous conventional system, and exposes workers to a new or larger number of related system failures, then serious injuries will most likely increase.

Each protective design element is evaluated for the applicable accident class and the results then summarized to allow an overview of the analysis. Table 5-6 is provided as an example to demonstrate how the results of the severity analysis might be presented. In summarizing the results of this analysis, it is important to indicate whether the new design protects the body components most severely effected by hazards, and whether a protective envelope or barrier against the major hazards associated with roof and face falls, haulage, machinery, and handling materials is provided. The only step remaining is to place a numerical measure on the subjective levels of performance (i.e., the numerical definition of d_j). This is accomplished by consulting the group of experts and asking what they feel the subjective measures would equate to in terms of reductions for both serious and total injuries.

The total injury rates for the new system are computed by summing all the projected injury rates for each accident class affected, as well as those classes not affected. Though protective measures may not apply to all accident classes, it is perfectly feasible that hazards associated with these classes could be mitigated through other exposure time design changes. Both projecions would then be combined to form an overall assessment of safety.

3. Preparatory Steps Required for Making Injury Projections

The preceding sections provided the framework for making injury projections using both exposure indices and protective design measures. Many elements in the expressions (such as injury data, and task time data) need to be defined in greater detail in order to project injuries. Guidance must be provided on where to obtain injury data for both coal mining systems and other systems which may not have immediate mining applications, but may be similar enough to be used as a baseline for comparison. The injury data reporting format is also important since it must conform with the analysis. Task time data for both existing systems and the new design must be tabulated and formated properly in order to allow an appropriate comparison of the two systems. This section explains the sources for all the data elements, and shows how they are organized for use in preparing the projection expressions.

a. Detailed Description of the New System. The new system must be defined in terms of task times, manpower, worker locations, and machinery design in order to have sufficient data to understand potential exposure time reductions or the protective elements. The system description provided at the conceptual design phase merely explained the various tasks. At the preliminary

Table 5-6. Evaluation of Relative Success of New Design in Mitigating Hazards Using Protection

Expected performance of new system as compared against existing systems / Accident Classes	Head			Eyes			Trunk			Arms/Hands			Legs/Ankle/ Feet		
	<	=	>	<	=	>	<	=	>	<	=	>	<	=	>
Rock Falls															
Haulage (Pinched/Squeezed)															
Machinery															
Handling/Material															
Bumps/Bursts															
Electrical															
Slips/Falls															
Explosion/Ignition															
Fire/Chemical Burns or Irritation															
Other															

design stage, functional block diagrams delineating each task, order of performance relative to other tasks, and the amount of time required, is necessary. An example of the level of functional breakdown intended is provided in Figure 5-1 for the Hydraulic Borehole Mining concept discussed earlier (see Section IV-B). This information now provides an estimate of the amount of time exposed to the hazards which were identified through the hazard analysis. Similarly, the intended manning levels for each task must also be provided. This information is necessary for determining the location and size of the risk population. Two final elements that must be provided are the operational and design characteristics of equipment. These can be defined through operating specifications and blueprints (i.e., operating speeds, line pressures, power requirements and basic design of the mining equipment, as well as special support equipment which may be used in positioning the miner, etc.). Understanding these elements of the machinery is essential for evaluating protective features of a new system.

Other data which are useful but not required at the preliminary design stage relate to specific site conditions. As indicated earlier in Sections II and V-B, certain hazards are aggravated by working in low seam heights, and by extremely wet floor or poor geology conditions. These elements could be considered as representative site conditions and would therefore be important to the group of experts in the final adjustment process.

Task time and manpower data for conventional equipment complete the needed information for the exposure time analysis. Sources for these data are industrial engineering studies done on several types of equipment. These studies were conducted by Ketron (Conventional Mining and Longwall Conveyor System Study)(18,19), J. J. Davis (Continuous Miner Study)(20), and Theodore Barry (Augering and Surface Mining Study)(21,7). The results of these studies are summarized in the Appendix to assist the evaluator in performing the exposure index calculations. Some surface equipment is included in the summary in the event a new design is intended to operate from the surface, thereby replacing an underground technique (such as the hydraulic borehole), or uses similar equipment (such as a small road scraper which removes heaves and rolls in the main entries). The Appendix is not comprehensive but serves as a reasonable foundation which the evaluator may supplement as needed.

b. <u>Sources and Organization of Injury Data</u>. The primary source of historical injury data is MSHA. MSHA provides several different types of injury reporting formats which vary in detail. For example, the yearly summary of fatalities, disabling and non-disabling injuries is provided in the MSHA Information Report entitled "Injury Experience in Coal Mining" (15). This report aggregates injuries for the industry by state, by accident, and class, and then as a function of body component. This report is adequate for the protection evaluation but does not provide the necessary detail for the exposure time analysis. The summary which does provide the appropriate breakdown of injuries by accident class and task is report number CM341L2 entitled "Coal Employment and Injury Summary by Month" (22). This particular format is useful because it defines each activity clearly enough to link the associated injuries with the detailed tasks and hazards previously provided in Section II of this methodology. Each accident class is coded as shown in Table 5-7. Since the

