General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Requirements for the Conceptual Design of Advanced Underground Coal Extraction Systems

Mukund D. Gangal
Milton L. Lavin

December 15, 1981

Requirements for the Conceptual Design of Advanced Underground Coal Extraction Systems

Mukund D. Gangal
Milton L. Lavin

ABSTRACT

This document presents conceptual design requirements for underground coal mining systems having substantially improved performance in the areas of production cost and miner safety. Mandatory performance levels are also set for miner health, environmental impact, and coal recovery. In addition to mandatory design goals and constraints, the document identifies a number of desirable system characteristics which must be assessed in terms of their impact on production cost and their compatibility with other system elements. Although developed for the flat-lying, moderately thick seams of Central Appalachia, these requirements are designed to be easily adaptable to other coals.

FOREWORD

This document describing conceptual design requirements for underground coal mining systems reports results from the initial phase of a program to define, develop, and demonstrate advanced equipment suitable for the resources remaining beyond the year 2000. This project is funded by the Division of Coal Mining, United States Department of Energy through an interagency agreement, DE-AI-01-76 ET12548, with the National Aeronautics and Space Administration (Task RD 152, Amendment 90). William B. Schmidt, Director of the Division of Coal Mining, is the project officer for the Department of Energy.

The requirements developed in this document are meant to implement the broad systems performance goals formulated by Goldsmith and Lavin (1980) by providing a rational point of departure for the design of underground mining systems with emphasis on Central Appalachian coals. Because no one has yet attempted to design to these requirements, they may contain some inconsistencies and need clarification in some areas. Accordingly, the authors would very much appreciate comments and suggestions from those who have used or critically reviewed these requirements.

This report is the result of the collaborative efforts of individuals representing a variety of disciplines and perspectives. Mukund Gangal sketched the broad outlines of the document and formulated the major ideas in each section. Jack Harris and Anthony Lynn assembled much of the material on mining conditions applicable to the target resource and had a major part in identifying operational constraints on contemporary underground systems. Much of the geological information on the Central Appalachian coals was adapted from a recently completed study of continental coal resources by Prof. John Ferm and Paul Muthig, both of the University of Kentucky. Milton Lavin formulated the rationale for using labor productivity as a design variable and contributed several ideas to the section on production cost requirements. Wayne Zimmerman was the principal architect of the requirements for miner safety and health, and Elizabeth Dutzi played a similar role in the development of environmental impact requirements. Prof. Gib Akin of the University of Virginia prepared the appendix on psychosocial factors in equipment design.

Throughout the lengthy process of putting this document together, Lionel Isenberg was of invaluable assistance in articulating the philosophy of conceptual design requirements, and in applying this philosophy to the particular needs of underground coal mining. We are also indebted to the following reviewers and critics who helped sharpen and elaborate the content of the requirements: Charles Beswick, Charles Bickerton, Roger Bourke, Elmer Floyd, Martin Goldsmith, John Hoag, James Land, William Mabe, David Maynard, Robert Phen, Prof. Patrick Sullivan, Katsuaki Terasawa, and Paul Wiener. Finally, we wish to express our appreciation to Shirley Stroup who typed and retyped the manuscript, and Patricia South who supervised final assembly of the document.

ORIGINAL PAGE IS
OF POOR QUALITY

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY OF DESIGN REQUIREMENTS

This document presents conceptual design requirements for advanced underground coal mining systems appropriate for the flat-lying coals of Central Appalachia. As described in Section 2, the physical boundaries of the system extend from the face to the loading dock; temporal boundaries include all activities from property assessment and mine planning through mine close. These requirements are intended to assist a conceptual designer achieve the performance goals previously reported in JPL Publication No. 80-39, "Overall Requirements for an Advanced Underground Coal Extraction System." As background for appreciating the need for advanced technology, current-day mining problems are discussed in Section 3. The rationale for individual requirements is presented in Section 4. The following summary of requirements lists them in the order in which they appear in Section 4 and includes a text reference for the reader's convenience. Requirements are grouped into nine categories:

  (1) DESIGN OBJECTIVE AND DOCUMENTATION
  (2) REQUIREMENTS IMPOSED BY THE TARGET RESOURCE
  (3) PRODUCTION COST
  (4) MINER SAFETY AND HUMAN FACTORS
  (5) MINER HEALTH
  (6) ENVIRONMENTAL IMPACT
  (7) COAL CONSERVATION
  (8) REQUIRED MINE PLAN
  (9) GENERAL REGULATIONS AND STANDARDS

Requirements labeled "M" are mandatory; whereas, those labeled "D" constitute desirable characteristics to be incorporated at the option of the designer.

DESIGN OBJECTIVE AND DOCUMENTATION

M.1 Conceptual Design Objective: THE CONCEPTUAL DESIGN SHALL BE PRESENTED IN A DOCUMENT WHICH (1) DESCRIBES THE DESIGN DETAILS OF THE COAL MINING SYSTEM, (2) DEMONSTRATES THAT THE DESIGN MEETS ALL MANDATORY REQUIREMENTS LISTED IN THIS DOCUMENT, AND (3) INCORPORATES AS MANY OF THE DESIRABLE CHARACTERISTICS AS FEASIBLE. THE ADVANCED SYSTEM SHALL BE DESIGNED FOR OPERATION IN FLAT-LYING CENTRAL APPALACHIAN COALS OF MODERATE THICKNESS AND MODERATE COVER, REMAINING IN THE YEAR 2000. PRIMARY OBJECTIVES ARE (1) A RETURN ON INCREMENTAL INVESTMENT OF AT LEAST 1.5 TIMES THE RATE REQUIRED OF THE AVERAGE CAPITAL IMPROVEMENT PROJECT AND, (2) A REDUCTION OF 50% IN DEATHS AND DISABLING INJURIES. ALTHOUGH ADVANCES IN ALL ASPECTS OF SYSTEM PERFORMANCE ARE DESIRABLE, IMPROVEMENTS IN PRODUCTION COST AND MINER SAFETY ARE MANDATORY.

REQUIREMENTS IMPOSED BY THE TARGET RESOURCE

M.2 Seam Thickness: THE SYSTEM SHALL BE DESIGNED TO OPERATE IN A SEAM OF 50 IN. NOMINAL THICKNESS, WITH ±12 IN. LOCAL VARIATION WITHIN THE MINE PROPERTY.

  Other Seam Thicknesses: IN ADDITION, IT MUST BE SHOWN HOW THE DESIGN CAN BE EXTENDED (e.g. MODELS) TO MINE SEAMS RANGING FROM 28 IN. TO 180 IN.

Exception and Alternative Requirement: SOME DESIGNS MAY BEST BE APPLIED IN SEAM THICKNESSES OTHER THAN THE 50 IN. SPECIFIED ABOVE. IN SUCH A CASE THE DESIGN POINT FOR SEAM THICKNESS MUST BE SPECIFIED AND A LOCAL THICKNESS VARIATION OF ± 12 IN. MUST BE OBSERVED. IN ADDITION, THIS DESIGN MUST DEMONSTRATE THE CAPABILITY TO BE APPLIED TO APPROXIMATELY 75% OF THE RESOURCES FROM 14 IN. TO 180 IN., AS SHOWN IN FIGURE 4-2.

M.3   Depth of Cover : THE SYSTEM SHALL BE DESIGNED TO OPERATE AT A NOMINAL DEPTH OF 1000 FT.

Other Depths: IN ADDITION, IT MUST BE SHOWN HOW THE DESIGN CAN BE EXTENDED TO MINE SEAMS RANGING FROM 500- TO 2000-FT DEEP.

Alternative Design Point: AN ALTERNATIVE DESIGN POINT FOR DEPTH MAY BE SELECTED, HOWEVER, IN SUCH A CASE THE DESIGN MUST DEMONSTRATE THE CAPABILITY TO BE APPLIED TO 75% OF THE RESOURCE BETWEEN 0 AND 2000 FT. (Table 4-2).

M.4   Seam Dip: THE SYSTEM SHALL BE CAPABLE OF OPERATING IN A SEAM HAVING AN AVERAGE DIP OF 0°, AND LOCAL SLOPES OF ±10°.

M.5   Seam Anomalies: THE SYSTEM SHALL HAVE THE CAPABILITY OF HANDLING (1) SPLITS, PARTINGS, AND LENSES AS A ROUTINE OPERATIONAL PROBLEM (I.E., EVERY PRODUCTION SHIFT); AND (2) LARGE SULFUR BALLS, FAULTING, WASHOUTS, AND SLICKENSIDES ON ROOF AND FLOOR AS AN OCCASIONAL OPERATIONAL PROBLEM (I.E., ONE OCCURRENCE EVERY 1000 FT OF ADVANCE).

D.1   Multiple Seams: IT IS HIGHLY DESIRABLE THAT THE SYSTEM HAVE THE CAPABILITY TO DEAL WITH MULTIPLE SEAMS CHARACTERIZED BY AN INTERBURDEN RATIO OF 25 OR LESS.

M.6   Ability to Excavate Rock: THE SYSTEM SHALL HAVE THE CAPABILITY OF ROUTINELY EXCAVATING PARTINGS, SPLITS, LENSES, AND OTHER SEDIMENTARY ROCK ASSOCIATED WITH A COAL SEAM HAVING A COMPRESSIVE STRENGTH VARYING BETWEEN 10,000 PSI (SHALE) AND 16,000 PSI (HARD SANDSTONE), AND CONSTITUTING UP TO 50% BY WEIGHT OF THE RAW TONNAGE. UNDER THESE SEVERE CONDITIONS THE PERFORMANCE MAY FALL BELOW THE DESIGN POINT PERFORMANCE DEFINED IN SECTION 4.6. THE DESIGNER MUST ESTIMATE THIS REDUCTION IN PERFORMANCE.

M.7   Ground Control Plan: THE DESIGN SHALL INCLUDE AN APPROACH FOR CONTROLLING THE STABILITY OF THE MINE OPENINGS AS SPECIFIED IN THE MINE PLAN (REQ. M.41). THE PLAN MUST ASSUME "AVERAGE" ROOF, FLOOR AND RIB CONDITIONS AS DESCRIBED BY TOTH (1981). THE GROUND CONTROL PLAN MUST DESCRIBE HOW TO DEAL WITH UNSTABLE ROOFS, FLOORS, AND RIBS, AND IN ADDITION, HOW TO COPE WITH LARGE ROOF FALLS, FLOOR HEAVES, AND RIB SLUFFING AFTER THEY HAVE OCCURRED.

Exceptions: SOME DESIGNS MAY RELY ON INHERENTLY STABLE OPENING CONFIGURATIONS. IN SUCH A CASE, THE DESIGN MUST DEMONSTRATE (VIA THEORETICAL CALCULATIONS, FINITE ELEMENT ANALYSIS, OR FIELD OBSERVATIONS) STABILITY UNDER "AVERAGE" CONDITIONS (AS DESCRIBED IN TOTH, 1981), AND THE CAPABILITY TO CONTROL WEAK GROUND SATISFACTORILY.

M.8   **Methane Emission:** THE MINING SYSTEM MUST MAINTAIN SAFE LEVELS OF METHANE, ASSUMING THAT THE METHANE CONTENT OF A VIRGIN SEAM IS 10 CC/G WITH A POSSIBLE MAXIMUM VALUE OF 20 CC/G LOCALLY.

M.9   **Water Seepage:** THE SYSTEM SHALL BE CAPABLE OF ROUTINE OPERATION IN UP TO 12 IN. OF STANDING WATER AND SHALL BE CAPABLE OF HANDLING OCCASIONAL UNDERGROUND SPRINGS (ONCE EVERY 5000 FT OF ADVANCE) WITH A FLOW RATE OF 100 GAL/MIN.

M.10 **Coal Price:** THE TARGET PRICE FOR STEAM COAL PRODUCED IN CENTRAL APPALACHIA IN THE YEAR 2000 WILL BE $33.00 PER TON, MEASURED IN CONSTANT 1980 DOLLARS, FOR COAL CONTAINING LESS THAN 2% SULFUR. ALL OF THE PRODUCTION COST REQUIREMENTS (SECTION 4.6) MUST BE MET IN TERMS OF THIS TARGET PRICE.

M.11 **Utilities and Services:** THE DESIGN SHALL REFLECT BOTH THE CAPITAL AND OPERATING COSTS OF SUPPLYING THE MINE SITE WITH ALL NECESSARY UTILITIES AND SERVICES, INCLUDING ELECTRIC POWER, WATER, ROADS, RAIL, AND TELEPHONE SERVICE.

M.12 **Labor Characteristics:** THE DESIGN SHALL SPECIFY THE EDUCATIONAL PROFILE OF THE LABOR NEEDED FOR ROUTINE OPERATION OF THE SYSTEM, SHOWING THE NUMBER AND TYPE OF EACH SPECIALTY NEEDED, AND PROJECTING THE COST OF ANY ON-THE-JOB TRAINING REQUIRED FOR SYSTEM STARTUP AND ROUTINE OPERATION.

M.13 **Mine Size:** THE MINING SYSTEM EITHER SHALL BE SIZED FOR 150,000 TONS/YR OR 1,000,000 TONS/YR OF CLEAN COAL, ASSUMING THREE SHIFT OPERATION AND 220 WORKING DAYS PER YEAR.

Size Variation: WHATEVER MINE SIZE IS SELECTED, THE DESIGN MUST SHOW HOW THE RATE OF RETURN ON TOTAL INVESTMENT VARIES WITH AN ANNUAL PRODUCTION CAPACITY RANGING BETWEEN 100,000 AND 2,000,000 TONS/YR.

Retrofit: SINCE RETROFIT CAPABILITY IS HIGHLY DESIRABLE, THE DESIGN SHALL SPECIFY UNDER WHAT CONDITIONS IT WILL BE POSSIBLE TO USE THE NEW SYSTEM IN EXISTING MINES.

PRODUCTION COST

M.14 **Cost Analysis:** THE SYSTEM SHALL ACHIEVE AN AFTER TAX, INTERNAL RATE OF RETURN EXCEEDING 22% ON INCREMENTAL INVESTMENT. INCREMENTAL INVESTMENT WILL BE DETERMINED BY COMPARING THE SYSTEM WITH THE APPROPRIATE YEAR 2000 EVOLUTIONARY SYSTEM OPERATING IN AVERAGE CONDITIONS, AS DESCRIBED BY BICKERTON AND WESTERFIELD (1981). The cost estimates shall include the following:

(a)   Equipment list and prices.
(b)   List of major construction items.
(c)   Tabulation of initial capital investment.
(d)   Capital expenditures during the life of the mine.
(e)   Manning tables, wage rates, and manpower costs applicable in the year 1980 using the 1981 Bituminous Coal Wage Agreement.
(f)   Table of expendables showing the cost estimates for parts, utilities, royalties, and other tonnage-related costs.

(g) A summary of annual operating costs.
(h) Environmental costs including mine closure and land rehabilitation.
(i) The final computation showing the rate of return.

M.15   Productivity Design Goal: THE PRODUCTIVITY OF THE SYSTEM SHALL BE AT LEAST 32 TONS OF CLEAN COAL PER MAN-SHIFT BASED ON THE TOTAL MINE PAYROLL AND STANDARD EIGHT-HOUR SHIFTS, AVERAGED OVER THE PRODUCTIVE PHASE OF THE MINE LIFE, ASSUMING OPERATION IN A NOMINAL 50-IN. SEAM WITH A REJECT RATE OF 25%. THE PRODUCTIVE PHASE OF MINE LIFE BEGINS WITH INITIAL DEVELOPMENT AND ENDS WHEN THE LAST PRODUCING SECTION CEASES OPERATION. PRODUCT QUALITY MUST MEET OR EXCEED THE SPECIFICATIONS FOR WASTE ROCK (IN ADDITION TO INHERENT ASH) AND FREE MOISTURE (IN ADDITION TO INHERENT MOISTURE) GENERALLY REQUIRED FOR BOILER FUELS IN THE CENTRAL APPALACHIAN REGION IN 1981. UNLESS ALTERNATIVE VALUES CAN BE JUSTIFIED, WASTE ROCK MUST BE 5% OR LESS BY WEIGHT, AND FREE MOISTURE MUST BE 6% OR LESS.

Exception: SOME BENEFICIATION SCHEMES MAY PRODUCE WATER-BASED COAL JEL AND, THEREFORE, WOULD NOT MEET THE 6% MOISTURE REQUIREMENT. IN SUCH CASES THE ECONOMIC COMPUTATIONS SHALL USE AN EQUIVALENT COST DETERMINED ON THE BASIS OF NET HEAT AVAILABLE.

D.2   System Availability: IT IS HIGHLY DESIRABLE THAT THE SYSTEM HAVE A SYSTEM AVAILABILITY (AS DISTINGUISHED FROM SECTION AVAILABILITY) OF AT LEAST 65% OF THE SHIFT TIME, AVERAGED OVER TWELVE MONTHS OF OPERATION.

D.3   Continuous Unit Operations: IT IS HIGHLY DESIRABLE THAT THE UNIT OPERATIONS OF THE SYSTEM BE CONFIGURED TO PERMIT A CONTINUOUS FLOW OF COAL FROM FACE TO PORTAL (OR STORAGE BUNKER), INTERRUPTED ONLY BY MAJOR EQUIPMENT MOVES.