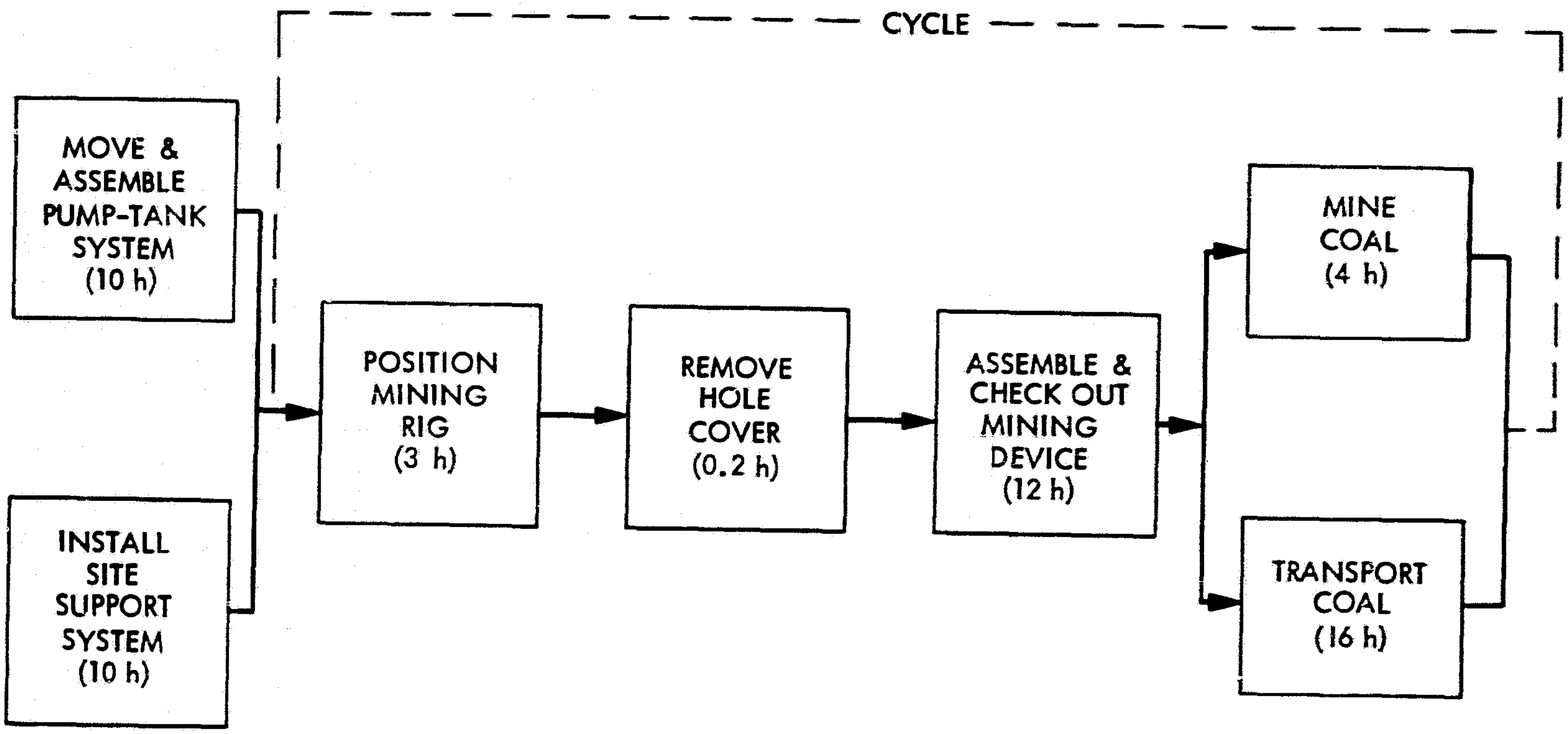

Figure 5-1. Borehole Hydraulic Miner Production Phase Functional Diagram

Table 5-7. Accident Class Codes and Descriptions

Accident Class	Description
01	Electrical (current producing)
02	Entrapment
03	Exploding vessels under pressure (air hoses, air tanks, hydraulic lines, hydraulic hose burst, etc.)
04	Explosives and breaking agents (e.g., Airdox, Cardox)
05	Falling, rolling or sliding rock or material of any kind
06	Fall of face, rib, side or highwall
07	Fall of roof (Underground mines only)
08	Fire
09	Handling material (lifting, pulling, pushing, shoveling)
10	Hand tools (not electric and air-powered tools)
11	Nonpowered haulage: wheelbarrows; manually pushed mine cars and trucks. Motion of haulage causes accident
12	Powered haulage (include motors and rail cars, conveyors shuttle cars, haulage trucks, front-end loaders, load haul dumps, CAVO, forklifts, etc.). Motion of haulage causes accident
13	Hoisting (cages, skips, ore buckets, elevators, etc.). Motion of haulage causes accident
14	Ignition or explosion of gas or dust
15	Impoundment unstable condition (include refuse pile, or culm bank)
16	Inundation (inrush of water or mud or both)
17	Machinery (include electric and air-powered tools; mining machines; draglines, shovels, gathering arm loaders, stationary mucking machines, slushers, etc.). Motion of machinery causes accident
18	Slip or fall of person (include stepping in hole)
19	Stepping/kneeling on object where object is cause of accident
20	Striking or bumping while not handling material, while not on machinery or haulage, or not using handtool. Code only where no other applies
21	Other (not occupational illness)

activities are already delineated in the report data base, the evaluator simply requests the report number (CM341L2) and the desired accident class codes from MSHA. Other pertinent MSHA injury summaries are the so-called "Yellow Jacket" reports. These are specific studies which examine injuries in a given accident class as a function of hazards and activities, equipment involved, and other variables such as worker age and years of experience (12, 23, 24, 25).

The OSHA injury data base may be used if it is more appropriate to compare a new design against equipment used in metal and non-metal mining, or the natural gas, petroleum, and construction industries. OSHA publishes a yearly summary of injuries by industry. However, this summary is confined to total deaths and disabling and non-disabling injuries because of the large number of reporting industries. Detailed reports of injuries by accident class must be obtained by formal request. Additionally, each request must delineate the coded accident class desired. This is done by selecting the appropriate Standard Industrial Classification (SIC) codes which refer to both the industry and equipment, and then choosing the desired accident class from the Supplemental Data System (SDS) codes. The SDS takes the total injuries associated with a given industry and type of equipment and separates them by the major sources of the accident. For example, the latest 1978 SDS tabulation of pressure release injuries associated with petroleum and natural gas extraction is on the order of 600 (i.e., 400 injuries associated with being struck by the medium of oil or gas, and another 200 injuries caused by being struck by pressure lines) (26). If the evaluator desires a more detailed breakdown of SDS injuries by activity at the time of injury, then a representative state can be selected to establish the general percentage contributions of each activity to the total injuries. In the case of the petroleum and natural gas industries, Texas might be selected as a significant source for this information. Table 5-8 summarizes the industry and equipment SIC codes which would most likely be used in the methodology.

Once obtained, the historical injury data must be organized according to mining method (i.e., longwall, continuous mining, or conventional cut and shoot). Activities in some accident classes (such as roof falls, and machinery) stipulate the equipment type, or application. However, activities in other accident classes (such as handling material, electrical, and handtools) do not indicate the mining method employed at the time of injury. This problem can be resolved by obtaining a breakdown of injuries related to each generic mining technique by accident class via a special MSHA report, or by proportioning the injuries in the accident classes not broken down by equipment by the fraction each method contributes to the overall injuries. The proportioning method may be more practical if the MSHA breakdown is unavailable, or if minor errors in apportioning injuries by mining technique do not greatly effect the injury rate. The following discussion demonstrates the insensitivity of the injury rates to minor errors in injury tabulation.

Table 5-9 indicates the magnitude and percentage each underground method contributes to the average total yearly injuries.

Table 5-8. Standard Industrial Classification (SIC) Codes for Selected Industries and Equipment

SIC Code	Industry/Equipment
10	Metal mining
14	Non-metal Mining
131	Crude Petroleum and Natural Gas Extraction
162	Heavy Construction
3531	Construction Machinery
3533	Oil Field Machinery
3535	Conveyors
3536	Hoists, Cranes
3537	Industrial Trucks and Tractors
3561	Pumps and Compressors
3560	Power Transmission Equipment

Table 5-9. Contribution of Each Major Underground Mining Method to Total Yearly Injuries

Mining Method	Average Contribution to the Total Yearly Injuries	Percent Contribution to the Total Yearly Injuries
Conventional	5,000	27
Continuous	11,000	60
Longwall	2,000	13
Total	18,000	100

Reference:

MSHA Tabular Report ABO-60LA for 1979

The yearly accrued worker hours for each of the above respective mining methods are on the order of 60, 200, and 20 million man hours. Considering the magnitudes of the total yearly injuries and man hours, one could mistakenly apportion as many as 50 injuries to the wrong mining method in all of the nine major accident classes and only generate a maximum error of about 15% in the overall injury rate. This would not effect the injury projection and subsequent acceptance of a new design (i.e., a promising new design that was within 15% of the overall injury requirement would be examined for possible improvements that would allow it to meet the requirement in the prototype phase). Furthermore, some of these errors can be rectified during the interview process with the experts. For example, if the analysis placed a disproportionate number of conveyor injuries with conventional mining, then the experts might correct the baseline during the interview. The projection for the new design would then be adjusted accordingly.

c. Organization of Task Time Data for the New and Conventional Comparison Systems. In many instances a new concept may identify various task activities such that they are compatible with conventional tasks. However, it is very likely that a new design may define worker tasks differently from conventional equipment. This could occur because of architectural or operational differences. To determine exposure time indices for this situation, the evaluator should define the tasks for both the new and conventional comparison systems using a generic classification such as ground control, machinery maintenance, machinery operation, etc. The exposure times for all the various activities would then be aggregated under one task classification and an overall exposure index would be calculated. For example, the comparison of a tunnel borer with room and pillar mining equipment (see Section IV-B), would require the assessment of very different roof support activities. The tunnel borer might shotcrete in one single procedure as opposed to the normal temporary support, roof testing, and roof bolting activities practiced in room and pillar. Nevertheless, all of these tasks could be grouped under the classification of ground control and compared as an aggregate when projecting injuries due to roof falls.

4. Illustrative Example

The auger-hydraulic borehole example discussed in Section IV-B identified the following hazards experienced by these systems in the haulage accident class:

(1) Surface Auger

(a) Workers can be struck by the conveyor chain drive which can fail under load.

(b) Workers can be struck by conveyor fragments resulting from belt failure under load, or can become entrapped in the moving conveyor.

(c) Workers can be struck by debris falling off the conveyor.

(d) Workers can suffer injuries in the process of moving large debris which has fallen off the conveyor.

(2) Hydraulic Borehole Miner

- Workers can be struck by high pressure fluid or pressure line fragments in the event the input or output lines fail.

In summary, the hydraulic borehole system appeared safer because it: (1) reduced the number of workers performing support tasks around the haulage equipment; (2) removed the need for a conveyor, thereby streamlining the haulage operation; and (3) provided a barrier (i.e., cab) to protect the operator against falling drill or cutter pipe segments, and pressure line failures. Hazard reduction design features 1 and 2, above, relate to exposure time reductions, and the cab feature relates to protection. The pertinent data required for this safety comparison are shown in Table 5-10.

The exposure time calculation uses the data which refers to the comparable haulage tasks for the auger and borehole systems. The hydraulic borehole resembles the oil and natural gas industry in terms of the hazards associated with pressure release. Therefore, the protection the cab affords will be evaluated by its ability to reduce the characteristic injuries caused by these hazards in the oil and natural gas industry.

The exposure time calculation is performed using the expression developed in Section V-C.

$$n_i = N_i \frac{t_i}{T_i} f_i g_i$$

Entering the data from Table 5-10 in the above expression immediately shows that both the overall and serious injury rates are 0 because the exposure index is 0.

The evaluation of the hydraulic borehole cab design requires a determination of the degree of operator protection. In order to feel confident that the cab serves its purpose, it must be verified that the cab provides a complete protective envelope for the worker (i.e., he will not be required to leave the protection). The task requires that the operator control and monitor the mining and slurrying process from the cab. This implies that any fluctuations in pressures prior to line rupture or major blockage can be observed prior to catastrophic failure. Additionally, the elimination of the extra worker normally required on oil and natural gas extraction rigs reduces exposure further (see Table 5-10). Table 5-10 also indicates that the cab is designed in accordance with OSHA falling object and rollover protection standards. This information, coupled with use of reinforced, shatterproof glass, implies that the cab could withstand reasonably high impact forces (i.e., the 4500 psi inlet pressure). The actual extent of the protection provided the operator would be determined by the group of experts; but the

Table 5-10. Detailed Data Elements for the Auger and Hydraulic Borehole Haulage Activity