D.4   Disciplined Materials Flow: IF THE SYSTEM UTILIZES TECHNOLOGY FOR CONTINUOUS MATERIALS HANDLING, IT IS DESIRABLE (1) THAT THE SYSTEM MAINTAIN POSITIVE CONTROL OVER MATERIAL SIZE, AND (2) THAT THE CHANGES IN DIRECTION OF THE FLOW BE ENGINEERED TO ENSURE A SMOOTH TRANSITION FOR THE WORST COMBINATION OF SPEED, LOADING, AND MATERIAL SIZE.

D.5   Matching Equipment Moves with Planned Downtime: IT IS HIGHLY DESIRABLE THAT THE SYSTEM BE DESIGNED SO THAT EQUIPMENT MOVE CYCLES COINCIDE WITH CYCLES OF PLANNED DOWNTIME FOR SHIFT CHANGE, MAINTENANCE, RESUPPLY, ETC.

D.6   Parallel Unit Operations: IT IS HIGHLY DESIRABLE THAT THE SYSTEM EMBODY PARALLEL UNIT OPERATIONS FOR EXCAVATION, TRANSPORT, AND GROUND CONTROL WITH RESPECT TO EACH WORKING FACE; I.E., SERIAL OPERATION ON A WORKING FACE IS HIGHLY UNDESIRABLE.

D.7   Equipment Availability: IT IS DESIRABLE THAT INDIVIDUAL PIECES OF EQUIPMENT USED IN THE CRUCIAL UNIT OPERATIONS OF THE SYSTEM, EACH HAVE AN AVAILABILITY OF 95%, WHEN OPERATED UNDER A PREVENTATIVE MAINTENANCE POLICY WHICH PERMITS TWO HOURS OF ROUTINE MAINTENANCE BETWEEN WORKING SHIFTS, AND EIGHT HOURS OF EXTENDED MAINTENANCE EVERY FIFTEEN SHIFTS.

4

D.8   Mean Time to Failure: IT IS DESIRABLE THAT INDIVIDUAL PIECES OF EQUIPMENT USED IN THE CRUCIAL UNIT OPERATIONS OF THE SYSTEM EACH HAVE A MEAN TIME TO FAILURE NO LESS THAN 120 HOURS WHEN OPERATED UNDER THE MAINTENANCE POLICY DESCRIBED IN REQUIREMENT D.7.

D.9   Degraded Operation: REDUNDANCY SHOULD BE INCORPORATED INTO THE DESIGN AT EVERY LEVEL POSSIBLE.   IT IS DESIRABLE THAT THE SYSTEM SUSTAIN PRODUCTION AT 50% CAPACITY EVEN WHEN A SUBSYSTEM FAILS (AT LEAST DOUBLY REDUNDANT DESIGN WHENEVER POSSIBLE).

D.10   Surface Exploration: IN SUPPORT OF MORE EFFECTIVE MINE PLANNING, IT IS DESIRABLE THAT THE SYSTEM BE PROVIDED WITH SURFACE EXPLORATION TECHNIQUES THAT ARE CAPABLE OF (1) DETERMINING THE THICKNESS AND PROPERTIES OF A COAL SEAM AND SURROUNDING ROCK, AND (2) DEFINING MAJOR ANOMALIES WITHIN THE SEAM.

D.11   In-Seam Exploration: IN SUPPORT OF OPERATIONAL PLANNING, IT IS DESIRABLE THAT THE SYSTEM BE ABLE TO IDENTIFY AND DESCRIBE CONDITIONS FAR ENOUGH IN ADVANCE OF THE FACE (OR RIB) TO PERMIT DEVELOPING A SOLUTION TO AN IMPENDING PROBLEM.   THUS, THE LOOK-AHEAD DISTANCE MUST CONSIDER THE ADVANCE RATE OF THE FACE, TOGETHER WITH THE TIME NEEDED TO ADAPT TO CHANGED CONDITIONS (SEE REQUIREMENT D.12).   ROOF AND FLOOR ROLLS, FAULTS, SPLITS, WASHOUTS, LARGE SULFUR BALLS, AND GAS POCKETS ARE OF PARTICULAR INTEREST.

D.12   Rapid Reconfiguration of Mining Equipment: IT IS HIGHLY DESIRABLE THAT THE MINING EQUIPMENT USED BY THE SYSTEM HAVE THE CAPABILITY OF BEING RAPIDLY RECONFIGURED TO COPE WITH SUDDEN CHANGES IN MINING CONDITIONS.   IT IS SUGGESTED THAT THE TIME TO RECONFIGURE REQUIRE NO MORE THAN ONE HOUR IN NORMAL CIRCUMSTANCES.

M.16   Mine Management System: IT IS HIGHLY DESIRABLE THAT A COMPREHENSIVE MINE MANAGEMENT SYSTEM SUPPORTING THE PLANNING, OPERATIONS, AND COMMUNICATIONS NEEDS IDENTIFIED IN TABLE 4-6, BE A PART OF THE SYSTEM.   THE DESIGN OF A MINE MANAGEMENT SYSTEM MUST DESCRIBE NECESSARY HARDWARE, SOFTWARE AND COMMUNICATION FACILITIES, AND MUST PROVIDE ESTIMATES FOR CAPITAL AND OPERATING COSTS.

D.13   Beneficiation: IN ADDITION TO MEETING THE PRODUCT QUALITY STANDARDS SET FOR PHYSICAL CLEANING IN REQUIREMENT M.15, IT IS HIGHLY DESIRABLE THAT THE SYSTEM INCORPORATE TECHNOLOGY FOR CHEMICAL CLEANING WHICH PERMITS THE PRODUCT TO COMPLY WITH APPLICABLE ENVIRONMENTAL STANDARDS FOR COMBUSTION PRODUCTS.

D.14   Methane Usage: IT IS HIGHLY DESIRABLE THAT METHANE PREDRAINAGE BE INCORPORATED INTO THE SYSTEM AND PROVISION MADE FOR CAPTURE AND USE OF THIS GAS.

M.17   <u>Roof Support</u>: THE SYSTEM SHALL SUPPORT THE ROOF IMMEDIATELY AFTER MINING, IN ALL AREAS WHERE MINERS MAY HAVE ACCESS. THIS SUPPORT MAY BE TEMPORARY OR PERMANENT, BUT MUST BE INSTALLED AS THE SYSTEM ADVANCES.

D.15   <u>Restricted Entry Under Unsupported Roof</u>: IT IS HIGHLY DESIRABLE THAT THE SYSTEM BE DESIGNED TO PREVENT ANYONE FROM GOING UNDER ANY UNSUPPORTED ROOF, INCLUDING OPENINGS NOT INTENDED FOR HUMAN PRESENCE.

M.18   <u>Falling Object Protection</u>: ALL MACHINERY OPERATING UNDER RECENTLY SUPPORTED ROOF WITH PERSONNEL ON BOARD MUST PROVIDE PROTECTION AGAINST SMALL FALLS OF ROOF OR RIB, OR DISLODGED GROUND CONTROL STRUCTURES. RECENTLY SUPPORTED ROOF MEANS ROOF WHICH HAS BEEN REINFORCED WITHIN THE PREVIOUS 24 HRS OF OPERATION. A SMALL FALL REFERS TO A FRAGMENT OF ROOF ROCK (SANDSTONE OR SHALE) HAVING A VOLUME OF 1- TO 2-FT^3 OR AN EQUIVALENT VOLUME OF RIB COAL.

D.16   <u>Robustness of Ground Control Components</u>: IT IS DESIRABLE THAT THE SYSTEM UTILIZE PERMANENT AND TEMPORARY GROUND CONTROL COMPONENTS DESIGNED SUCH THAT THEY CANNOT BE EASILY DISLODGED BY IMPACT RESULTING FROM MACHINERY OR OTHER OBJECTS.

M.19   <u>On-Board Operation of Vehicles</u>: THE SYSTEM SHALL BE DESIGNED SO THAT THE OPERATORS OF ALL VEHICLES OR MOBILE EQUIPMENT WHICH ARE NOT REMOTELY CONTROLLED ARE REQUIRED TO TRAM OR REPOSITION THE EQUIPMENT FROM A CAB OR OTHER PROTECTED ENCLOSURE ON THE MACHINE.

M.20   <u>Collision Avoidance</u>: THE VEHICLES AND OTHER MOBILE EQUIPMENT EMPLOYED BY THE SYSTEM SHALL BE DESIGNED TO PROVIDE AN UNOBSTRUCTED FIELD OF VISION FOR THE OPERATOR, ILLUMINATION SUFFICIENT TO SEE PERSONNEL IN THE VEHICLE PATHWAY FOR ALL POSSIBLE DIRECTIONS OF TRAVEL, AND DEVICES WHICH GIVE CLEAR WARNING OF APPROACH UNDER THE WORST EXPECTED CONDITIONS OF LIGHTING, MASKING EQUIPMENT NOISE, AND LIMITED ABILITY TO SEE AROUND CORNERS.

M.21   <u>Sudden, Unanticipated Motion</u>: COMPONENTS OF MOBILE EQUIPMENT WHICH ARE FREQUENTLY REPOSITIONED IN THE COURSE OF OPERATION MUST BE DESIGNED TO (1) GIVE AUDIBLE AND OR VISIBLE WARNING OF IMPENDING MOVEMENT AND (2) START THE MOVEMENT IN A GRADUAL MANNER. ALTERNATELY, THE DESIGN MAY INCORPORATE PEOPLE SENSORS OR EQUIVALENT FAIL-SAFE DEVICES TO AVOID "HIT BY MACHINE" ACCIDENTS.

M.22   <u>Protection Against Collision Impacts</u>: VEHICLES AND OTHER MOBILE EQUIPMENT EMPLOYED BY THE SYSTEM SHALL BE DESIGNED TO PROTECT THE OPERATOR AGAINST IMPACT INJURY IN THE EVENT OF A COLLISION WITH A RIB OR OTHER OBJECT, OR AN UPSET.

M.23   <u>Illumination of the Workplace</u>: THE SYSTEM SHALL BE DESIGNED TO ASSURE THAT THE WORKPLACE AND ASSOCIATED EQUIPMENT ARE ILLUMINATED TO ALLOW UNOBSCURED VISION OF ALL OPERATIONS IN ACCORD WITH THE INTENT OF ALL MSHA REGULATIONS.

M.24   Guards on Moving Machinery: GUARDS SHALL BE PROVIDED TO PREVENT
       CONTACT WITH ROTATING OR MOVING MACHINERY WHILE THE MACHINERY IS
       OPERATING.   THESE GUARDS SHALL BE DESIGNED TO BE FAIL-SAFE, IN THAT
       OPERATION IS NOT POSSIBLE WHEN THE GUARD IS REMOVED.

D.17   Materials Handling Assistance: IN A SYSTEM WHICH REQUIRES THE
       HANDLING OF HEAVY, CUMBERSOME MATERIAL, IT IS HIGHLY DESIRABLE THAT
       THESE TASKS BE MECHANIZED.

M.25   Compliance with Electrical Regulations: ALL MSHA ELECTRICAL
       REGULATIONS TOGETHER WITH INDUSTRY STANDARDS AND PRACTICES SHALL BE
       FOLLOWED IN THE DESIGN OF THE SYSTEM.

M.26   Exposed Conductors and Terminals: EXPOSED TROLLEY WIRES, OTHER
       EXPOSED CONDUCTORS, AND EXPOSED TERMINALS SHALL NOT BE PERMITTED
       DURING NORMAL OPERATION OF THE SYSTEM.

M.27   Electrical Fault Isolation: FAIL-SAFE SHUT OFF OR FAULT ISOLATION
       SYSTEMS SHALL BE PROVIDED TO PREVENT PERSONNEL FROM INADVERTENTLY
       COMING INTO CONTACT WITH AN ENERGIZED CONDUCTOR.

D.18   Remote Shot Firing: IT IS HIGHLY DESIRABLE THAT A SYSTEM WHICH USES
       EXPLOSIVES TO FRAGMENT ROCK OR COAL INCORPORATE MEANS TO BOTH SET AND
       FIRE THE CHARGES REMOTELY.

M.28   Methane Explosions: THE DESIGN OF THE SYSTEM SHALL MEET ALL CURRENT
       REGULATIONS RELATING TO METHANE CONCENTRATION.   IN ADDITION, THE
       DESIGN MUST CONTAIN AN EXPLICIT APPROACH TO REDUCING THE HAZARDS
       PRESENTED BY LOCAL POCKETS OF METHANE FORMED DURING EXCAVATION.

       Exception: SOME DESIGNS MAY BE BASED UPON AN OXYGEN-FREE ENVIRONMENT
       IN THE MINE AND THUS NEED NOT COMPLY WITH MSHA REGULATIONS ABOUT
       METHANE DILUTION.   IN SUCH CASES, THE DESIGN SHALL INCORPORATE A
       FAIL-SAFE APPROACH TO PREVENT EXPLOSIVE MIXTURES OF AIR AND METHANE.

D.19   Benign Excavation Techniques: IT IS HIGHLY DESIRABLE THAT THE SYSTEM
       EMPLOY EXCAVATION METHODS WHICH DO NOT CAUSE METHANE IGNITION WHILE
       EXCAVATING.

M.29   Dust Explosions: THE DESIGN SHALL INCLUDE POSITIVE MEANS OF
       CONTROLLING THE DUST EXPLOSION HAZARD THROUGHOUT THE SYSTEM OVER THE
       EXPECTED RANGE OF OPERATING CONDITIONS.

D.20   Continuous Monitoring of Dust and Dangerous Gas: IT IS DESIRABLE
       THAT THE VENTILATION SYSTEM CONTINUOUSLY MONITOR GAS AND DUST BUILDUP
       AND ALTER THE FLOW TO MAINTAIN SAFE CONCENTRATIONS AS ESTABLISHED BY
       MSHA.   IN ADDITION, IT IS DESIRABLE THAT THIS MONITORING SYSTEM
       PROVIDE HIGHLY VISIBLE WARNING TO ALL WORKERS IN AN AREA WHERE THE
       RATE OF INCREASE OF DUST OR GAS THREATENS TO CREATE AN UNSAFE
       CONDITION.

D.21   <u>Isolation of Fires and Explosions</u>: IT IS DESIRABLE THAT THE SYSTEM QUICKLY SEAL OFF AREAS IMPACTED BY FIRE OR EXPLOSION AND PROVIDE A SOURCE OF BREATHABLE AIR FOR THOSE CAUGHT IN THE SEALED OFF AREAS.

M.30   <u>Safety Audit</u>: TO ENSURE COMPLIANCE WITH THE INTENT OF SAFETY REGULATIONS AND SAFETY DESIGN REQUIREMENTS, AND TO IDENTIFY HAZARDS NOT SPECIFICALLY ADDRESSED IN THESE REGULATIONS AND REQUIREMENTS, THE DESIGN MUST BE SUBJECTED TO A SAFETY AUDIT AS DESCRIBED BY ZIMMERMAN (1981), AND THE COSTS OF ANY REQUIRED DESIGN MODIFICATIONS MUST BE ADDED TO THE SYSTEM COST ESTIMATES.

M.31   <u>Human Factors</u>: THE SYSTEM DESIGN SHALL DEMONSTRATE THAT ADEQUATE SPACE IS AVAILABLE TO OPERATE AND MAINTAIN THE EQUIPMENT WITHOUT PLACING PHYSICAL STRESS ON THE OPERATOR, THAT THE HUMAN TASKS ARE WITHIN THE CAPABILITY OF THE AVERAGE MINER, AND THAT NECESSARY SUPPORT EQUIPMENT HAS BEEN DESCRIBED AND COSTED.

MINER HEALTH

M.32   <u>Compliance with Health Regulations</u>: THE SYSTEM SHALL MEET ALL APPLICABLE FEDERAL HEALTH REGULATIONS, WITH SPECIAL ATTENTION TO DUST, KNOWN CARCINOGENS AND MUTAGENS, EXPOSURE TO NOXIOUS SUBSTANCES, NOISE, VIBRATION, LIGHTING, AND THE EFFECTS OF WORKING IN A CONSTRAINED SPACE.

M.33   <u>Health Audit</u>: TO ENSURE COMPLIANCE WITH THE INTENT OF HEALTH REGULATIONS AND TO IDENTIFY HAZARDS NOT SPECIFICALLY ADDRESSED IN THESE REGULATIONS, THE DESIGN MUST UNDERGO A HEALTH AUDIT, AS DESCRIBED BY ZIMMERMAN (1980, 1981), WITH EMPHASIS ON LABORATORY TESTS OF SUBSTANCES AND/OR CONDITIONS SUSPECTED OF BEING HARMFUL. SINCE LABORATORY TESTS MAY TAKE A VERY LONG TIME, IF POSSIBLE, THE DESIGNER SHOULD SPECIFY ALTERNATE SAFE CHEMICALS AND ESTIMATE THE COST PENALTY.

ENVIRONMENTAL IMPACT

M.34   <u>Subsidence</u>: THE SYSTEM SHALL BE CAPABLE OF HANDLING TWO MODES OF SURFACE SUBSIDENCE, DEPENDING UPON FUTURE LAND USE: (1) NO SURFACE SUBSIDENCE IN SOME REGIONS OF THE MINE DURING MINING AND AFTER THE CESSATION OF MINING ACTIVITY; (2) UNIFORM SUBSIDENCE OVER DISTANCES OF THE ORDER OF 500 FT. THE PATTERN AND EXTENT OF SURFACE SUBSIDENCE SHALL BE ESTIMATED FOR BOTH MODES FROM A REPRESENTATIVE MINING PLAN (REQ. M.42).

M.35   <u>Refuse Disposal</u>: ALL GROUND WASTE PRODUCED DURING THE PROCESS OF MINING MUST BE DISPOSED OF IN A MANNER THAT AVOIDS SEDIMENT RUNOFF INTO STREAMS; CONTAMINATION OF SURFACE OR GROUND WATER BY ACID DRAINAGE OR OTHER POLLUTANTS; UNSTABLE SLOPES, IN VIEW OF REGIONAL PRECIPITATION PATTERNS; AND SPONTANEOUS COMBUSTION OF REFUSE CONTAINING COAL. MOREOVER, THE DESIGN OF ANY SURFACE DISPOSAL SITES MUST COMPLY WITH STATE AND FEDERAL REGULATIONS.

M.36   Disruption of Groundwater Aquifers: THE SYSTEM SHALL PERMIT
        FRAGMENTATION AND CONTAMINATION OF OVERLYING GROUNDWATER AQUIFERS
        WHICH IS NO MORE SEVERE THAN EXISTING SYSTEMS UNDER CONDITIONS OF
        BOTH (1) SOME AREAS OF NO SURFACE SUBSIDENCE AND (2) UNIFORM
        SUBSIDENCE OVER DISTANCES OF 500 FT. THE SUBSIDENCE CHARACTERISTICS
        OF THE SYSTEM (REQ. M.34) WILL BE USED TO JUDGE COMPLIANCE WITH THIS
        REQUIREMENT.

M.37   Disruption of Surface Water Flows: THE SYSTEM SHALL MINIMIZE
        DISRUPTION OF RIVERS, STREAMS, LAKES, AND OTHER SURFACE WATER BODIES
        SUCH THAT THE QUANTITY AND USABILITY OF THE SURFACE FLOWS REMAIN
        UNCHANGED. THE APPROXIMATE COST OF PREVENTION OR MITIGATION MEASURES
        MAY BE ESTIMATED FROM SULLIVAN AND LAVIN (1981) OR EQUIVALENT DATA.

M.38   Treatment of Contaminated Water: THE SYSTEM SHALL PROVIDE FOR
        CAPTURE AND TREATMENT OF ALL CONTAMINATED WATER WHICH IS IN A
        POSITION TO DRAIN OFF THE MINE SITE INTO ADJACENT LANDS OR SURFACE
        WATERS. THE METHOD OF TREATMENT SHOULD ASSUME THAT ACID IS THE
        PRINCIPAL CONTAMINANT AND MUST PRODUCE AN EFFLUENT WHICH COMPLIES
        WITH APPLICABLE STATE AND FEDERAL WATER QUALITY GUIDELINES. COST OF
        TREATMENT MAY BE ESTIMATED AS $1.00 PER TON (IN 1980 DOLLARS) UNLESS
        JUSTIFICATION IS PRESENTED FOR AN ALTERNATIVE FIGURE.

M.39   Site Reclamation: THE MINING SYSTEM SHALL COMPLY WITH ALL APPLICABLE
        LOCAL, STATE, AND FEDERAL ENVIRONMENTAL REGULATIONS CONCERNING
        RECLAMATION OF THE SITE FOLLOWING MINE CLOSURE. THE COST OF
        RECLAIMING THE LAND SHALL BE ESTIMATED IN CONJUNCTION WITH PREPARING
        A MINE PLAN (REQ. M.42).

M.40   Projection of Mitigation Costs: COSTS FOR MITIGATING ADVERSE
        ENVIRONMENTAL IMPACTS DURING AND AFTER MINING, IN CONFORMANCE WITH
        APPLICABLE REGULATIONS, SHALL BE DETERMINED USING THE MINE PLAN
        PREPARED FOR REQUIREMENT M.42. THE COST FOR ENVIRONMENTAL IMPACT
        MITIGATION SHALL NOT EXCEED THE COSTS FOR EXISTING TECHNOLOGY
        OPERATING IN COMPARABLE CONDITIONS.

COAL CONSERVATION

M.41   Coal Recovery: THE SYSTEM SHALL HAVE A CONSERVATION PERFORMANCE AT
        LEAST AS GOOD AS EXISTING EQUIPMENT OPERATING IN COMPARABLE
        CONDITIONS. THE RECOVERY MINIMUMS SET FOR EXISTING SYSTEMS ARE GIVEN
        IN TABLE 4-9. GUIDANCE IN THE USE OF THESE MINIMUMS MAY BE FOUND IN
        GOLDSMITH AND LAVIN (1980).

REQUIRED MINE PLAN

M.42   Mine Plan: THE DESIGN SHALL INCLUDE A REPRESENTATIVE MINING PLAN
        SUITABLE FOR IMPLEMENTING THE SYSTEM IN A TYPICAL CENTRAL APPALACHIAN
        SETTING. THE RECOMMENDED SETTING IS THE MINE SITE DESCRIBED BY DUTZI
        ET AL (1980). THIS PLAN SHALL DESCRIBE AND ILLUSTRATE THE PHYSICAL
        PLANT LAYOUT, DETAILS OF UNDERGROUND CONSTRUCTION, PLANS FOR PROPER
        DEPLOYMENT OF EQUIPMENT AND PERSONNEL, PROCEDURES TO BE USED FOR
        GROUND CONTROL AND VENTILATION, PROPOSED MEASURES TO CONTROL
        UNDESIRABLE ENVIRONMENTAL IMPACTS, AND TREATMENT OF RELEVANT

HEALTH AND SAFETY ISSUES. THE PLAN SHALL ALSO PRE⟨ T THE TEMPORAL
DEVELOPMENT OF THE MINE FROM EXPLORATION TO CLOSURE. ANY
NONCONVENTIONAL APPROACHES EMPLOYED IN THE PLAN SHALL BE JUSTIFIED BY
ANALYSIS AND SHOWN TO BE FEASIBLE AND SAFE. THIS PLAN SHALL THEN BE
USED BY THE DESIGNER AS THE BASIS FOR ESTIMATING THE DESIGN POINT
PERFORMANCE OF HIS SYSTEM.

GENERAL REGULATIONS AND STANDARDS

M.43   Regulations and Standards: THE DESIGN SHALL COMPLY WITH ALL
         APPLICABLE FEDERAL, STATE, AND LOCAL REGULATIONS, AND INDUSTRY
         STANDARDS. EXCEPTIONS TO THE REGULATIONS AND STANDARDS MAY BE
         PERMITTED PROVIDED THAT THE DESIGNER MEETS THE INTENT OF THE
         REGULATIONS. SUBSTANTIAL JUSTIFICATION WILL BE NEEDED FOR THE
         ACCEPTANCE OF EACH EXCEPTION.

SECTION 1

INTRODUCTION

The purpose of this document is to formulate engineering requirements for the conceptual design of advanced underground coal mining systems such that the resulting designs will achieve the system performance goals defined by Goldsmith and Lavin (1980). The resources addressed by these requirements are the flat-lying Central Appalachian coals remaining in the year 2000. These coals are typically less than 120 in. thick, lie under less than 2000 ft of cover, and outcrop extensively. These coals were chosen as the initial target for development of advanced technology because they have been and will continue to be a commercially significant source of underground production. However, the contents of the engineering requirements are, in many aspects, independent of seam geometry or location and, therefore, are readily adaptable to the design of systems for mining other coals.

1.1 SUMMARY OF SYSTEM PERFORMANCE GOALS

In addition to regional geology, the system performance goals address target mine size, production cost, miner safety, miner health, environmental impact, and resource conservation. For the benefit of the reader who is unfamiliar with the contents of Goldsmith and Lavin's report, the system performance goals are briefly summarized here.

Appalachian mines range in size from small "Mom-and-Pop" operations producing less than 100,000 tons per year to large mining complexes with an annual capacity exceeding 2,000,000 tons. Currently, the average mine produces 125,000 to 150,000 tons per year, with 75% of these smaller mines being owned or operated by large firms. However, the 1980 Keystone Coal Industry Manual suggests that there has been a marked shift toward larger mines. Reported plans for new mines and expansion of existing mines indicate an average annual capacity of 1,000,000 tons.

In summary, it is clear that there are two distinct requirements for mine size in Central Appalachia: (1) A small mine producing less than half a million tons per year, physically self-contained even though it be part of a larger operation; and (2) A large mine producing more than a million tons/year. It is unrealistic to require that one system address both needs. However, market considerations imply that a system suitable both for one section operation (the small mine) and for retrofit to multi-section mines would be especially attractive.

Any change from established methods of mining to a new technique has a certain degree of risk associated with it over and above that experienced in normal mining. A mine operator would be expected to try the new technique only if it promises a higher economic reward consistent with the added risk. Mansfield's (1968) study of industrial innovations including the shuttle car, mobile loader, and continuous miner indicated that a novel system must show a promise of increasing the return on incremental capital investment of 1.5 to 2.5 times the minimum return on investment (ROI) expected by the industry. A recent edition of the Fortune Double 500 Directory indicates a return on equity of about 15% for the mining industry. Therefore, in the current

economic environment an advanced system must provide a minimum return of 22 to 37%, depending upon the degree of risk associated with it.

Underground coal miners work in a very hazardous environment. However, trends in the rate of total injuries to coal miners, including both disabling and nondisabling injuries, indicate that safety regulations are having an effect, and if the trends continue, the overall injury rate to coal miners may well be reduced to about the rates experienced by workers in comparable industries such as heavy construction, petroleum production, etc. Nonetheless, the rates of serious injuries resulting in permanent disability or fatality are substantially higher for coal miners than for other industrial groups. Therefore, one performance goal for an advanced mining system is to reduce the rate of those serious injuries by at least 50%, so that coal mining will suffer incidence rates similar to the rates experienced by these comparable industries. Currently, the major sources of serious injuries are falls of roof, rib, and back; impact by moving machinery; handling materials; fires and explosions; and contact with energized electrical cables and components.

The primary impact on miners' health arises from dust in the atmosphere of the mine. An advanced mining system must comply with the legal requirement of maintaining dust levels at less than 2 mg/m^3, either by keeping the dust level throughout the mine under control or by separating the miner from the dust-laden areas. A secondary goal suggests that the mine atmosphere be kept within reasonable bounds of humidity and temperature in order to minimize respiratory illness. An advanced mining system must also comply with other applicable work environment regulations, such as noise and illumination.

The social choice between cost of production and environmental protection is implemented through law and regulation. Any advanced mining system must meet existing or future environmental laws. Since the cost of mitigating off-site impacts must be added to the production cost for the system, an intrinsically non-impacting system would have an economic advantage. The second environmental goal is that any mining system permit the land to be returned to its former use, and the cost of reclamation be added to the cost of producing the coal.

Currently, recovery runs about 50% of the available resource, with the remaining coal left as isolated pillars and, thus, difficult to extract at a later date. However, conservation is not regarded as a pressing problem in view of the several trillion tons of virgin coal in the ground. This abundant supply of coal gives us ample time to develop the technology to tap new energy sources or extract energy from difficult-to-mine resources. Thus, Goldsmith and Lavin (1980) were unable to justify a numerical goal for the degree of resource recovery or conservation performance to be achieved by an advanced mining system. However, in light of the relatively low recovery of contemporary technology, together with its adverse impacts on later exploitation of closely adjacent coals, conservation performance inferior to existing technology is regarded as needlessly wasteful. Therefore, the conservation performance of an advanced system is constrained to be as good as that of existing technology operating in comparable conditions.

1.2   THE SCOPE OF THE CONCEPTUAL DESIGN REQUIREMENTS

Conceptual design of an advanced system consists of selecting and defining _all_ major elements in sufficient detail to estimate system performance and production cost. In underground coal mining the major elements include buildings, roads, and other surface construction; coal preparation plant and loading facilities; shaft or other seam access; underground roadways, rail lines, and other transport facilities; provision for power, water, and other utilities; mining equipment and supplies; mining and management personnel; and operating procedures and a mining plan detailed enough to project cycle times and operating rates. Designs are to be developed within the boundaries of the engineering and cost requirements contained in this report. These requirements supply the following specific information to the designer:

(1)   A description of the operating environment.

(2)   Minimum performance goals for the advanced system.

(3)   A definition of physical, financial, and institutional constraints.

(4)   Desirable attributes of the system, in view of the state of the art.

(5)   Procedures and standards to be used in preparing the design.

The remainder of the document is devoted to developing a rationale for these requirements and stating them in a form useful to the conceptual designer. In Section 2, the mining system is described in terms of mining functions, inherent operating cycles, and the basic technologies used. The problems encountered in the use of existing systems are described in Section 3. The requirements, themselves, are formulated in Section 4. Additional material relevant to the production cost requirements is included in appendixes.

SECTION 2

THE COAL MINING SYSTEM

A generalized description of an underground coal mining system is presented below, especially as it pertains to conceptual design. Following that, the stages in the life cycle of a mine, the major constituent mining functions, and the characteristic operating cycles are discussed briefly.

2.1   MINING SYSTEM DEFINITION

The structure of a mining system can be described in terms of a hierarchy of systems, as shown in Figure 2-1. For the purposes of this document, the hierarchy of mining systems is divided into the following five levels:

I.   The macrosystem.

II.   Major systems within the macrosystem.

III.   Elements within major systems.

IV.   Functional subsystems within elements.

V.   Components within subsystems.

The first three levels fall within the domain of conceptual design, the last two, under detailed design. The scope of mining activity at each of the five levels is described below.

2.1.1   Level I: The Macrosystem

The words "mining system" are used to describe a macrosystem encompassing everything within the physical boundaries of the mine property and temporal boundaries of the mine life span. This includes a mine plan; buildings, roads, and other surface facilities; shafts or other seam accesses; underground railroads and other transportation facilities; provision for power, water, and other utilities, mining equipment and supplies; and mining and management personnel together with operating procedures. The mine life span begins with exploration and mine planning, followed by surface construction and initial development. Operation at full capacity occupies most of the remainder of the mine life, which is terminated by recovery of salvageable equipment and final site rehabilitation. The stages in the life cycle of a mine are described in more detail in Section 2.2.

2.1.2   Level II: Major Systems

The macrosystem contains a number of major systems, each oriented towards performing a specific mining task. Examples include the coal excavation system, transport system, ground control system, ventilation system, and so on. Major mining functions are described in Section 2.3. The
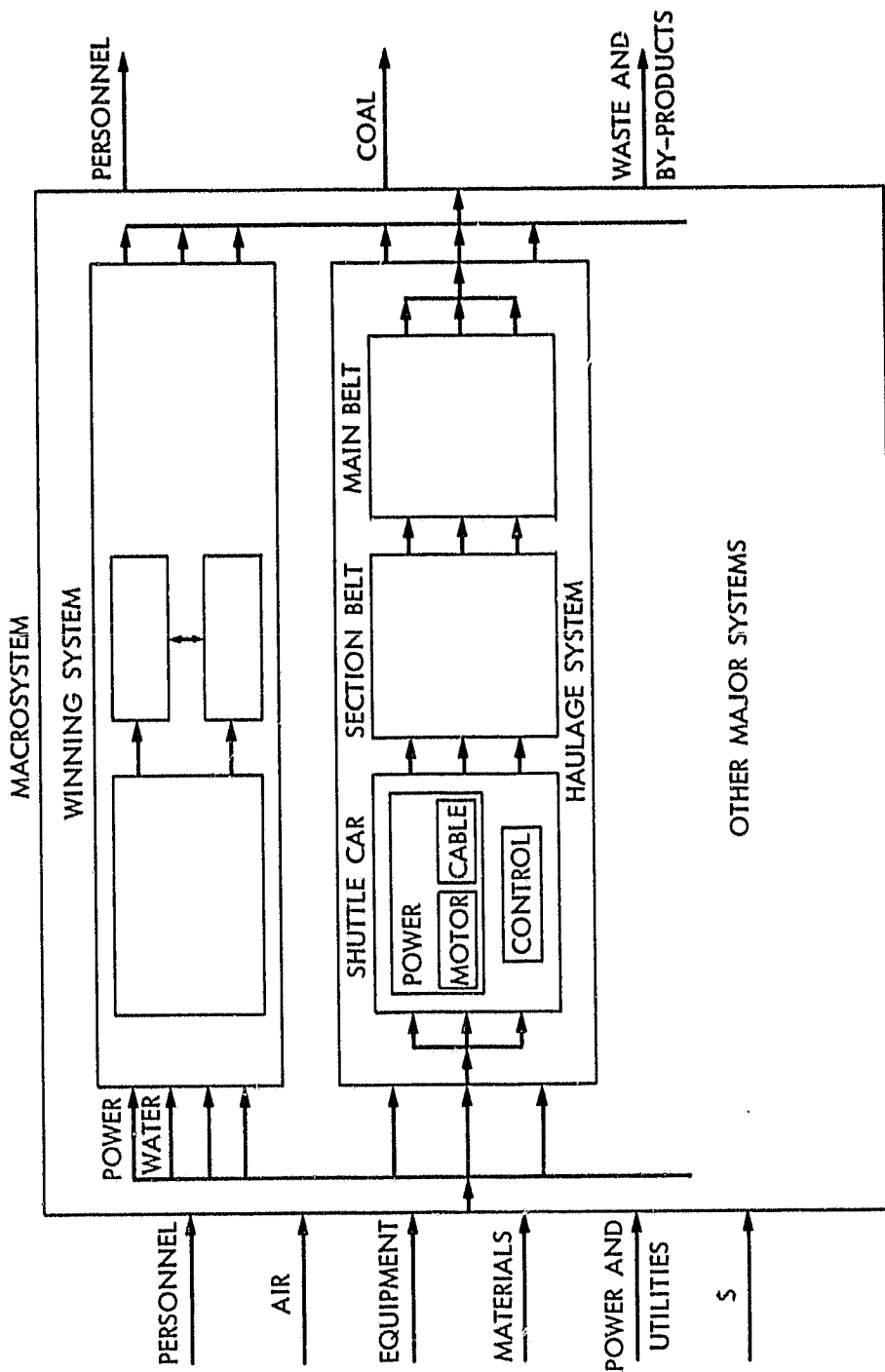
Figure 2-1. Hierarchical Structure of an Underground Mining System

conceptual designer must determine approaches to accomplishing all major mining tasks and determine the configuration of major systems and their interactions within the boundary of the macrosystem.