Data Element Description	Quantified Parameters
Conventional Auger	
- Task time required for inspecting coal entering conveyor, and cleaning up around conveyor while conveyor is operating (per shift)	2.5 hours
- Number of workers involved	2 workers
- Number of yearly injuries related to the haulage accident class (1979)	7 total injuries per year
Oil and Natural Gas Extraction	
- Task time for operating equipment	Not pertinent
- Number of workers involved in operating pumps and monitoring equipment (such as line pressures, etc.) in proximity to rig	2 workers
- Number of yearly injuries caused by pressure bursts (either being struck by fluid or fractured pressure lines)	600 total injuries per year (most of which are to the head, trunk, arms, and hands)
Hydraulic Borehole	
- Task time required to perform cleanup around haulage line while system is operating (per shift)	0
- Number of workers involved in monitoring and operating system	1 worker
- Line pressures	Inlet pressure-4500 psi: outlet pressure-700 psi
- Location of operator and protection afforded	Protective cab designed in accordance with OSHA falling object and roll-over protection standards; reinforced shatter-proof glass is also standard protection

References:

MSHA Injury Summary, Informational Report No. IR1112, 1979.
Auger Haulage Task Times, Extracted from Appendix A.
Floyd, E., "Borehole Hydraulic Coal Mining System Analysis," JPL pub. 77-19, April 1977.
OSHA, Supplemental Data System, Pressure Release Injuries in the Petroleum and Natural Gas Extraction Industries, 1978.

preliminary conclusion could be made that the cab design is sound and that there is a high probability of mitigating the pressure release hazard (and the normal yearly injuries associated with this hazard).

The above discussion provides a very basic illustration of the exposure time analysis and a comprehensive example of the protection analysis. A more representative example of a typical exposure time calculation would apply to the handling material accident class. Protection is not considered in this example. The pertinent task time and injury data for this are shown in Table 5-11.

The primary handling material hazards associated with these systems are: (1) workers being struck by machine components when hoisting or replacing them, and (2) workers being pinched while securing auger or borehole pipe segments together. Examination of Table 5-11 indicates that hydraulic borehole tasks are more complex, and could therefore aggravate these hazards. The possibility of reducing exposure by cutting crew size is eliminated since the number of workers are the same. Further examination of the tasks in Table 5-11 reveals that the general operating and repair procedures are the same. Therefore, the tasks can be compared generically under the following headings:

Task 1 - Handling material activities during coal extraction.

Task 2 - Handling material activities while repairing equipment.

The injury calculation for the first task is done using the same expression as before:

$$n_i = N_i \frac{t_i}{T_i} f_i g_i$$

The subscript (i) is now (1) and the respective parameters for the extraction task are defined as:

N_1 = 7 injuries/yr
t_1 = 40 hrs
T_1 = 3.6 hrs
f_1 = 1
g_1 = the final adjustment factor provided by the group of experts.

The initial projection (less the input from the experts) is then,

$$n_1 = 7 \left(\frac{40}{3.6}\right) (1) = 78 \text{ injuries/yr}$$

The serious injuries are projected using the expression (see Section V-C):

$$S_i = n_i R_i$$

where,

n_1 = 78 injuries/yr

R_1 = 0.75 (the ratio of serious to total injuries for these activities)

Table 5-11. Detailed Data Elements for the Auger and Hydraulic Borehole Handling Material Activities

Task Description	Time Task, h	Approximate Number of Yearly Injuries
Auger (one place change)		
- Auger sections added during extraction process	2.5	Fatalities - 0 Disabling - 3
- Auger sections removed after extraction	1.1	Non-disabling - 4
- Bits inspected and replaced (in place)	1.0	Fatalities - 0
- Repair and replacement of hoist components or tread pads (in place)	0.25	Disabling - 1 Non-disabling - 1
- Unscheduled repair of machine components (in place)	1.0	
- Number of workers involved (3)		
Hydraulic Borehole (one place change)		
- Hoist drill segments in place, drill borehole and install casing segments	18	
- Assemble mining device (hoist borehole miner pipe sections in place, secure sections and lower into borehole)	12	TBD*
- Dismantle mining sections after extraction completed	10	
- Inspect drilling and mining devices and make repairs (in place)	2.0	TBD*
- Number of workers involved (3)		

* TBD - To be determined.

References:

Auger Handling Material Task Times, Extracted from the Appendix.

Floyd, E., "Borehole Hydraulic Coal Mining Systems Analysis," JPL publ. 77-19, April 1977.

MSHA Injury Summary, Informational Report No. IR1112, 1979.

Discussions with MSHA Health and Safety Analysis Center (Separation of Auger Injuries by Task Activity), February 26, 1981.

The initial estimate for serious injuries is then,

$$S_1 = 78\ (0.75) = 59 \text{ injuries/yr}$$

Similarly, the maintenance task would be the second handling materials task, and the projected total and serious injuries are 2 and 1/yr, respectively. The sum of the projected handling materials injuries for both tasks is then 80/yr. The total serious injuries are projected to be 60/yr. The projected increase in injuries is based on the large amount of time required to handle heavy, cumbersome drill, casing and borehole miner components. This could indicate a design weakness and point to an area where the process might be streamlined.

The evaluator would then proceed to make injury projections for the activities and hazards related to the remaining accident classes and hazards in the same manner. The final step would be to present these projections to a group of experts to determine if they represent reasonable projections based on the group's experience. This process is discussed in the next section, followed by an example using the same two systems.

5. Projection Adjustments Based on the Consensus of Safety Experts

In Section V-C, some crucial assumptions were made about the relationship between exposure and injuries and design effectiveness; namely, that:

(1) Injury occurrence is directly proportional to exposure.

(2) Safety-related design changes will be completely effective in mitigating hazards.

Historical injury data suggest that these assumptions are not always well-founded (12). However, the projection process would be very complicated if an attempt were made to consider these realities during the analysis. For this reason, the final evaluation and adjustment of the injury projections is reserved for a group of experts in the field of mine safety. A representative group would include members from the United Mine Workers (UMW), MSHA, OSHA, Department of Energy, and perhaps industry.

The projection adjustment is basically an iterative questioning process which first introduces the new design concept to the panel of experts, and then, using both the present and projected injury levels, asks the group to refine this range of injuries by applying its experience.

The introduction of the new concept must be thorough because the review group may not be familiar with the new technology. This introductory step should include the following information:

(1) Graphic displays of the new design architecture and functional block diagrams of the complete system.

(2) Complete descriptions of system operations, including major control variables (i.e., component reliability, cutting speeds, line pressures, power requirements), and system limitations (i.e., maximum roof load system can support, etc.).

(3) Explanation of the selection criteria for the conventional comparison and review of the system failures and hazards for each system.

(4) Review of historical injury experience for the analogous conventional system with an explanation of the new design features that may affect the injury levels through exposure time, protection, or labor reductions.

(5) Review of other factors which may affect safety such as the possible need for more structured training and certification, or, representative geological and environmental conditions (if known).

The final step in the adjustment process is to provide the group of experts with the injury projections for the various activities and hazards as compared against the historical injury levels. This is done so that the experts have a baseline from which they can extrapolate their own projections while weighing the new design features and variables such as nonlinearities between exposure time and injuries, ways in which workers may not utilize protection afforded, or how the mine environment prevents equipment from operating as designed. The interactive questioning process commences with the evaluator asking the experts if they feel the realistic injury level is closer to the projection or the historical injuries. The experts may agree with the projection or indicate an initial estimate elsewhere within the range. In any case, the experts must provide reasons for their estimates. The evaluator then chooses a smaller range around the initial estimate and again queries the group for an estimate of where the injury level may be (i.e., is it closer to the new lower or upper value). This process is continued until the experts reach a point of agreement, at which time the final injury level is expressed as a range. This procedure is done for all the activities and hazards in each accident class. The injuries are summed over all the tasks and accident classes and divided by the yearly man hours worked on the conventional comparison (because the new design would theoretically replace the existing system) to establish the injury rate. This rate is then compared against the requirement to determine if the new design is acceptable.

A new design might fall short of the safety requirement but still show merit in other areas such as production. In this case, the experts would review those design areas that could improve on safety and recommend changes that could be incorporated in the detailed design and prototype phase.

6. Illustrative Example

The auger-hydraulic borehole miner example was continued in the last section with a quantitative projection of injuries for the haulage and handling materials accident classes. The projection reflected a total removal of injuries associated with normal conveyor haulage tasks (since the borehole miner slurrys the coal out of the seam); a high probability of mitigating pressure release hazards using the cab; a substantial increase in materials handling injuries associated with the borehole miner drill stem, casing, and borehole segments; and the same number of handling material injuries related to maintenance (since the tasks are similar and of the same duration). The next step is to approach a group of experts and use the interactive questioning technique outlined above to refine these projections in light of their experience. Two industry experts with substantial experience in surface mining and oil extraction technology were chosen to participate in this phase of the methodology. Each expert was provided a description of the borehole-miner; a comparison of the borehole miner, auger, and oil, natural gas extraction hazards; and the historical and projected injury levels. Tables 5-12 and 5-13 summarize the results of the interviews.

The results of the interviews show that the experts agreed with the exposure time calculations, but had some reservations about the ability of the cab to completely protect the operator. These reservations were based on the experts' experience with what one may call the "curiosity" of the operator to confirm that a line rupture is actually occurring. Therefore, the final injury projection for the protection aspect of the design would be as follows:

$$b_j = B_j d_j$$

where,

B_j = 600 (the historical injuries per year caused by pressure release)

d_j = 0.1 - 0.2 (the injury reduction factors provided by the experts)

Thus, the refined injury projection would be,

b_j = 60 - 120 injuries per year

The two experts were asked for design suggestions that might help resolve the handling material hazards. Both industry experts replied that the large amount of pipe handling required for drilling and mining could be streamlined by using a "merry-go-round" system. This technique, presently employed in the oil drilling industry, is a semi-automated system which picks up a drill segment and inserts it vertically into a carousel which can hold several segments. As each segment is placed in the hole, the carousel automatically rotates the next segment in place. The whole system requires two operators; one for operating the machine that places drill pipe in the carousel, and one for operating the carousel. The suggestion was made that the borehole miner operator could operate the carousel along with monitoring the mining process.

The final adjustment of the injury projections by the safety experts, concludes the safety analysis. In summary, the evaluator has been provided a systematic method of analyzing the safety of new designs. This procedure started at the conceptual design level with a detailed hazard analysis, general regulatory test, and identification of hazard reduction features. This was followed by a quantitative projection of the injury levels for a new design, considering the hazard reduction features. A structured approach for adjusting the projections (using a group of safety experts) was then outlined, considering weaknesses inherent in most modeling processes.

Table 5-12. Results of the Interactive Questioning Procedure with Expert 1

Accident Class and Description of Hazard Exposure Elements	Injury Adjustment	Reason
Haulage		
Removal of conveyor-related hazards using the coal slurrying process	None	Agree with projection; the streamlined process completely removes hazards
Cab protection against pressure release	1/10	Protection cab affords and removal of additional worker usually required on oil rigs will substantially reduce injuries; however, workers may still be induced to leave cab to inspect rig for impending failure and be exposed at that time
Handling Material		
Increase in exposure to being struck or pinched by hydraulic borehole drill, casing, and miner pipe segments	None	Agree with projection - the borehole requires an excessive amount of large component handling; the hoist system is very cumbersome and allows considerable ways for workers to be struck or pinched by swinging pipe segments
Inspection and maintenance tasks	Agreement	Two injuries per year is not unreasonable

Table 5-13. Results of the Interactive Questioning Procedure with Expert 2

Accident Class and Description of Hazard Exposure Elements	Injury Adjustment	Reason
Haulage		
Removal of conveyor-related tasks using the coal slurrying process	None	Agree with projection; closed loop process eliminates hazards
Cab protection against pressure release	1/10	Protection will not be complete because worker may leave cab to inspect rig for leaks; or, if the pressure line bursts at 4500 psi, fragments could hit workers setting up another rig in the vicinity
Handling Material		
Increase in exposure to being struck or pinched by hydraulic borehole drill, casing, and miner pipe segments	None	Agree with projection - handling large components like drill stems and casing segments is extremely hazardous
Inspection and maintenance tasks	Agreement	This is a reasonable injury level for tasks like this

This methodology was designed to represent a realistic approach to measuring the safety performance of new designs by, (1) establishing practical goals for overall safety performance, (2) measuring the safety of new designs based on their own merits and not assuming the hazards will remain the same as existing systems, (3) addressing a wide variety of ways hazards may be reduced, (4) giving direction to the designer through identification of major hazards, key risk populations, and design guidelines, (5) providing a means of locating weak design areas, and (6) incorporating actual safety experience through the group of experts to adjust the results so they represent realistic measures of performance.