2.1.3　Level III: Elements of Major Systems

Each major task-oriented system consists of a number of elements. The transport system, for example, may use shuttle cars, a crusher, a section conveyer, a main line conveyer, underground storage, transportation control center, jeeps, scoops, personnel, and many other elements. The conceptual designer must determine the type, quantity and size of the equipment, and specify the supplies, materials, facilities and the manpower needed to operate it. He must also determine the equipment performance rates, and the sequences of events required to accomplish each major mining task. Operating cycles characterizing the mining process are described in Section 2.4.

2.1.4　Level IV: Functional Subsystems

Each of the above elements is composed of subsystems such as the propulsion unit, structure (frame), power package, sensing transducers, control system, etc. The conceptual designer should be generally aware of the approaches used to accomplish each function and be able to determine the approximate performance and the cost of each subsystem. However, he will not generally need to design any of these functional subsystems. Hence, functional subsystems are not discussed in this report. Subsystem design is governed by functional requirements determined after the system elements are selected and the elemental performance envelope has been defined.

2.1.5　Level V: Components

Each functional subsystem is made of a number of components such as printed circuit boards, electric motors, gears, shafts, etc. Components are typically designed after the configuration and performance of each subsystem is defined in depth. However, the performance of a key component may require a substantial advance in the state of the art. In such a case, the conceptual designer may be forced into taking an in depth look at it.

2.2　THE MINE LIFE CYCLE

The physical processes involved in underground coal mining create a life cycle pattern which is substantially the same for all mining systems. Although procuring coal supply contracts, acquiring a mining property and obtaining the necessary permits are important premining activities, for the purposes of conceptual design, mine life can be assumed to begin with site exploration and proceed through five distinct stages.

2.2.1 Detailed Exploration

In this step the mine property is explored in detail to obtain a three-dimensional picture of the coal seam to be mined. In exploration it is important to determine the seam thickness, slope, faulted zones and other difficult to mine areas, general structure of the roof, and other information useful to the the mine planner.

2.2.2 Planning

The next step is to prepare mining plans including surface facilities, seam access, details of underground openings and construction, ventilation, ground control plans, storage, supply, manpower loading, utilities, and many other details. The mine plan is based upon a production target determined by long-term supply contracts and other marketing factors.

2.2.3 Mine Opening

The third step is to establish access from the surface to the seam. Usually this opening is reinforced in some fashion. A staging area at the inbye* end of the opening is constructed; and utilities, shops, and storage facilities may be installed to start development. Contemporary technology accesses the seam via horizontal drifts, sloping tunnels, or deep vertical shafts, depending upon the seam geology.

2.2.4 Development

The mine plan typically divides the property into production panels or blocks which may be viewed as little mines within the larger mine. All excavation, construction, and support activities necessary to access each panel and prepare it for production are collectively labeled as "development." Invariably, much of the excavation work during development takes place within the coal seam. Thus, often a significant amount of coal is produced during initial development.

For convenience, this phase is divided into two parts, initial development and production development. The development work required to place all of the planned mining sections into production is called "initial development." Much of the initial development is devoted to the construction of strongly reinforced entries, called mains and submains, which are intended to remain open for the life of the mine. The mine continues to develop after reaching its planned capacity, entering what is called the "production development" or simply "development" phase. Here the effort is split between extending the mains and submains, and developing new production panels.

---

*Inbye is a mining term meaning in the direction of the face.

2.2.5 Production

The era beginning with the completion of initial development and ending with the start of mine closing activity is called "capacity production", or simply the "production" phase. Here the primary activity is developing and extracting blocks of coal from panels. Nominally the output of a mine is more or less level during capacity production although market conditions, the acquisition of new equipment, or the addition of new sections will cause deviations from the annual capability which was projected initially. During this period, development and production activities occur simultaneously throughout the mine; some panels are being developed while others are in production.

2.2.6 Mine Closing

After the property is mined out, all of the useful equipment is salvaged, and the major openings are sealed, including the seam access. Finally, disturbed land is restored to its premining use according to conditions set in the mining permit. During this era, mine output goes from full capacity down to zero.

2.2.7 Economically Important Phases

Although the ultimate success of a mining venture depends upon success at every stage in the life of the mine, the economic payoff comes mainly from the development and production phases. These two phases cover over 80% of the life span of a mine, require most of the investment, and produce all of the economic benefits. Accordingly, these two phases will be emphasized in the formulation of conceptual design requirements.

2.3 GENERALIZED MINING FUNCTIONS: MAJOR TASKS IN MINING

There are several basic functions that any underground mining system must perform. Although the terminology used to describe these functions is borrowed from current practice, the functions as defined below occur in all systems irrespective of the processes used, including in situ extraction. The conceptual designer must determine an approach for accomplishing each of the mining functions or tasks listed below.

(1) Winning: In this process, coal is fragmented and dislodged from the face. Winning is a European term; in Appalachia terms like "cutting" or "getting" are commonly used. For our application, the nondescript term, winning, is more appropriate.

(2) Haulage: Haulage is the transport of raw coal within the mine. Since coal is typically the only revenue-generating product,* its transportation is described by a separate term, haulage.

---

* The coal train is called "Mother Load" in some mines and is given priority over everything else except safety-related vehicles.

(3) Transport: The term transport is used to describe the movement of all other materials, supplies, equipment, and personnel with the exclusion of coal and ventilation air.

(4) Environmental Control and Monitoring: Environmental control and monitoring comprises a set of activities concerned with creating and sustaining a physical workplace that is safe and productive. Key activities include ground control, ventilation, methane monitoring, rock dusting, fire bossing, belt cleaning, and removal of drainage water. Ground control is preeminent because it maintains the network of underground passages needed for winning, haulage, transport, and other functions. Ventilation is charged with supplying fresh air in sufficient quantities to sustain life and discourage the buildup of dust and gases which could cause fire, explosion, or suffocation. Systems which do not require ventilation have been proposed but have not passed beyond the exploratory stage. Often ventilation requirements determine the number of mine entries. The remainder of the environmental control and monitoring functions are primarily concerned with the prevention of fires and explosions, and the maintenance of conditions necessary for effective operation of the mining equipment.

(5) Coal Preparation: Coal produced from the mine is called raw coal because it contains rock and a number of other impurities. During preparation, coal is separated, sized, washed, cleaned, dried and made ready for delivery. Advanced beneficiation may include the removal of chemically bound impurities such as sulfur, nitrogen compounds and a number of trace elements in coal which are environmentally or commercially undesirable.

(6) Other Logistics and Support Functions: There are several other operations and functions which are required to sustain the mining activity. These include maintenance, utility installation, hiring, training, purchasing, accounting and many other indirect activities. These essential activities are not defined as core mining functions for purposes of this document and hence are lumped into the "other" category.

2.4 INHERENT CYCLES AND PRODUCTIVE CAPACITY OF THE SYSTEM

A microscopic look at the mining process shows mining activites occurring in a pattern of cycles within bigger cycles. The cycles common to most of the mining systems are described below.

(1) Face Traverse Cycle: In the winning activity, the winning device, say the excavator, cannot operate over the whole face at once because that would leave no place for the dislodged coal to go. Thus, the excavator* must move across the entire face area. This cycle, therefore, is called the face traverse cycle.

---

* This cycle is meaningful even in schemes which do not use mechanical excavators, e.g., in solution mining the whole face is not dissolved all at once, there is a basic cycle to the process involving periodic dissolution and flushing.

(2) <u>Face Advance Cycle</u>: After removing a layer from the face, the excavator advances to start its next sweep across the face of the newly exposed surface. This is followed by the face traverse cycle, and again, a forward move of the face.

(3) <u>Face Logistic Cycle</u>: After several face advance cycles, when the working face has receded some distance, immediate support to the excavator must be extended or reconfigured. Moving ventilation equipment up and cable handling are examples of this cycle.

(4) <u>Panel Logistic Cycle</u>: The logistic cycle at the panel level occurs after several face logistic cycles. Typically, the local supply lines become stretched and must be shortened by moving the base of support for the panel. Examples are periodic construction of rail lines, transformer moves, and extensions of conveyors and water lines.

(5) <u>Development Cycle</u>: This is a mine level cycle. Here, whole panels are developed, excavated, and abandoned in sequence over the life of the mine.

<u>Other Cycles</u>: This listing of cycles is by no means complete. Each mining system has several additional cycles associated with its own specific characteristics. Some cycles are time-dependent, e.g., the methane checks required by law; other cycles are determined by tonnage of coal produced, e.g., shuttle car loading times; and still others are cycles governed by total advance, e.g., the 20-ft move cycle dictated by the roof bolting rquirement; and so on.

When these cycles are intertwined together, the resulting mosaics consists of a large number of series and parallel activities, with delays built-in at each change in activity. Thus, cycle patterns are important determinants of the efficiency of a given system, more complex patterns being generally more inefficient. Presently, the instantaneous productive capacities of individual devices far exceed the system capacity. An obvious means of improving system performance is to streamline these cycles so that the ratio of peak capacity to capacity averaged over all system cycles is improved.

2.5   CLASSIFICATION OF MINING TECHNOLOGIES

The principal task of the mining engineer is to establish control over the roof, floor, and ribs (walls) of mine openings, and to ensure that the mine passages remain open until no longer needed for mining activities. Thus, ground control assumes central importance in defining mining technologies, of which there are two basic types -- noncaving and caving.

2.5.1 Noncaving Systems

A network of underground openings can be created in such a way that the roof is left standing for a long time after mining is completed. Naturally, the coal still remaining in place (pillars) must carry the load not supported by the opening. In this case, the quantity of coal recovered decreases with increasing depth of cover and decreasing strength of coal. Both conventional mining (drill and blast) and continuous mining equipment can be used in noncaving methods, achieving a recovery which is generally less than 50%.

Noncaving systems do not produce significant surface subsidence over short periods of time (usually months). Thus, this type of mining does not immediately disrupt neighboring seams. However, over longer time spans, subsidence does occur and can be quite damaging. Because subsidence is typically nonuniform, it makes agricultural use of the land very difficult, and causes cracking of surface roads and structures as well. After closure, the mine cavity accumulates water, methane and other gases, making it dangerous to reopen the mine.

2.5.2 Caving Systems

As the depth of the coal seam increases, the recovery ratio allowable in noncaving systems becomes too small to be economical, and the openings begin to close under the overburden pressure. Thus, a caving technology which allows the roof to collapse after the coal has been extracted, becomes attractive. Higher extraction ratios are possible in caving systems. However, before applying the caving technology, a significant amount of development work must be done with noncaving methods. Some coal must also be left behind in protective barrier pillars between panels or at the property boundaries. Thus, the combined recovery ratio of noncaving development and caving production, seldom exceeds 70%.

In some types of caving, the roof is held up using temporary support. Then, after extracting the coal, the suppports are either removed or moved closer to the face. This use of temporary support is a characteristic of caving systems. Longwall mining, which uses frames, chocks or shields for temporary support, is a good example of caving technology. In situ gasification is an example of caving technology which does not use any mechanical temporary supports.

The subsidence produced by caving systems is fairly uniform over the width of the panel. Generally, it causes less disruption in ground water flow patterns and in the patterns of land usage, except in the transition zones between subsided and unsubsided ground.

2.5.3 Backfilling

It is possible to fill some portion of the mine cavity with inexpensive materials such as mine refuse, sand, or dirt, to achieve better ground control and reduce subsidence. Backfilling may be used with either caving or noncaving methods and, therefore, does not constitute a separate category of mining methods.

SECTION 3

A SUMMARY OF PROBLEMS EXPERIENCED BY CONTEMPORARY SYSTEMS

The designer should have an appreciation for the problems encountered by existing mining systems so that he can focus on the most promising opportunities while synthesizing a conceptual design. There are three contemporary mining systems in use today, namely, conventional mining (drill and blast), continuous mining, and longwall mining. A few shortwalls have been tried, with the adoption of this technology proceeding very slowly (Gangal, 1981a). Hydraulic mining, used in many other countries, has not found application in flat coal seams of moderate thickness and, therefore, is not widely employed in the U. S.

The major problems in coal mining include those resulting from difficult geological conditions, a proportionately large amount of built-in downtime, unreliable equipment, insufficient maintenance, inadequate tools for planning and management, an unhealthy and unsafe working environment, and environmentally harmful mining practices. There is very little one can do about changing the geological conditions such as variable seam thickness, seam discontinuities, poor roof and floor, excessive water or methane, etc; one must learn to master them with proper system design or cope with them through effective planning and application of technology. However, the problems which have their roots in system structure should be addressed in conjunction with the development of an advanced system. Examination of the sources of the remaining problems suggest that they may be grouped into the following categories:

    (1)   Lack of scientific knowledge.

    (2)   Lack of suitable technology.

    (3)   Insufficient use of available technology.

    (4)   Inadequate industrial engineering.

3.1   LACK OF SCIENTIFIC KNOWLEDGE

There are a number of problems arising from our lack of knowledge about the phenomena involved; the important ones are described below.

3.1.1   Inadequate Exploration

Our knowledge about the details of coal seam geology in an undeveloped property is very limited. Most of the information is obtained by drilling exploratory holes ("boreholes") at spacings of several thousand feet. Because of the wide spacing between boreholes and frequent variations in seam geology, mining crews often do not know that they are approaching difficult-to-mine areas until they are in them. The result is that a great deal of time and effort must be spent in diagnosing the problem and correcting it on an ad hoc basis. Seismic, radar, and sonar techniques are now in the experimental stages of development and show considerable promise. When perfected, they may be capable of producing clear three-dimensional pictures

ORIGINAL PAGE IS
OF POOR QUALITY

of the seam in sufficient detail to locate major faults, partings, lenses, and sand channels so that the mine plan can be structured to avoid serious delays.

3.1.2   Ineffective Ground Control

Despite a substantial amount of theoretical research and the installation of approximately one hundred million roof bolts every year, knowledge about the behavior of mine roof is very limited. The problem is twofold. First, there is little knowledge about the local stresses, strength, and degree of fragmentation in the immediate roof. Second, the variability of roof strength in response to the changing characteristics of roof materials is not well understood. Knowledge about the stability of ribs and floors is similarly incomplete. Current regulations require that mines use an approved ground control plan. Generally, difficult roof is handled by substantially reduced bolt spacing and additional secondary support. Despite this, injuries and deaths from roof and rib falls are the leading safety problems in coal mining.

The future does not appear very promising for understanding the physical phenomena at the level of detail required to solve everyday ground control problems. Thus, the conceptual designer may be forced into using extensions of current ground control practice.

3.1.3   Health Factors

There is incomplete knowledge about the quantitative links between ailments and various chemicals present in the mine environment, and a lack of understanding about predisposing factors which make some miners more prone to pneumoconiosis, emphysema, and other respiratory diseases (Zimmerman, 1980). However, this ignorance is not expected to have a major impact on developing an advanced mining system. Current regulations limit dust and noise exposure to presumably safe limits which the designer must observe. Vibrations and chemicals indigenous to the mining environment are not regulated to the same degree. Thus, the system designer must verify that the mechanical and chemical agents selected can be used safely in the mining environment.

3.2   LACK OF SUITABLE TECHNOLOGY

In many cases the basic scientific knowledge exists but suitable technology has not yet been developed to take advantage of that knowledge, particularly in the following areas.

3.2.1   Continuous Cutting, Roof Support and Haulage in Room and Pillar Mining

A major cause of low productivity is the intermittent nature of contemporary room and pillar technology. Indeed, the principal advantage of longwall mining is that it provides for parallel execution of cutting, roof support, and haulage at one producing face. Chironis (1981) describes a number of government-sponsored efforts to develop similar technology for room and pillar mining, including a miner-bolter, an automated extraction system, and a continuous haulage system. DOSCO's In-seam Miner, and Lee Norses' In Place Miner are examples of continuous mining schemes being developed by the private sector. All of these projects are currently in the stage of precommercial development. Although in theory it is possible to achieve high

ORIGINAL PAGE IS
OF POOR QUALITY

productivity by batch operations, experience suggests that continuous cutting, roof support, and haulage should be incorporated into an advanced system in order to obtain substantial increases in productivity.

3.2.2 Coal Beneficiation

"Clean" coal sold on the market still contains ash, as well as compounds of sulfur and nitrogen which produce environmentally damaging combustion products. A technology to remove sulfur and nitrogen would be very attractive, and recent research indicates that it may be feasible to remove sulfur using rather inexpensive reagents (Kalvinskas, 1980); nitrogen removal, however, is far more difficult. In either case, translating research results into a viable technology remains a formidable task.

3.2.3 Mine Communications

Communications within the mine leave a lot to be desired. The noisy and poorly lit working environment forces the face personnel to communicate primarily by lamp signals. In some cases the communication is not overt, but is accomplished by equipment operators becoming intimately familiar with each other's "style." Unfortunately, this contributes to hazardous conditions at the face and to low productivity. Moreover, machinery noise, electrical disturbances, and lack of suitable equipment cause most telecommunications to be garbled. Sullivan and Cawley (1980) describe improved systems for underground telephone, radio, and through-the-earth communications which are under development, indicating many interesting possibilities for future mine communications systems.

3.2.4 Noise Reduction

In addition to the hazard of hearing loss, high noise levels at the face reduce clarity in voice communications and also lead to worker fatigue, thus contributing to a safety hazard as well. To a large measure, noise reduction technology exists. However, experience has shown that current noise abatement measures become ineffective quickly. Conveyor chains, cutter chains, gear drives, and pumps are especially noisy components. Further efforts are necessary to reduce noise and keep it low during the service life.

3.2.5 Backfilling Technology

Backfilling and disposal of refuse in the mine cavity may be desirable for controlling subsidence and avoiding environmental problems created by refuse piles on the surface. It may also help to improve resource recovery and offer greater flexibility in mine planning. However, at present, backfilling is too costly and its environmental consequences are not well understood.

Although individual pieces of equipment are available for dewatering tailings and deploying the backfill materials so as to provide sufficient support to the roof, an integrated backfilling technology for modern room and pillar operations does not exist, according to the National Research Council (1975). Moreover, new technology is needed for separating waste from coal near the face and for protecting groundwater from contamination by backfill materials. The latter is especially important because the coal horizon is in many cases an aquifer.

Backfilling is currently an active field for R&D. In addition, the United States Bureau of Mines (USBM) is funding several field projects using the Abandoned Mine Lands Fund. One recent project (Smith, 1980) was aimed at controlling subsidence caused by old, abandoned coal mines under habitated areas of Fairmont, West Virginia. Clearly, the designer may find this to be a fruitful area for innovation.

3.2.6   Sensor Technology

A number of mining problems stem from the lack of suitable sensors to detect problems before they occur. The list of potentially applicable sensors is very long and includes methane sensors, roof monitoring sensors, TV cameras, vibration sensors, machine diagnostic sensors, heat sensors, coal-rock interface detectors, proximity sensors, motion sensors, etc. Many of these devices are readily available for above ground use, but cannot be used underground because of the dirty environment and electrical safety regulations. In other instances, (e.g., coal-rock interface detector), the necessary technology is just being developed. Adapting existing sensors to mining applications, and developing additional sensors and information processing capability may be one of the most important tasks in the design of an advanced underground mining system.

3.3   INSUFFICIENT USE OF AVAILABLE TECHNOLOGY

In many instances technology is available but is simply not used in the mine. Most cases of insufficient use are related to the need for improved equipment design, better personnel training, and enhanced communication between mine operators and equipment manufacturers. Some of the problems are discussed below.

3.3.1   Reliability

Equipment reliability in the mine is very poor. Over the years, manufacturers have provided more powerful machines. Only recently have they turned their attention to reliability. Marrus, et al (1976) show that mean output between failures for a continuous miner is only 1400 tons. In other words, a machine capable of producing coal at a rate of 7 tons/min, will break down, on the average, after a service of only 200 min at full load! Certainly this can and must be improved. Operators also share the blame for unreliable equipment. Mine maintenance practice leaves much to be desired, as indicated below.

3.3.2   Maintenance

Although equipment has become more powerful, productivity has not improved proportionately, in part because of poor maintenance. Indeed, a recent study by the General Accounting Office (1980), suggested that a significant fraction of the observed decline of productivity was caused by poor reliability and maintenance. Few underground mines practice preventative maintenance or other systematic procedures to assure high equipment availability. Many are not even aware of all the costs directly related to maintenance.

Component design often contributes to the maintenance problem. The use of intrinsically unreliable chain drives, less than optimum pick design, unprotected and unsealed hydraulics, and the lack of modularity in design are all factors contributing to poor maintenance.

3.3.3   Health and Safety

A number of techniques and devices are available for dust control*, roof fall protection, electrical safety, and machine maintenance. Many of these devices are regarded as inconvenient to use or an unnecessary impediment to production. In any event, for a number of reasons these devices are not utilized effectively. The result is that deaths and disabling injuries in underground coal mining are twice as high as in comparable industries. Clearly, the designer of an advanced system must consider the likelihood of effective use when specifying health and safety equipment and procedures.

3.3.4   Environmental Control Technology

Many procedures and processes have been developed and tested for the control of polluted mine drainage, particularly acid mine waters, including both in-mine source control methods and treatment of the water after it leaves the mine. Although the technology for treating acid mine drainage is developing rapidly, lime neutralization with sludge disposal remains the most common means of treatment in Central Appalachia, due to custom, low cost, and lack of information about alternative methods. The replacement of obsolete treatment plants with more effective, lower cost equipment should be encouraged.

3.4   INADEQUATE INDUSTRIAL ENGINEERING

The use of industrial engineering techniques, although common in many large mines, is far from realizing its potential in underground coal mining. Computer programs developed in recent years to simulate underground mining operations (Manula and Rivell, 1974; Kohler et al, 1981) indicate that often simple modifications in operating practice can improve productivity dramatically. Operations, inventory control, and mine planning can all benefit from the industrial engineering approaches already used in many industries. Thus, the designer should seriously consider including an industrial engineering package as one of the management tools incorporated into an advanced system.

The above list of problems is by no means complete. There are numerous other problems associated with present mining practice, many of which are related to specific mine sites, equipment, and the techniques used. These problems, which are basically institutional in nature, are beyond the scope of conceptual design and are, therefore, not discussed here.

---

* One exception should be noted here. In the case of the longwall mining system, truly reliable dust control technology is not yet available. Several R&D projects sponsored by U.S. Bureau of Mines are expected to develop workable approaches (see, for example, Kissell et al, 1981).

SECTION 4

REQUIREMENTS FOR CONCEPTUAL DESIGN

4.1   INTENDED USE AND SCOPE

The conceptual design requirements presented in this chapter are derived from the system performance goals summarized in Section 1.1. These requirements define the following: (a) operating environment, seam geology, market price of coal, and characteristics of available resources including manpower, water, power, other utilities and services; (b) operating constraints imposed by the need to protect the environment and to provide healthy and safe working conditions for mine personnel; (c) primary system performance goals; and (d) desirable technical and economic characteristics of the system which would make it more attractive than evolutionary systems.

During conceptual design, the systems designer determines the approaches to accomplish all major mining functions (see Section 2.3), defines operating cycles (Section 2.4) and solves the major problems associated with contemporary systems (Section 3). In the process, the designer must size all of the elements of the system and determine their performance individually and collectively for the system as a whole. Then the designer must determine capital costs, manpower requirements and operating costs, and subsequently show that the system offers greater potential than competing systems.

The conceptual designer is unlikely to be concerned with the details of individual subsystems and components unless the success of the system depends upon them. For example, if a pump is used in a routine low pressure application, the designer does not need to know the details of the design. On the other hand, if the pump is to be run at pressures exceeding current experience, the designer must demonstrate that such a device can be fabricated satisfactorily. A systematic statement of conceptual design requirements is also useful in selecting candidate concepts for development, and for determining how each should be pursued. Concepts which exceed performance goals, meet all constraints, and incorporate more of the important desirable attributes merit higher ranking than those which do not.

In conclusion, the principal purpose of these requirements is to guide the design effort so that the resulting concepts fall within the envelope defined by system performance goals. In scope these requirements cover systems level performance, sizing of principal elements, and economic evaluation. They stop short of detailed specifications at the subsystem and component level.

4.2   CLASSIFICATION OF REQUIREMENTS

The requirements listed in this chapter are classified into two groups, <u>mandatory requirements</u> and <u>desirable system characteristics</u>. A requirement becomes mandatory if fulfilling it is <u>necessary</u> to (1) satisfy a system performance goal in a manner which ensures that the system is truly advanced, or (2) to meet some external constraint. The specifications of geological conditions, limits on dust and methane levels in the operating environment, and a productivity goal are examples of mandatory requirements.

ORIGINAL PAGE IS
OF POOR QUALITY

Although usually left unstated in the phraseology of individual requirements, it is incumbent on the designer to demonstrate compliance with each mandatory requirement. Typically this demonstration takes three forms:

(1) Inspection (all vehicles are designed to permit onboard operation).

(2) Analysis (production projections determine whether the requirement on labor on labor productivity is met).

(3) Test (a simple mockup of a new shield design confirms the ability to cope with soft floor).

For additional clarity a mandatory requirement may contain guidance on how to demonstrate compliance. Such guidance constitutes a procedural requirement on documentation of the design. Guidance about estimation of production cost is an example of a procedural requirement.

A desirable characteristic is one which may help attain a system performance goal but, by itself, it is neither necessary nor sufficient for achieving it. For example, it is highly desirable that the face equipment have an on-board power supply. Having no power cables, the system should be more mobile, thus reducing downtime consumed in equipment moves and setups, and consequently contributing to the production cost goal. However, it may be possible to achieve an equally good productive capacity without an on-board power supply. Thus, this is merely a desirable characteristic.

The remainder of this chapter is devoted to the formulation of conceptual design requirements following a formal statement of the design objective and documentation guidelines. These requirements are organized into the following categories:

(1) Constraints imposed by target resource.

(2) Mine size.

(3) Production cost goals and constraints.

(4) Safety and human factors requirements.

(5) Health requirements.

(6) Environmental impact constraints.

(7) Conservation - resource recovery constraints.

(8) General regulations and standards.

Each requirement is preceded by a discussion of the underlying rationale. The mandatory requirements are labeled by the letter M, and desirable characteristics are labeled D.

4.3   DESIGN OBJECTIVE AND DOCUMENTATION GUIDELINES

The first requirement states the design objective, defines pertinent terms, and indicates what formal documentation is expected after a conceptual design is completed.

M.1   Conceptual Design Objective: THE CONCEPTUAL DESIGN SHALL BE PRESENTED IN A DOCUMENT WHICH (1) DESCRIBES THE DESIGN DETAILS OF THE COAL MINING SYSTEM, (2) DEMONSTRATES THAT THE DESIGN MEETS ALL MANDATORY REQUIREMENTS LISTED IN THIS DOCUMENT, AND (3) INCORPORATES AS MANY OF THE DESIRABLE CHARACTERISTICS AS FEASIBLE. THE ADVANCED SYSTEM SHALL BE DESIGNED FOR OPERATION IN FLAT-LYING CENTRAL APPALACHIAN COALS OF MODERATE THICKNESS* AND MODERATE COVER*, REMAINING IN THE YEAR 2000. PRIMARY OBJECTIVES ARE (1) A RETURN ON INCREMENTAL INVESTMENT OF AT LEAST 1.5 TIMES THE RATE REQUIRED OF THE AVERAGE CAPITAL IMPROVEMENT PROJECT AND, (2) A REDUCTION OF 50% IN DEATHS AND DISABLING INJURIES. ALTHOUGH ADVANCES IN ALL ASPECTS OF SYSTEM PERFORMANCE ARE DESIRABLE, IMPROVEMENTS IN PRODUCTION COST AND MINER SAFETY ARE MANDATORY.

Underground Coal Mining System: Consists of all elements required to mine coal and to clean it, located within the boundaries of the mine property, and extending over the entire life of the mine, starting with exploration and ending with mine closure.

Conceptual Design: Consists of selecting, sizing, and configuring all important elements of the system (see Section 2.1), and determining their interrelationships in sufficient detail to permit an evaluation of the performance and cost of the whole mining system.

Incremental Investment: Consists of all expenditures on equipment or construction which are different from the evolutionary baseline technology with which the advanced system is being compared (see Bickerton and Westerfield, 1981, for projections of evolutionary technology).

Concept Design Documentation: Must include all of the items listed below.

Approach: The designer must summarize the essence of the main ideas embodied in the design, and indicate how the mandatory design requirements will be met.

Description: The system description addresses the construction and mode of operation of major system elements, utilizing illustrations wherever appropriate. The system description must cover operations over the entire life cycle of a mine.

Technical Profile: In this section, the designer describes the performance of the system under the normal and abnormal working conditions specified in the requirements. Computations must be supported by references, backup data, and where feasible, engineering analysis.

---

* Defined in Section 4.4.1.

Economic Profile: The designer is to develop equipment tables, manning tables, capital and operating costs (including surcharges and contingencie's), and a computation of the rate of return on incremental investment. Assumptions must be stated clearly, and backup provided for all major cost items.

Conclusions: This section summarizes the strengths and weaknesses of the design; identifies areas of uncertainty and approaches to resolve them, and estimates the time and cost required to design, build, and test the system.

4.4   REQUIREMENTS IMPOSED BY THE TARGET RESOURCE

The selection of central Appalachia as the target region automatically imposes certain restrictions and constraints pertinent to the geology, geography, and other aspects of the operating environment. The system performance goal identifies the target resource as the flat-lying seams of moderate thickness and moderate cover remaining in the year 2000.

Figure 4-1 presents an overview of the relationship between the conceptual design requirements and the constraints imposed by the Central Appalachian target resource, namely: (a) the system must function in the geological conditions typical of the area; (b) it must be cost competitive, given the mine mouth price projected for target region; (c) it must use the local labor pool; and (d) it must use locally available utilities and services. In a later section on environmental impact, the system is required to take into consideration local topographical features. For ease of reference, Figure 4-1 and subsequent graphic overviews of requirements identify mandatory and desirable requirements by number.

4.4.1   Mining Conditions

The geology of the coal seam and the surrounding host rock impose significant constraints on the design and operation of an underground mining system. Camilli et al (1981) discuss coal geology from the perspective of the mining engineer, devoting considerable effort to relating information on the depositional setting to potential mining problems. In addition to a rather general treatment of mining conditions, Camilli, et al, present a description of the Central Appalachian resources in the format of a baseline mining environment. Here that description has been condensed into requirements in nine areas: seam thickness; depth of cover; dip; anomalies; multiple seams; ability to excavate rock; roof, floor, and rib stability; methane; and water.