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APPENDIX

EXPOSURE TIME DATA

FOR

CONVENTIONAL MINING EQUIPMENT

Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Site prep/seam access – also applies to surface extraction if equipment is used for strip mining				
a) Bulldozer	1) Equipment inspection & normal maintenance	1) Handling material 2) Slips/falls	14	operator – 1
	2) Tram to work area	1) Impact by machinery 2) Collision of vehicles	3-4	operator – 1
	3) Operating bulldozer (lowering blade, cutting vegetation, stripping, & moving load to edge)	1) Impact by machinery (rolling/tipping) 2) Fall of face	288.5	operator – 1
	4) Reversing back to face	1) Impact by machinery	117	operator – 1
b) Front-end loader	1) Equipment inspection & maintenance	1) Handling material 2) Slips/falls	8	operator – 1
	2) Tram to work area	1) Impact by machinery 2) Collision of vehicles	3-4	operator – 1
	3) Moving to face & operating loader (lowering/loading bucket, unloading)	1) Impact by machinery 2) Fall of face	320	operator – 1
	4) Reversing back to face	1) Impact by machinery	80.6	operator – 1

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)		Average number of workers involved in activity
				24-29 cubicyards	50-60 cubicyards	
	1 Surface					
Seam Extraction	a) Shovel/Dragline	1) Dragline operation	1) Electrical 2) Impact by machinery 3) Slips/falls 4) Fall of face	290	200	operator - 1 oiler - 1 or 2 general - 1 maintenance
		2) Delays due to power failure	1) Electrical	9		electrician - 1
		3) Tramming to new location	1) Impact by machinery 2) Electrical	41		4
		4) Maintenance (lubricating crawler tracks, gears, etc., checking for boom cracks)	1) Impact by machinery 2) Slips/falls 3) Electrical 4) Face fall	65		oiler - 1 or 2 general - 1 maintenance
	b) Drilling & blasting	1) Operating drill, changing bits, spotting holes, & drilling	1) Impact by machinery 2) Slips/falls 3) Fall of face	210		operator - 1 spotter - 1
		2) Loading holes with dynamite	1) Explosion/ignition 2) Fall of face	240		loader - 4
		3) Blasting	1) Explosion/ignition 2) Fall of face	30		blaster - 1
	c) Coal shovel (avg scoop size 16-17 cubic yds)	1) Operating shovel (lowering scoop, digging, unloading)	1) Electrical 2) Impact by machinery 3) Fall of face 4) Slips/falls	204		operator - 1 oiler - 1
		2) Power shutdown, inspection/ maintenance required on generators, circuit breakers, etc.	1) Electrical 2) Slip/fall	5		electrician - 1
		3) Tramming to new place & setting up	1) Impact by machinery 2) Electrical	17		operator - 1 oiler - 1
		4) Scheduled/unscheduled maintenance (lubricating tracks, moving parts, or checking boom for cracks, replacing worn out parts)	1) Handling material 2) Slips/falls 3) Electrical 4) Face fall	19		oiler - 1
	d) Auger	1) Auger-in operation (drive mechanism started, hydraulic operator & pinpuller add sections to auger, inspect coal, cleanup around auger & conveyor)	1) Impact by machinery 2) Slips/falls 3) Material handling 4) Face fall	160		operator - 1 hydraulic operator - 1 pin-puller - 1
		2) Auger is backed out & sections removed	1) Impact by machinery 2) Slips/falls 3) Material handling 4) Face fall	69		operator - 1 hydraulic operator - 1 pin-puller - 1

	Basic Equipment	General Tasks/Delay	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Seam Extraction (cont'd)	d) Auger (cont'd)	3) Auger trammed to new location, aligned with conveyor, & bits inspected & replaced as required	1) Impact by machinery 2) Slips/falls 3) Material handling 4) Face Fall 5) Pinched/squeezed	55.5	operator - 1 hydraulic operator - 1 pin puller - 1
		4) Hoists, pads & moving parts are inspected	1) Slips/falls 2) Impact by machinery 3) Material handling 4) Face fall	17	hydraulic operator - 1 pin puller - 1
		5) Unscheduled breakdown repairs in place	1) Material handling 2) Slips/falls 3) Face fall	63	hydraulic operator - 1 pin puller - 1

C-2

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Seam Extraction (cont'd)	II Underground a) Cutter (saw)	1) Positioning, & operating cutters at face	1) Electrical 2) Impact by machinery 3) Roof/face fall 4) Rock bumps/bursts 5) Dust/noise 6) Explosion/ignition 7) Fire	112.5	operator - 1 helper - 1
		2) Moving electrical umbilical cable out of way	1) Handling material injuries 2) Electrical 3) Slips/falls 4) Noise/dust	7	helper - 1
		3) Clearing debris & coal out of way of cutter & removing equipment	1) Handling material 2) Slips/falls 3) Roof/face falls 4) Dust/noise 5) Impact by machinery	127	operator - 1 helper - 1
		4) Scheduled/unscheduled maintenance in place	1) Electrical 2) Handling machinery 3) Dust 4) Roof/face falls	Cable/power components-29 hydraulic-9 electrical components-8 other-26 Total time - 72	operator - 1 helper - 1
		5) Traffic congestion	1) Collision of vehicles 2) Impact by machinery	14.5	2 or more machines - minimum of 4 people
		6) Safety (excessive dust/gas delay)	1) Explosion/ignition/ suffocation 2) Dust	20	operator - 1 helper - 1
		7) Tramming to new place	1) Impact by machinery 2) Collision of vehicles	93	operator - 1 helper - 1
	b) Face Drill/ Shooting	1) Positioning, & operating face drill	1) Impact by machinery 2) Roof/face fall 3) Rock bumps/bursts 4) Dust/noise 5) Explosion/ignition 6) Electrical 7) Fire	94.5	operator - 1 helper - 1
		2) Moving electrical umbilical cable out of way	1) Handling material 2) Electrical 3) Slips/falls	9.5	helper - 1
		3) Clearing debris & coal out of way of drill & removing equipment	1) Handling material 2) Slips/falls 3) Dust/noise 4) Roof/face fall 5) Impact by machinery	170	operator - 1 helper - 1

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Seam Extraction (cont'd)	b) Face Drill/ Shooting (cont'd)	4) Unscheduled maintenance in place	1) Electrical 2) Handling material 3) Dust 4) Roof/face falls	Cable/power components-30 hydraulic-9.6 electrical components-8 other-28 Total time - 76	operator - 1 helper - 1
		5) Traffic congestion delays	1) Collision of vehicles 2) Impact by machinery	10.5	2 or more machines - minimum of 4 people
		6) Safety (dust/gas) delay	1) Explosion/ignition/ suffocation 2) Dust	14	operator - 1 helper - 1
		7) Tramming to new place	1) Impact by machinery 2) Collision of vehicles	91	operator - 1 helper - 1
		8) Loading charges, setting up electrical lines, & blasting face	1) Explosion/ignition 2) Electrical 3) Slip/fall 4) Fire 5) Roof/face fall	70	operator - 1 shot fireman - 1
	c) Longwall miner	1) Setting up, positioning, & operating shearer at face	1) Impact by machinery 2) Roof/face fall 3) Rock bumps/bursts 4) Dust/noise 5) Explosion/ignition 6) Electrical 7) Fire	162	shearer operator - 2 mechanics - 2
		2) Unscheduled shearer maintenance, roof jack & placement, & clearing activities under shearer at face	1) Handling material 2) Dust 3) Roof/face falls 4) Slips & falls 5) Electrical	low coal 36-48": 70 high coal >48": 33	shearer operator - 2 mechanics - 2 general helper - 1 material supplier - 1 shaker - 1
		3) Water pump repairs	1) Handling material 2) Dust 3) Roof/face falls	4	mechanics - 2
		4) Section power/water power repairs to providing water at the face	1) Handling material 2) Electrical 3) Dust 4) Roof/face falls 5) Slips/falls	7	utility man - 1
	d) Continuous miner	1) Setting up, positioning, & operating continuous miner	1) Impact by machinery 2) Roof/face fall 3) Rock bumps/bursts 4) Dust/noise 5) Explosion/ignition 6) Electrical 7) Fire	166	Lead man - 1 Miner operator - 1

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Seam Extraction (cont'd)	d) Continuous miner (cont'd)	2) Performing equipment inspection, moving umbilical cable, additional bolting, electrical maintenance	1) Handling material 2) Dust 3) Electrical 4) Roof/face falls 5) Slips/falls	85	lead mean - 1 section mechanic - 1 utility man - 1 bolters - 2
		3) Performing equipment maintenance/normal servicing (lubrication, etc.) in place	1) Handling material 2) Dust 3) Roof/face falls 4) Slips/falls	50	miner operator - 1 section mechanic - 1 lead man - 1
		4) Environmental control of gas, dust, or obstructions	1) Dust 2) Explosion/ignition 3) Roof/face falls	15	lead man - 1 miner operator - 1
		5) Performing clearing activities under miner	1) Handling material 2) Dust 3) Roof/face falls 4) Slips/falls	24	miner operator - 1 lead man - 1

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Haulage	a) Head gatherer/ shuttle car loading combination for conventional mining equipment	1) Loading shuttle car at face	1) Electrical 2) Roof/face fall 3) Rock bumps/bursts 4) Explosion/ignition 5) Dust/noise 6) Fire	103.5	loader operator - 1 standard shuttlecar operator/helper - 2 off-standard shuttle car operator/ helper - 2
		2) Moving loader electrical umbilical cable out of way of shuttlecar	1) Material handling 2) Electrical 3) Slips/falls	3	loader helper - 1
		3) Clearing spilled debris & coal or removing other equipment	1) Material handling 2) Slips/falls, 3) Roof/face falls 4) Dust/noise 5) Impact by machinery	34	loader helper - 1 shuttlecar helper - 1
		4) Unscheduled maintenance in place	1) Handling materials 2) Dust 3) Roof/face falls 4) Slips/falls	40	loader helper - 1 shuttlecar helper - 1
		5) Delays due to traffic congestion	1) Collision of vehicles 2) Impact by machinery	13	loader operator helper - 2 shuttlecar operator/ helper - 2
		6) Environmental control of dust, gas, etc.	1) Dust 2) Explosion/ignition 3) Roof/face falls	19	loader operator/ helper - 2 shuttlecar operator/ helper - 2
		7) Tramming material to dump point	1) Collision of vehicles 2) Impact by machinery 3) Roof/face falls 4) Pinched, squeezed by machinery 5) Electrical	low coal 16-48": 90 high coal >48": 68	shuttlecar operator/ helper (both standard & off-standard) - 4
	b) Longwall conveyor with stage loader	1) Loading & operating conveyor	1) Electrical 2) Impact by machinery 3) Roof/face falls 4) Dust/noise 5) Rock bumps/bursts 6) Explosion/ignition 7) Fire	170	Headgate man - 2 Tailgate - 1 mechanics - 2 snaker - 1
		2) Breaking up oversize lumps, rearranging support at head/ tail, unjamming conveyor, or adjusting the conveyor chain	1) Material handling 2) Roof/face falls 3) Dust 4) Slips/falls	11	Headgate man - 2 Tailgate - 1 general helper - 1