4.4.1.1   Seam Thickness. The distribution of Central Appalachian coal resources by seam thicknesses is shown in Figure 4-2. After comparing this description of the resources with data on the seam height of producing mines and estimates of the seam height for new mines opened in the year 2000, we selected a nominal seam thickness of 50 in. (see Appendix A). Appalachian coal seams show considerable variation in seam thickness over distances of a few hundred feet. The system must be designed to accommodate these variations. Available data show that typical seam thickness variations within individual mines may be of the order of 2 ft (Camilli et al, 1981; Ferm, 1981).
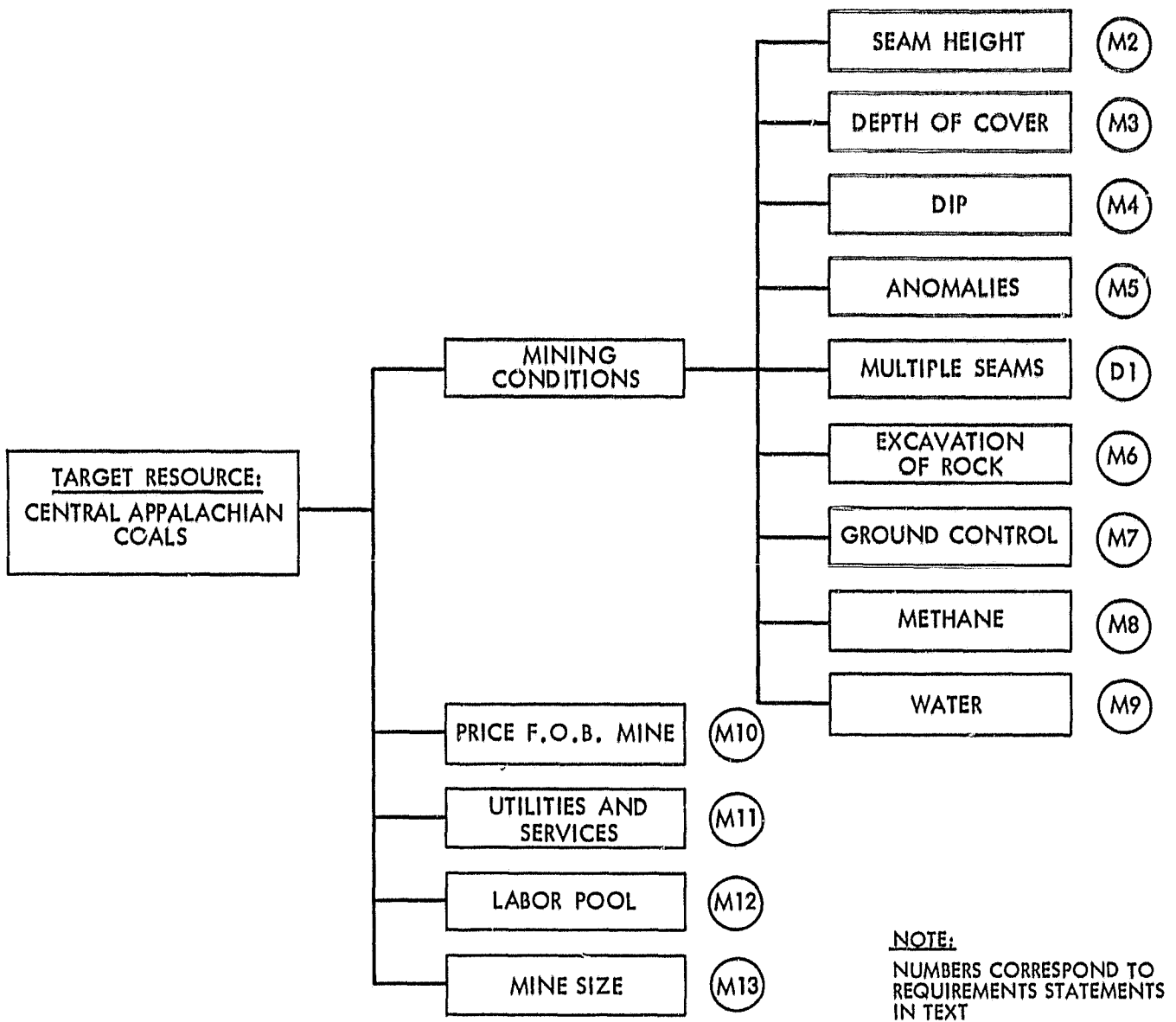
Figure 4-1. Overview of Target Resource Requirements
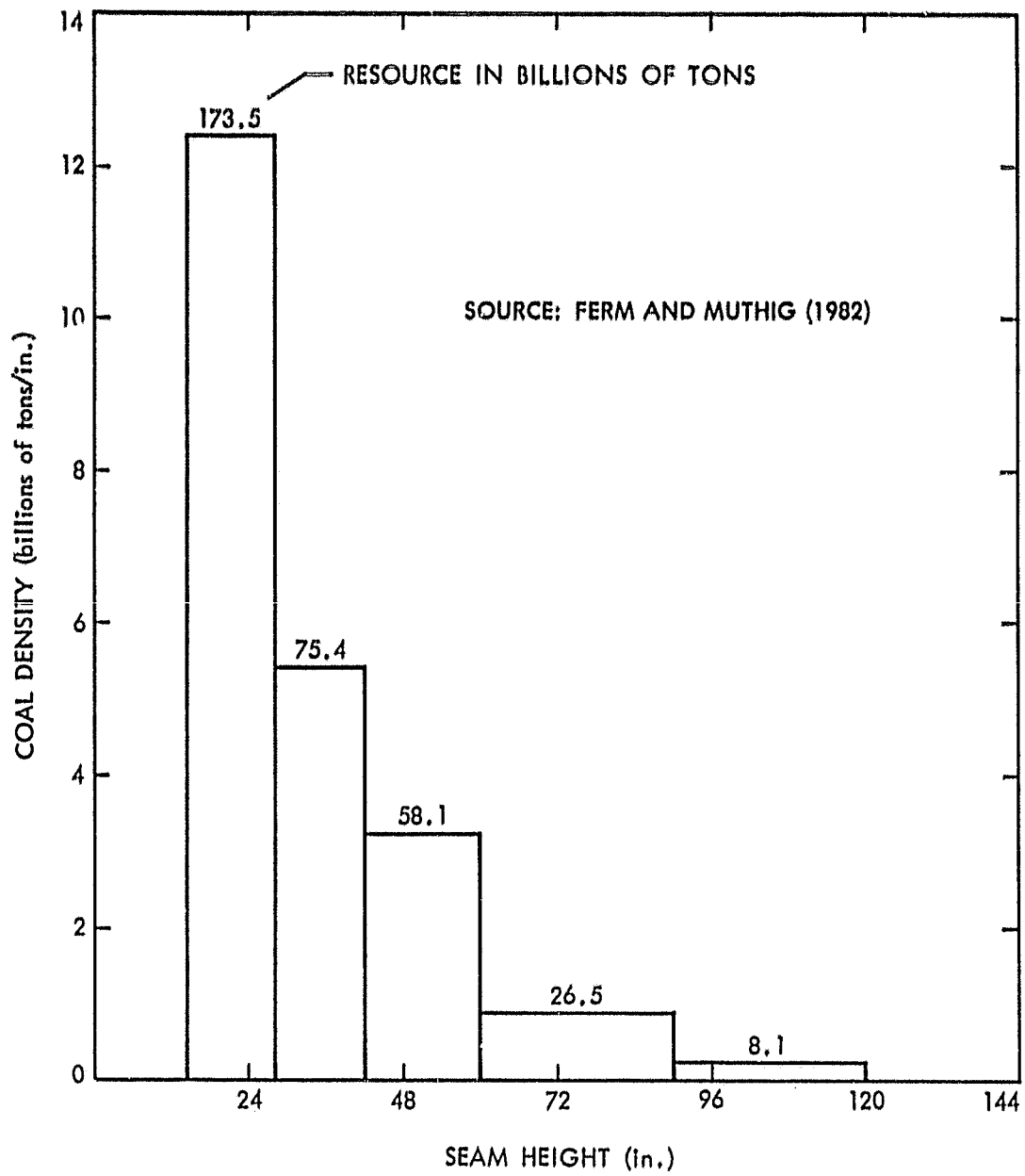
Figure 4-2. Distribution of Flat-Lying Central Appalachian
Coals by Seam Height, Prior to Mining

ORIGINAL PAGE
OF POOR QUALITY

Generally, the production rate and hence, operating costs are functions of seam thickness (Suboleski, 1978). This is to be expected, since more coal is produced during each face traverse cycle in thicker seams than in thinner seams; thicker seams can use bigger and more powerful equipment; and movements of men and machines are less restricted in thicker seams than in the thinner seams. To facilitate the comparison between competing conceptual designs, all designs must use the nominal seam thickness of 50 in. for estimating performance, unless the system is designed specifically for thinner seams.

In current practice, the equipment manufacturers supply several models of each type of machine to cover the range of seam thicknesses. For example low machines may be used in seams from 26 to 42 in.; mid-size machines, in 42- to 72-in. seams; and high machines, in seams above 72 in. The actual range of seam thickness covered by each model varies from manufacturer to manufacturer. In longwall mining, plows are preferred in seams below 48 in., and shearers above 48 in. Since the designer needs some flexibility in determining the best way to realize his ideas, an advanced system may or may not use the multiple model approach to cover the thickness range. Therefore, the designer has two choices: (1) cover the entire range of seam thickness from 28 to 180 in. with several "models" as currently practiced, or (2) to select a range of thicknesses most suitable for his technique. In the later case the designer should address at least 75% of the resource between 28 and 180 in.

M.2   Seam Thickness: THE SYSTEM SHALL BE DESIGNED TO OPERATE IN A SEAM OF 50 IN. NOMINAL THICKNESS, WITH ±12 IN. LOCAL VARIATION WITHIN THE MINE PROPERTY.

Other Seam Thicknesses: IN ADDITION, IT MUST BE SHOWN HOW THE DESIGN CAN BE EXTENDED (e.g., MODELS) TO MINE SEAMS RANGING FROM 28 IN. TO 180 IN.

Exception and Alternative Requirement: SOME DESIGNS MAY BEST BE APPLIED IN SEAM THICKNESSES OTHER THAN THE 50 IN. SPECIFIED ABOVE. IN SUCH A CASE THE DESIGN POINT FOR SEAM THICKNESS MUST BE SPECIFIED AND A LOCAL THICKNESS VARIATION OF ± 12 IN. MUST BE OBSERVED. IN ADDITION, THIS DESIGN MUST DEMONSTRATE THE CAPABILITY TO BE APPLIED TO APPROXIMATELY 75% OF THE RESOURCES FROM 28 IN. TO 180 IN., AS SHOWN IN FIGURE 4-2.

4.4.1.2 Depth of Cover. Table 4-1 shows a breakdown of resources by depth from Ferm and Muthig (1982). Surface mining techniques are routinely used up to a 200-ft depth* and may be economic to depths of the order of 500 ft. Seams under moderate cover of 500 to 2000 ft are being mined today by underground mining techniques. The Central Appalachian resources below 2000 ft are not substantial and will, therefore, not be addressed in these requirements.

---

* Surface mining economics depends upon the ratio of coal to waste rock. Since Appalachian seams rarely exceed 10 ft in thickness, current economics limits cover depths to about 200 ft. Beyond that limit, overburden handling is too expensive at this time.

Suboleski (1978) and Mabe (1979) found that cover depth has a small but measurable impact on both production rate and mining costs. Seam access costs increase with increasing depth and so do the hoisting costs. Additionally, as the depth increases, it becomes more and more difficult to keep mine passages open against ground pressure, and eventually caving methods become the only acceptable mining technique.

For the sake of uniformity of response, a nominal design point depth of 1000 ft is specified. As in the case of seam thickness, the designer has the option of selecting another nominal design depth; however, if he does so, the system must address 75% of the resource within the range of 0 to 2000 ft.

M.3   Depth of Cover : THE SYSTEM SHALL BE DESIGNED TO OPERATE AT A NOMINAL DEPTH OF 1000 FT.

Other Depths: IN ADDITION, IT MUST BE SHOWN HOW THE DESIGN CAN BE EXTENDED TO MINE SEAMS RANGING FROM 500- TO 2000-FT DEEP.

Alternative Design Point: AN ALTERNATIVE DESIGN POINT FOR DEPTH MAY BE SELECTED, HOWEVER, IN SUCH A CASE THE DESIGN MUST DEMONSTRATE THE CAPABILITY TO BE APPLIED TO 75% OF THE RESOURCE BETWEEN 0 AND 2000 FT. (Table 4-2).

Note that if the designer addresses 75% of the resource by thickness and 75% by depth, his system will apply to approximately 50% of the total resource (in seams thicker than 28 in.), assuming that depth and thickness are independent random variables.*

Table 4-1. Estimates of Central Appalachian Coal Resources
by Cover Depth (Billions of Tons)

Source: Ferm and Muthig (1982)

Cover Depth	Coal Resources
0 to 500 ft	101
500 to 2000 ft	245
2000 to 4000 ft	nil
Total Resources	346

4.4.1.3   Seam Dip. The consideration of dip may be important in some designs. The target resource contains coal seams which are fairly flat,

---

* It is not known if seam thickness and depth are statistically independent of each other or not. However, the observation that in Appalachia seams frequently outcrop through the mountainous terrain indicates that these two are probably independent of each other.

dipping no more than 3° for the most part (Ferm and Muthig 1982). However, in local spots, the dips may approach 10°, especially, in areas of seam rolls.

M.4   Seam Dip: THE SYSTEM SHALL BE CAPABLE OF OPERATING IN A SEAM HAVING AN AVERAGE DIP OF 0°, AND LOCAL SLOPES OF ±10°.

4.4.1.4 Seam Anomalies. Appalachian seams contain many geological anomalies, such as, lensing, faulting, washouts or sand channeling, seam splits, inclusions of hard sulfur balls (iron pyrite), and slickenside rocks in the roof or floor near fault areas. The mining system must be able to deal with these problems without serious deterioration in overall performance. Possible approaches include: (1) avoiding anomalies through better exploration and planning, and (2) designing the system to deal with the eventualities which cannot be avoided. In general, anomalies listed in Table 4-2, group A, can be minimized by careful planning, while those in group B must be dealt with routinely without deterioration in system performance.

M.5   Seam Anomalies: THE SYSTEM SHALL HAVE THE CAPABILITY OF HANDLING (1) SPLITS, PARTINGS, AND LENSES AS A ROUTINE OPERATIONAL PROBLEM (I.E., EVERY PRODUCTION SHIFT); AND (2) LARGE SULFUR BALLS, FAULTING, WASHOUTS, AND SLICKENSIDES ON ROOF AND FLOOR AS AN OCCASIONAL OPERATIONAL PROBLEM (I.E., ONE OCCURRENCE EVERY 1000 FT OF ADVANCE).

To demonstrate compliance with this requirement, the design must specify the special equipment and procedures needed to overcome the problems in group A of Table 4-2. However, no lower limit can be justified for deterioration in system performance. Therefore, the variation in performance due to anomalies will be a factor in judging the overall attractiveness of a system.

Table 4-2. Classification of Seam Anomalies

A: Anomalies Encountered Occasionally	B: Anomalies Encountered During Routine Operations
Sulfur ball inclusions Faulting Washouts Slickensides on roof and floor	Splits and partings Lenses

4.4.1.5 Multiple Seams. Most coal deposits consist of coal seams interspersed with rock strata with the interburden between seams varying considerably. Seams of reasonable thickness which are close together are often mined as one unit; seams which are more widely separated may be extracted via distinct mining efforts, often not contemporaneous. Coals in the former situation are described as having rock partings, while those in the latter are termed multiple seams. Extracting one member of a grouping of

ORIGINAL PAGE IS OF POOR QUALITY

multiple seams will frequently create problems for mining the adjacent members of the group. In particular, if one defines the interburden ratio as the interburden divided by the thickness of the lower seam, Peng and Chandra (1980) report that interseam interference is quite probable for an interburden ratio as low as 25 to 30, with the disturbance becoming worse as the interburden ratio gets smaller. Multiple seam coals are quite common, constituting a substantial subresource of flat-lying coals. Therefore, a capability to extract multiple seams is a highly desirable characteristic of the system. It is not a mandatory requirement because of the technical complexity and added costs such a requirement may impose.

Work is currently underway to determine the amount of resources in these multiple seams. If the results show that substantial resources may be lost by high grading, a multiseam mining capability should be mandated. Pending this resolution, the following desirable characteristics are included in the requirements.

If the designer chooses to address multiple seams, he must make an economic choice as to how many seams to extract, how much disturbance that would create, and how much of the total resource impacted can be ultimately recovered. In such a case, the designer must provide for precise mapping of the mining excavation so that its impact on neighboring seams can be accurately determined.

D.1   Multiple Seams: IT IS HIGHLY DESIRABLE THAT THE SYSTEM HAVE THE
        CAPABILITY TO DEAL WITH MULTIPLE SEAMS CHARACTERIZED BY AN
        INTERBURDEN RATIO OF 25 OR LESS.

4.4.1.6 Rock Strata. Mining engineers define coal seams as minable units of coal and rock strata containing at least 50% coal by weight, with each unit bounded by coal layers at the top and the bottom (Ferm, 1981). Moreover, seams in the target region are extremely variable and often contain partings; field visits indicate that continuous miners frequently have to cut rock layers from roof, floor, or in the middle of the seam (middleman rock). One manufacturer estimates that his machines cut 40% rock on a routine basis (Gangal, 1981b). Table 4-3 shows the types of rocks found in the region and their approximate physical properties.

M.6   Ability to Excavate Rock: THE SYSTEM SHALL HAVE THE CAPABILITY OF
        ROUTINELY EXCAVATING PARTINGS, SPLITS, LENSES, AND OTHER SEDIMENTARY
        ROCK ASSOCIATED WITH A COAL SEAM HAVING A COMPRESSIVE STRENGTH
        VARYING BETWEEN 10,000 PSI (SHALE) AND 16,000 PSI (HARD SANDSTONE),
        AND CONSTITUTING UP TO 50% BY WEIGHT OF THE RAW TONNAGE. UNDER THESE
        SEVERE CONDITIONS THE PERFORMANCE MAY FALL BELOW THE DESIGN POINT
        PERFORMANCE DEFINED IN SECTION 4.6. THE DESIGNER MUST ESTIMATE THIS
        REDUCTION IN PERFORMANCE.

4.4.1.7 Roof, Floor, and Rib Stability. The stability of mine roof, ribs, and floor depend upon the quality of rock strata, seam depth, shapes and sizes of mine openings, mine plan, water content, and many other factors. Even in the most current texts, roof characteristics are described only in qualitative terms, thus, little quantitative information can be supplied to the designer.

ORIGINAL PAGE IS
OF POOR QUALITY

M.7   Ground Control Plan: THE DESIGN SHALL INCLUDE AN APPROACH FOR
       CONTROLLING THE STABILITY OF THE MINE OPENINGS AS SPECIFIED IN THE
       MINE PLAN (REQ. M.42). THE PLAN MUST ASSUME "AVERAGE" ROOF, FLOOR
       AND RIB CONDITIONS AS DESCRIBED BY TOTH (1981). THE GROUND CONTROL
       PLAN MUST DESCRIBE HOW TO DEAL WITH UNSTABLE ROOFS, FLOORS, AND RIBS,
       AND IN ADDITION, HOW TO COPE WITH LARGE ROOF FALLS, FLOOR HEAVES, AND
       RIB SLUFFING AFTER THEY HAVE OCCURRED.