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Haulage (cont'd)	b) Longwall conveyor with stage loader (cont'd)	3) Performing unscheduled maintenance on conveyor such as chain drive failures, spill plate defects, flight defects, head & tail drive problems	1) Material handling 2) Dust 3) Rock/face falls 4) Slips/falls	40	headgate man - 2 tailgate - 1 mechanics - 2 material supplier - 1
		4) Performing maintenance on electrical power generators, cable defects, control panel	1) Electrical 2) Slips/falls 3) Handling material	7	utility man - 1 general helper - 1
		5) Performing unscheduled maintenance on the stage loader/crusher & adjusting	1) Handling material 2) Slips/falls 3) Dust 4) Rock/face falls	5	mechanics - 2
	c) Continuous miner - loader/shuttle car	1) Loading shuttle cars at face (time spent per car)	1) Electrical 2) Impact by machinery 3) Rock/face falls 4) Dust/noise 5) Rock bumps/bursts 6) Explosion/ignition 7) Fire	*47 *This value, times the number of shuttle cars in use	standard shuttle car operator - 2 off-standard shuttle car operator - 2
		2) Tramming shuttle cars & dumping load	1) Collision of vehicle 2) Pinched/squeezed 3) Electrical 4) Impact by machinery 5) Roof/face falls	low coal 36-48": Insufficient data high coal >48": 124	shuttle car operators - 4
		3) Moving loader	1) Material handling 2) Slip/fall 3) Electrical 4) Impact by machinery 5) Roof/face fall	41	shuttle car helpers - 2 scoop operator - 1
		4) Clearing spilled debris & coal	1) Material handling 2) Slips/falls 3) Roof/face falls 4) Dust/noise 5) Impact by machinery	26	shuttle car helpers - 2
		5) Moving umbilical cable, equipment & inspection	1) Electrical 2) Material handling 3) Slips/falls	104	headgate man - 2 tailgate - 1 mechanics - 2
		6) Operating crusher/feeder	1) Impact by machinery 2) Roof/face fall 3) Dust 4) Handling material	18	shuttle car helpers - 2

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Haulage (cont'd)	d) Rail car loading & dropping (underground & surface)	1) Operate lever to uncouple first car gradually release handbrake & position front of car under loading hopper or conveyor, control brake to inch car under chute or in place with conveyor, & load	1) Pinched/squeezed by machinery 2) Slips/falls 3) Impact by machinery	*5 min/car *This value, times the number of cars loaded per shift	operator - 1 groundmen - 2
		2) Couple to previously loaded cars (repeat steps (1) & (2) for next car)	1) Slip/fall 2) Pinched/squeezed 3) Impact by handling	*2 min/car *This value, times the number of cars loaded per shift	operator - 1 groundmen - 2

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)		Average number of workers involved in activity
Support Haulage Route	a) Roof Bolting (single boom bolter)	1) Position drill, drill starter hole, change steel, drill hole	1) Explosion/ignition 2) Electrical 3) Roof/face fall 4) Impact by machinery 5) Dust/noise 6) Fire	Bad Roof (33-43 bolts/shift) 79.5	Good Roof (30-40 bolts/shift) 79.5	Roof bolter - 1 helper - 1
		2) Insert & torque bolt	1) Handling material 2) Roof/face full 3) Slips/fall 4) Dust	25	25	Roof bolter - 1 helper - 1
		3) Move electrical umbilical cable out of way	1) Handling material 2) Electrical 3) Slip/fall	7		Roof bolter - 1 helper - 1
		4) Providing additional support (shocks, timber, etc.), inspecting roof & marking - under unsupported roof near face	1) Roof/face falls 2) Rock bumps/bursts 3) Handling material 4) Slips/fall	Bad Roof 420	Good Roof 200	chock setter - 2-4 material supplier - 1
		5) Unscheduled maintenance on bolter, in place (may occur under unsupported roof)	1) Roof/face falls 2) Handling materials 3) Slips/fall 4) Dust	67		Roof bolter - 1 helper - 1
	b) Roof bolting (single/dual boom bolter) with roof jacks	1) Positioning & drilling holes, inserting steel, setting bolts	1) Explosion/ignition 2) Roof/face falls 3) Dust/noise 4) Impact by machinery 5) Rock bumps/bursts 6) Electrical 7) Fire	Bad Roof (33-43 bolts/shift) 85	Good Roof (30-40 bolts/shift) 85	operator - 1 helper - 1
		2) Maneuvering bolter	1) Impact by machinery 2) Roof/face falls 3) Rock bumps/bursts 4) Pinched/squeezed 5) Electrical 6) Explosion/ignition	22.5		operator - 1 helper - 1
		3) Empty dust collectors	1) Dust	7		operator - 1 helper - 1
		4) Check roof & provide additional support, other than jacks on bolter (under semi-supported roof)	1) Rock bumps/bursts 2) Roof/face falls 3) Handling material 4) Slip/fall	16.5	6.5	chock setter - 2-4 material supplier - 1
		5) Dust rock	1) Dust	17		operator - 1 helper - 1

	Basic Equipment	General Tasks/Delays	Related Hazards	Avg time exposed to hazards during one 7 hr shift, as task is performed (min)	Average number of workers involved in activity
Support Haulage Route (cont'd)	b) Roof bolting (single/dual boom bolter) with roof jacks (cont'd)	6) Change bits on drill, prepare bolts, insert in bolter, back drill out due to binding (possibly under semi-supported roof)	1) Handling material 2) Roof/face fall 3) Impact by machinery 4) Rock bumps/bursts	31	operator - 1 helper - 1
		7) Additional bolt torquing	1) Material handling 2) Roof/face fall 3) Rock bumps/bursts	4	operator - 1 helper - 1
		8) Check methane/ventilation/dust	1) Dust 2) Explosion/ignition	20	operator - 1 head man - 1 helper - 1
		9) Scheduled/unscheduled maintenance (in place)	1) Handling materials 2) Roof/face falls 3) Rock bumps/bursts 4) Slips/falls	4	operator - 1 helper - 1 mechanics - 1
		10) Moving umbilical cable	1) Electrical 2) Handling material 3) Slips/falls	2.5	helper - 1
		11) Provide bolter supplied	1) Material handling 2) Slips/falls 3) Roof/face falls	11	helper - 1
	c) Other roof support (timbers, beams, etc.) for continuous/long-wall miners	1) Install timber/beams/chocks & snug against roof (under unsupported or semi-supported roof)	1) Material handling 2) Roof/face fall 3) Rock bumps/bursts 4) Dust 5) Slips/falls	Bad Roof 16.5 Good Roof 6.5	Chockmen - 2-4 material supplier - 1