       Exceptions: SOME DESIGNS MAY RELY ON INHERENTLY STABLE OPENING
       CONFIGURATIONS. IN SUCH A CASE, THE DESIGN MUST DEMONSTRATE (VIA
       THEORETICAL CALCULATIONS, FINITE ELEMENT ANALYSIS, OR FIELD
       OBSERVATIONS) STABILIITY UNDER "AVERAGE" CONDITIONS (AS DESCRIBED IN
       TOTH, 1981), AND THE CAPABILITY TO CONTROL WEAK GROUND SATISFACTORILY.

Table 4-3. Typical Rock Strata Associated
With Coal Seams in Appalachia*

Rock Type	Approximate Mean Compressive Strength, psi
Coal	2,500
Claystone	6,000
Siltstone	7,500
Shale	10,000
Sandy shale	12,000
Sandstone	16,000
Conglomerate	25,000

* These data are a composite of information reported by Krynine and Judd
   (1957), Leonards (1961), and Windes (1949).

4.4.1.8 Methane. The methane content of coal seams varies with the seam,
quality of coal (rank), depth, and location. Diamond and Levine (1981) show
that the the methane content of coals in the target area ranges from 0.1 to
21.6 cc/g with an average of 10 cc/g. They also show that total methane
emissions from coal mine openings increase linearly with gas content of the
coal.

M.8   Methane Emission: THE MINING SYSTEM MUST MAINTAIN SAFE LEVELS OF
       METHANE, ASSUMING THAT THE METHANE CONTENT OF A VIRGIN SEAM IS 10
       CC/G WITH A POSSIBLE MAXIMUM VALUE OF 20 CC/G LOCALLY.

4.4.1.9 <u>Water</u>. Water seepage into the coal mine can also be a problem. Flows of up to 100 gal/min are encountered occasionally in Appalachia. As a result, equipment must be designed to operate with water on the floor. Many continuous miners and shuttle cars routinely operate in 8 to 12 in. of water and mud.

M.9   <u>Water Seepage</u>: THE SYSTEM SHALL BE CAPABLE OF ROUTINE OPERATION IN UP TO 12 IN. OF STANDING WATER AND SHALL BE CAPABLE OF HANDLING OCCASIONAL UNDERGROUND SPRINGS (ONCE EVERY 5000 FT OF ADVANCE) WITH A FLOW RATE OF 100 GAL/MIN.

4.4.2   Coal Price

A detailed economic model consisting of regional coal resources, mining costs, market structure, and transportation costs was developed by Terasawa and Whipple (1980) to determine the target price for Appalachian coal in the year 2000. In terms of constant 1980 dollars, they estimate the price of low sulfur coal to be $33.00 per ton, F.O.B. mine; higher sulfur coal would fetch correspondingly lower prices. Because it places an upper bound on the revenue generated by the system, price becomes an important design requirement.

M.10   <u>Coal Price</u>: THE TARGET PRICE FOR STEAM COAL PRODUCED IN CENTRAL APPALACHIA IN THE YEAR 2000 WILL BE $33.00 PER TON, MEASURED IN CONSTANT 1980 DOLLARS, FOR COAL CONTAINING LESS THAN 2% SULFUR. ALL OF THE PRODUCTION COST REQUIREMENTS (SECTION 4.6) MUST BE MET IN TERMS OF THIS TARGET PRICE.

4.4.3   Utilities and Services

Water resources of Central Appalachia are quite plentiful. Well logs from the area show (P. J. Sullivan, 1981) that the flow rates range from 30-70 gal/min on hilltops, to 300-500 gal/min for wells drilled in alluvial valley floors. Additional quantities of water are available from streams in the alluvial valleys. On the basis of this information, a conservative value of 50 gal/ton of coal is recommended as the minimum available quantity of water.

Electric power from coal fired plants is readily obtainable in this area. Starting a new mining project may require a power company to install new transmission lines, the cost for which is site-specific. Accordingly, the designer needs to estimate only the cost of the substation at the mine property. The cost of electric power in the year 2000 has been projected by Bickerton and Westerfield (1981) at 0.035 $/kWh, in constant 1980 dollars.

The situation with respect to roads and railway access is analogous. Certainly, some new roads and possibly a rail line extension would be constructed to service a new mine. However, prior to selection of a particular site, the designer should be concerned with only approximate costs of road construction and the railway loading facilities on the mining property, unless the characteristics of the system require material expenditures on these facilities.

The cost of telephone service must be considered in determining total mine operating costs. Certain designs may require other special communications equipment, which the designer must specify.

Mines of the future will most likely employ extensive data networks for sensing, monitoring, and controlling various functions within the system. This network, in addition to interpersonal communication, is expected to contribute to the productivity and safety. This command-control network must be interpreted with the mine management system described later. The designer should study the two areas together in formulating needs for special communication equipment.

M.11   Utilities and Services: THE DESIGN SHALL REFLECT BOTH THE CAPITAL AND OPERATING COSTS OF SUPPLYING THE MINE SITE WITH ALL NECESSARY UTILITIES AND SERVICES, INCLUDING ELECTRIC POWER, WATER, ROADS, RAIL, AND TELEPHONE SERVICE.

4.4.4   Labor Pool Characteristics

Central Appalachia has a large labor force possessing the required mechanical skills and a longstanding coal mining tradition. The average educational level of the mine labor population in this area is low, with only 50% graduating from high school (Akin, 1981a). However, by the year 2000, many more high school and college graduates are expected to be available. Currently, many foremen and other underground workers are attending special courses at mines or at local community colleges. Thus, a small, but growing, number of highly trained technicians are available to work in sophisticated technologies such as advanced electronics, laser surveying, and so on. It is reasonable to expect that these trends will continue.

M.12   Labor Characteristics: THE DESIGN SHALL SPECIFY THE EDUCATIONAL PROFILE OF THE LABOR NEEDED FOR ROUTINE OPERATION OF THE SYSTEM, SHOWING THE NUMBER AND TYPE OF EACH SPECIALTY NEEDED, AND PROJECTING THE COST OF ANY ON-THE-JOB TRAINING REQUIRED FOR SYSTEM STARTUP AND ROUTINE OPERATION.

4.5   MINE SIZE

A survey of mine size showed that West Virginia, Tennessee, and Eastern Kentucky together have 75% of all underground coal mines in the country, and yet the region accounts for only 53% of the total underground coal production. This means that the mines in the region are relatively small, typically producing about 125,000 to 150,000 tons/yr. The mine size ranges from single section mines producing less than 50,000 tons/yr and employing only about twenty persons, to large mines producing over a million tons and employing twenty times more people.

Goldsmith and Lavin (1980) found that although there are many small mines operating in the area, the ownership of these mines is concentrated. On the average, a mine operator owns about 4.3 mines, accounting for an aggregate annual production of about half a million tons. Approximately 75% of these mines are owned by well-financed corporations.

Future trends are difficult to predict with certainty. A survey of plans for new mines and expansions of existing mines, reported by Nielsen (1981) indicated the average capacity of these mines will be 940,000 tons/yr (Table 4-4). A recent article from The Wall Street Journal (Petzinger, 1981) corroborates the trend to ownership of coal mines by large companies, and asserts that the small operator may be on the way out.

Table 4-4. Planned Capacity of New Mines and Expansions of Existing Mines During the Period 1978-1988

Source: Nielsen (1981)

State	Deep Mine Capacity (Million Tons)	No. of Deep Mines
Kentucky East	22	26
Kentucky West	3	2
West Virginia (N)	5	3
West Virginia (S)	33	36
Total	63	67

These two sets of data, both factual, suggest that small mines will continue to contribute significantly to Central Appalachian coal production over the next 20 years. However, the fraction of tonnage coming from larger mines is expected to increase with time.

Mine size is determined by market demand for coal, sales contract, property size, type of resource, transportation capacity, operating efficiency, availability of labor, and many other factors. Under the same operating conditions, unit mining costs decrease as production increases. Therefore, it is clear that small and large mines do not operate under the same conditions. Some of the differences are discussed below.

Smaller mines cannot afford to build deep shafts, perform extensive underground construction, and use costly longwall type equipment. Mines producing less than 150,000 tons/yr, tend to be drift mines using either conventional or continuous mining equipment. A survey of about twenty mines showed that these mines invested about $18 per ton of annual capacity and employed about 75 persons at the mine site.

By contrast, larger mines, producing over a million tons per year, have a sizeable network of underground openings and a considerable amount of other construction. Seam access, depending upon the location and the depth of the seam, may either be drift or shaft. These mines use continuous miners, longwalls, and sometimes conventional equipment. Toth (1981) indicates that a typical 1.0 million tons/yr longwall mine invests close to $44 per ton of annual capacity and employs 360 persons.

There is, however, a limit to economies of scale. Since operating efficiency is a very important consideration, large mine operators (Gangal, 1981a) consider five to seven sections as optimum. The preferred combination appears to be a mine with two longwalls and about five supporting continuous miner sections. Total output of this combination is between one and two million tons per year. As the operation expands beyond the indicated optimum number of sections, the coordination between operating units deteriorates, supply lines and logistics networks become strained, and the operating efficiency declines. Moreover, a strike, a serious accident, or other extensive interruptions are quite troublesome to an operator committed to supply under long-term contracts. Consequently, mines larger than two million tons are rarely seen in Central Appalachia.

An advanced system may have totally different characteristics: some systems are suitable only for small mines, others for large mines, and still others, for both small and large mines. The requirement on mine size recognizes the need for two different scales of operation.

M.13   Mine Size: THE MINING SYSTEM EITHER SHALL BE SIZED FOR 150,000 TONS/YR OR 1,000,000 TONS/YR OF CLEAN COAL, ASSUMING THREE-SHIFT OPERATION AND 220 WORKING DAYS PER YEAR.

Size Variation: WHATEVER MINE SIZE IS SELECTED, THE DESIGN MUST SHOW HOW THE RATE OF RETURN ON TOTAL INVESTMENT VARIES WITH AN ANNUAL PRODUCTION CAPACITY RANGING BETWEEN 100,000 AND 2,000,000 TONS/YR.

Retrofit: SINCE RETROFIT CAPABILITY IS HIGHLY DESIRABLE, THE DESIGN SHALL SPECIFY UNDER WHAT CONDITIONS IT WILL BE POSSIBLE TO USE THE NEW SYSTEM IN EXISTING MINES.

4.6   PRODUCTION COST REQUIREMENTS

The acceptance of an advanced mining system will depend largely upon the economic benefits which accrue to the mine operator or owner. Examination of the underground mining industry's acceptance of previous equipment innovations, together with general considerations of dealing with economic risk led to the following statement of the systems level requirement:

Any advanced mining system which is a serious candidate for development as a commercially attractive means of extracting a specified resource, must show promise of yielding a return on incremental investment of at least 1.5 to 2.5 times the minimum target Return on Investment (ROI) required by the industry for its average capacity expansion or replacement project at the projected time of first commercial use.

Recently, the target return on investment (ROI) for a normal capital project (e.g. refurbishing a section with the latest in proven mining equipment) is about 15%, after taxes. Thus, in the current economic environment, the minimum target return on incremental investment would be 22 to 37%, depending upon the degree of risk.

4.6.1 Selection of a Design Goal

In translating the ROI goal into design requirements for production cost, one begins by recognizing that underground coal mining belongs to a generic class of industry for which the meaningful cost factors are capital, labor, expendables, and annual capability. As shown in Appendix A, it is a straightforward matter to translate the system performance goal into a set of feasible combinations of investment per annual ton, labor productivity, and consumables per ton.

To provide a meaningful focus for design, one must develop quantitative goals for one or more of these factors, or their equivalent. Microeconomics provides one approach for setting goals, but requires specification of a production function. Such an approach embodies the implicit assumption that advanced technology will have a capital/labor/expendables structure not very different from today's technology. Since the results of such an analysis would be unduly restrictive, a more heuristic approach to goal setting was employed.

The point of departure for the heuristic approach was the selection of an output-input ratio as the measure of cost performance. For a number of reasons, the productivity of all the personnel at the mine site was the measure chosen:

(1)   It is a widely accepted measure of industrial efficiency.

(2)   It provides a clear incentive for additional mechanization and automation where appropriate, this being the traditional avenue of technological progress.

(3)   It encourages the designer to impact the core mining functions via the more effective use of the entire mine labor force, together with structural options that promise higher equipment utilization.

(4)   It contributes directly to the system performance goal of reduced deaths and disabilities per ton.

(5)   It is easy to convert into an operational performance measure, usable by all involved in system design and development.

Determination of a quantitative goal for labor productivity is based on the idea that the performance of an advanced system should be substantially better than the performance of contemporary technology projected twenty years into the future. The year 2000 baseline, summarized in Table 4-5, was obtained from Bickerton and Westerfield (1981), by adjusting output for operation in a 50-in. seam. A productivity goal for an advanced system was set by requiring a separation of two standard deviations from the year 2000

ORIGINAL PAGE IS
OF POOR QUALITY

baseline. The resultant goal of 32 clean tons per man-day implies a 99% probability that the new system be clearly superior to the weighted average performance of evolutionary room and pillar, and longwall technology. Note that a goal of 32 tons equates to a fourfold increase over 1980 underground productivity, and is double the 1969 peak of 16 tons.

Table 4-5. Extrapolated Technologies Operating Under Average Conditions in a 50-in. Seam in the Year 2000

	Room and Pillar	Longwall	Shortwall
Raw Annual Capacity (tons)	1,026,700	1,283,300	1,031,250
Total Personnel	313	364	329
Raw Tons/Man-Day	14.9	16.0	14.2

Source: Bickerton and Westerfield (1981)

In view of the above discussion, the production cost requirement has two components, both mandatory. The first requirement instructs the designer to perform a cost analysis as evidence of the system's ability to meet the goal of 22% return on incremental investment. This requirement assures the commercial viability of the system; however, it could be satisfied, in theory, by rather modest changes in system structure. The second requirement was formulated to force fundamental technological change by setting a goal for total labor productivity of 32 tons per man-day, a level of performance judged difficult to attain via straightforward extrapolation of contemporary equipment and its application.

M.14   Cost Analysis: THE SYSTEM SHALL ACHIEVE AN AFTER TAX, INTERNAL RATE OF RETURN EXCEEDING 22% ON INCREMENTAL INVESTMENT. INCREMENTAL INVESTMENT WILL BE DETERMINED BY COMPARING THE SYSTEM WITH THE APPROPRIATE YEAR 2000 EVOLUTIONARY SYSTEM OPERATING IN AVERAGE CONDITIONS, AS DESCRIBED BY BICKERTON AND WESTERFIELD (1981). The cost estimates shall include the following:

(a)   Equipment list and prices.
(b)   List of major construction items.
(c)   Tabulation of initial capital investment.
(d)   Capital expenditures during the life of the mine.
(e)   Manning tables, wage rates, and manpower costs applicable in the year 1980, using the Bituminous Coal Wage Agreement.
(f)   Table of expendables showing the cost estimates for parts, utilities, royalties, and other tonnage-related costs.
(g)   A summary of annual operating costs.
(h)   Environmental costs including mine closure and land rehabilitation.
(i)   The final computation showing the rate of return.

Assumptions: The following assumptions shall be made in the analysis:

(a) All costs are to be in constant 1980 dollars.
(b) Land is acquired via option-lease with $0.50/ton royalty fee.
(c) All equipment is purchased and not leased.
(d) Investment tax credits, depletion allowances and depreciation rates must be consistent with 1980 IRS regulations.
(e) Prices of nonexisting equipment are to be estimated in terms of 1980 dollars assuming commercial scale production (prototype costs are much higher and should not be used in the analysis).
(f) The designer may have to make additional assumptions. He must state them clearly and justify that they are reasonable.

Procedures: The designer may choose to follow the general economic analysis procedures used either in EPRI/NUS cost model (Toth, 1981) or the ADAMS model developed by Ketron Inc. (Kohler, 1981). Alternately, another well publicized coal mine cost model may be used provided it is referenced properly.

M.15   Productivity Design Goal: THE PRODUCTIVITY OF THE SYSTEM SHALL BE AT LEAST 32 TONS OF CLEAN COAL PER MAN-SHIFT BASED ON THE TOTAL MINE PAYROLL AND STANDARD EIGHT-HOUR SHIFTS, AVERAGED OVER THE PRODUCTIVE PHASE OF THE MINE LIFE, ASSUMING OPERATION IN A NOMINAL 50-IN. SEAM WITH A REJECT RATE OF 25%. THE PRODUCTIVE PHASE OF MINE LIFE BEGINS WITH INITIAL DEVELOPMENT AND ENDS WHEN THE LAST PRODUCING SECTION CEASES OPERATION. PRODUCT QUALITY MUST MEET OR EXCEED THE SPECIFICATIONS FOR WASTE ROCK (IN ADDITION TO INHERENT ASH) AND FREE MOISTURE (IN ADDITION TO INHERENT MOISTURE) GENERALLY REQUIRED FOR BOILER FUELS IN THE CENTRAL APPALACHIAN REGION IN 1981. UNLESS ALTERNATIVE VALUES CAN BE JUSTIFIED, WASTE ROCK MUST BE 5% OR LESS BY WEIGHT, AND FREE MOISTURE MUST BE 6% OR LESS.

Exception: SOME BENEFICIATION SCHEMES MAY PRODUCE WATER-BASED COAL JEL AND, THEREFORE, WOULD NOT MEET THE 6% MOISTURE REQUIREMENT. IN SUCH CASES THE ECONOMIC COMPUTATIONS SHALL USE AN EQUIVALENT COST DETERMINED ON THE BASIS OF NET HEAT AVAILABLE.

Clarification: The system performance goal, which requires a return on incremental investment equal to 1.5 times the return projected for a low risk capital project in the year 2000, must be satisfied in order for a system to be acceptable to the industry. Requirement M.15 has been set to discriminate truly advanced systems from those which have merely an attractive return on incremental investment. In other words, compliance with both the system performance goal and requirement M.15 is mandatory for a system to be regarded as advanced in the area of production cost.

Any further mandatory specifications about economic parameters would tend to tie the designer too closely to existing systems. To encourage creative solutions, he must be given the greatest possible freedom in selecting and configuring his system. Figure 4-3 identifies four generic approaches that contribute to the overall goal of achieving a higher rate of return on investment:
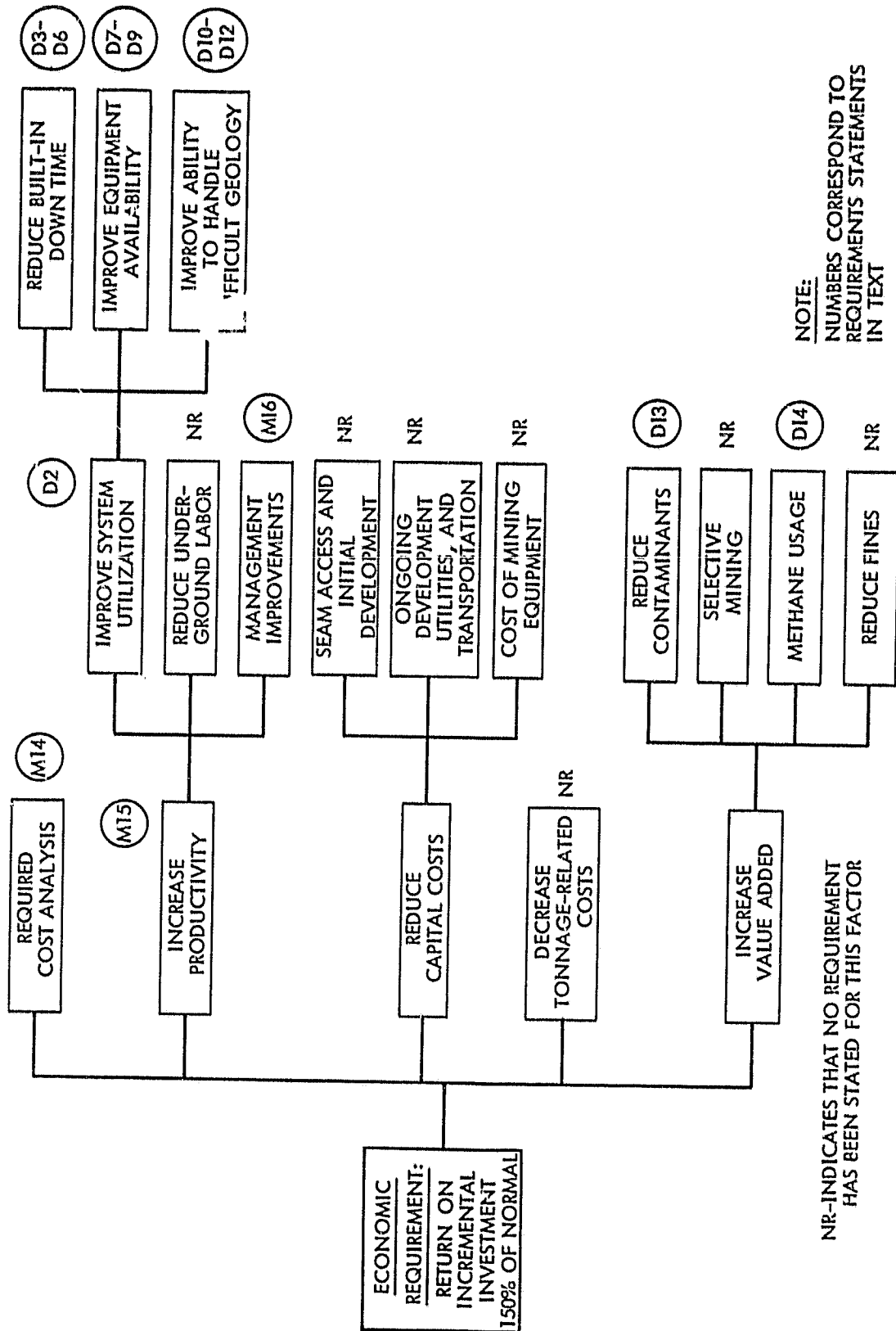
Figure 4-3. Overview of Production Cost Requirements

NR-INDICATES THAT NO REQUIREMENT
HAS BEEN STATED FOR THIS FACTOR

NOTE:
NUMBERS CORRESPOND TO
REQUIREMENTS STATEMENTS
IN TEXT

ORIGINAL PAGE IS
OF POOR QUALITY

(1) Increased productivity (for which a mandatory design goal has been set).

(2) Reduced capital costs.

(3) Reduced expendables costs.

(4) Increased value added to the product.

All of the approaches are discussed below in terms of "desirable characteristics" of the system. The designer should choose items from this "menu" as appropriate.

4.6.2 Increased Productivity

A variety of factors can contribute to increased productivity. Logically, they fall into four groups: (1) increased uprate, (2) increased system utilization, (3) reduction of underground personnel, and (4) management improvements. Uprate, that is, the mining rate while the system is excavating and transporting coal, is very system-specific, and thus, is not translatable into even a desirable performance level. Desirable design goals can, however, be set for the remaining three contributors to productivity.

System utilization is defined as the fraction of the total work time that the system is producing coal. Thus, utilization considers time lost due to maintenance and repair, difficult geology, safety checks, etc., as well as idle time due to set-ups, moves, and queued equipment. Although we have seen no published data on system utilization, studies of downtime, together with descriptions of industry maintenance practice indicate that utilization is currently very low -- probably no higher than 20 to 25% at best.

There have been several studies of both equipment and system availability, where availability is defined as the fraction of total shift time that the system (or piece of equipment) is ready to function. Thus, equipment moves, set-ups, and other forced idleness is counted as available time. A detailed study of 46 continuous miner sections by Marrus et al (1976) indicated a section availability of 38%, which leaves ample room for improvement. Because system availability is relevant to, but more easily estimated than system utilization, we will recommend a target for availability, and in addition, suggest ways of improving utilization.

4.6.2.1 <u>System Availability</u>. It is our judgment that routine maintenance of section equipment can be performed between shifts and that the time lost due to extended maintenance and/or repair of failed equipment should average no more than 30 min per shift, or about one shift out of fifteen for each section. Since the time between shifts, including shift change and lunch averages about two hours, it is reasonable to set a goal of 330 min of available time out of an 8-hr shift for each section. Since sections occasionally are idled because of problems with main line haulage, mine power supply, or other events beyond the section's control, it is prudent to set a system availability goal somewhat lower than 5 1/2 hours per 8-hr shift. This leads to the following requirement.

D.2   System Availability: IT IS HIGHLY DESIRABLE THAT THE SYSTEM HAVE A
       SYSTEM AVAILABILITY (AS DISTINGUISHED FROM SECTION AVAILABILITY) OF
       AT LEAST 65% OF THE SHIFT TIME, AVERAGED OVER TWELVE MONTHS OF
       OPERATION. Whether or not the design meets this requirement, the
       design must include a computation of system availability, noting key
       assumptions.

       The remainder of the discussion of improved productivity considers
desirable (not mandatory) ways of improving overall system utilization by (1)
reducing set-ups, moves, and other built-in idle time; (2) improving the
availability of individual pieces of equipment; and (3) enhancing the system's
ability to deal with difficult geology.

Reduction of Set-ups, Moves, and Other Built-in Idle Time

       The most obvious problem with present mining systems is the
substantial amount of downtime that is built into the operating structure (see
the discussion of cycles in Section 2.3). For example, a continuous miner is
capable of producing 6 tons of coal per minute; however, the net output is
less than one ton a minute, averaged over a shift. The principal sources of
built-in downtime are: (1) the use of discontinuous unit mining operations,
(2) the mismatch between equipment move cycles and planned downtime for
maintenance and logistical support and, (3) the use of unit operations in
series, which gives rise to queueing and consequent idle time. The
possibility of eliminating these inefficiencies leads to several
characteristics desirable in an advanced system.

       Both continuous miner and longwall equipment would be much more
productive if the technology permitted each of the unit operations to be
continuous. The continuous miner and longwall shearer each lose a significant
amount of time in a cutting cycle due to repositioning the cutting drum(s),
checking bits, cleaning up, etc. The unit operation of roof bolting exhibits
similar inefficiencies in repositioning the bolting machine, inserting and
removing drill steel, and preparing bolts for insertion. Finally, an
important source of continuous miner inefficiency is the need to stop
excavating in order to wait for the arrival of a shuttle car. In sum,
continuous unit operations appear to be a very attractive means of increasing
system productivity.

D.3   Continuous Unit Operations: IT IS HIGHLY DESIRABLE THAT THE UNIT
       OPERATIONS OF THE SYSTEM BE CONFIGURED TO PERMIT A CONTINUOUS FLOW OF
       COAL FROM FACE TO PORTAL (OR STORAGE BUNKER), INTERRUPTED ONLY BY
       MAJOR EQUIPMENT MOVES.

       Continuous mining and longwall systems each have the capability to
effect continuous haulage away from the cutting machine, with this being a key
feature of the longwall system (although commercially available now, bridge
conveyors and similar devices are not widely used because they can slow down
the entire mining cycle if improperly handled). As effective as such
equipment can be when running smoothly, observation of continuous haulage in
both longwall and continuous miner applications revealed a common set of
problems: lack of control over product size and/or poorly engineered transfer
points can jam the equipment, causing costly downtime. These problems suggest
the following requirement:

D.4   Disciplined Materials Flow: IF THE SYSTEM UTILIZES TECHNOLOGY FOR
        CONTINUOUS MATERIALS HANDLING, IT IS DESIRABLE (1) THAT THE SYSTEM
        MAINTAIN POSITIVE CONTROL OVER MATERIAL SIZE, AND (2) THAT THE
        CHANGES IN DIRECTION OF THE FLOW BE ENGINEERED TO ENSURE A SMOOTH
        TRANSITION FOR THE WORST COMBINATION OF SPEED, LOADING, AND MATERIAL
        SIZE.

        Comparison of equipment move cycles with planned downtime for
maintenance, resupply, and equipment rebuild/replacement reveals a substantial
mismatch with a resulting loss of operating time. Currently the continuous
miner moves several times a shift. If the technology permitted the miner to
cut continuously (without a place change, change in direction, or other
significant move) for some multiple of the working shift, the time between
shifts could be used for maintenance, resupply, and moves, thus reducing
non-productive time. Similarly, if the longwall were redesigned to permit
maintenance of major components like the conveyor and shearer over a weekend,
this machine could, in theory, operate continuously, given a mining plan which
does not require moves from one panel to another. These ideas give rise to
the following requirement:

D.5   Matching Equipment Moves with Planned Downtime: IT IS HIGHLY
        DESIRABLE THAT THE SYSTEM BE DESIGNED SO THAT EQUIPMENT MOVE CYCLES
        COINCIDE WITH CYCLES OF PLANNED DOWNTIME FOR SHIFT CHANGE,
        MAINTENANCE, RESUPPLY, ETC.

        From the viewpoint of the product, the mining process is serial in
nature. The material is first broken from the face, mucked into the transport
system, and then conveyed out of the pit. Current continuous mining
technology interposes roof support as an essential element of the serial
process, whereas longwall permits roof control in parallel with the continuous
excavation and haulage operations. It is clear that any system which requires
the completion of one unit operation (excavation) before another can begin
(roof support) will lead to idle time caused by queueing since the usual
variability in conditions will not permit a perfect match of cycle times.
Accordingly, we suggest the following:

D.6   Parallel Unit Operations: IT IS HIGHLY DESIRABLE THAT THE SYSTEM
        EMBODY PARALLEL UNIT OPERATIONS FOR EXCAVATION, TRANSPORT, AND GROUND
        CONTROL WITH RESPECT TO EACH WORKING FACE; I.E., SERIAL OPERATION ON
        A WORKING FACE IS HIGHLY UNDESIRABLE.

Improvement of Equipment Availability

        Within a unit operation, equipment availability is an important
determinant of system utilization, and consequently, productivity.
Underground mining equipment must work in a punishing environment which is not
very favorable to routine maintenance. Thus, it is no surprise that poor
reliability and maintainability of the mining equipment have been singled out
as important factors holding down productivity. According to Marrus et al.
(1976) equipment availability for the continuous miner is approximately 73%.
However, under the best conditions, 95% availability can be achieved from the
same machines. There is no reason why advanced equipment should not be able
to do as well as the best machines available today.

D.7   <u>Equipment Availability</u>: IT IS DESIRABLE THAT INDIVIDUAL PIECES OF EQUIPMENT USED IN THE CRUCIAL UNIT OPERATIONS OF THE SYSTEM, EACH HAVE AN AVAILABILITY OF 95%, WHEN OPERATED UNDER A PREVENTATIVE MAINTENANCE POLICY WHICH PERMITS TWO HOURS OF ROUTINE MAINTENANCE BETWEEN WORKING SHIFTS, AND EIGHT HOURS OF EXTENDED MAINTENANCE EVERY FIFTEEN SHIFTS.

Currently the continuous miner has a reliability of 1400 mean tons between failures, a mean time between failures of 3.73 shifts, and a mean corrective time of 2.2 hours per failure. Because of the mathematical relationship between equipment availability, mean time to failure, and mean time to repair, one cannot specify independent goals for these three factors. We prefer to set a goal for mean time to failure because the mean time to repair is equipment-specific. Current section equipment experiences about four failures every fifteen working shifts (or four failures per week for mines which have three production shifts a day, five days a week). Thus, in keeping with the fourfold improvement in productivity, it is desirable to reduce the incidence of failures to one every fifteen shifts.

D.8   <u>Mean Time to Failure</u>: IT IS DESIRABLE THAT INDIVIDUAL PIECES OF EQUIPMENT USED IN THE CRUCIAL UNIT OPERATIONS OF THE SYSTEM EACH HAVE A MEAN TIME TO FAILURE NO LESS THAN 120 HOURS WHEN OPERATED UNDER THE MAINTENANCE POLICY DESCRIBED IN REQUIREMENT D.7.

Because of the serial nature of the mining process described above, the failure of one machine very quickly idles an entire continuous miner or longwall section. Drill and blast technology is a bit different because of the slack provided by the larger number of unit operations. As a result, a drill and blast section can continue to function for perhaps half an hour after one piece of equipment goes down. This capability for degraded operation is a very desirable characteristic to have in an advanced mining system. Somewhat arbitarily, we shall set a design goal of operation at 50% of design capacity in the event of a failed component in one piece of mining equipment.

D.9   <u>Degraded Operation</u>: REDUNDANCY SHOULD BE INCORPORATED INTO THE DESIGN AT EVERY LEVEL POSSIBLE. IT IS DESIRABLE THAT THE SYSTEM SUSTAIN PRODUCTION AT 50% CAPACITY EVEN WHEN A SUBSYSTEM FAILS (AT LEAST DOUBLY REDUNDANT DESIGN WHENEVER POSSIBLE).

In conceptualizing equipment that will meet the above goals for equipment availability, the designer should give serious consideration to abuse-tolerant design, modularity, and redundancy. In <u>abuse-tolerant design</u>, one selects structural concepts and materials which will permit the mining equipment to cope with impacts from falling rock, ribs and other equipment; standing water and mud; an atmosphere containing abrasive dust; and the likelihood that the equipment will not be maintained as meticulously as the manufacturer had planned. <u>Modularity</u> refers to the idea of designing equipment so that defective components can be removed and replaced rapidly with an entirely new component if necessary. Thus, diagnosis need only go as far as identifying which module has failed; repair of a defective module can then be done deliberately in a clean, well-equipped work area. Modularity is also relevant to the desirability of quickly adapting equipment to changing mining conditions, such as, the need to cut through a parting. <u>Redundancy</u> refers to the idea of designing equipment so that key components such as

pumps, motors, or hydraulic lines are immediately backstopped by a partner in the event of failure. Fault tolerant design has been used extensively in many fields and could be profitably examined for its applicability to mining.

Improved Ability to Cope with Difficult Mining Conditions

Current exploration techniques produce rather limited data on buried coals. In preparation for mine planning, data on seam variations; roof and floor quality; Btu value; ash and sulfur content; etc. are obtained from boreholes spaced 1,000 to 5,000 ft apart. More detailed information on conditions accumulates as the mains, submains, and production entries are driven out from the access point. As a result, the section foreman often has no warning of difficult geology until it is practically confronting him. Examples of difficult geology include a sudden deterioration of the roof or floor; seam dislocations caused by a faulting; washouts, partings, sulfur balls, and other rock inclusions; gas pockets and unmapped gas wells; breach of an aquifer, etc. There are two strategies for dealing with sudden changes in conditions, and each is relevant to the design of an advanced system. The first strategy emphasizes getting more detailed information, farther in advance of mining; the second focuses on rapidly adapting to conditions as they are uncovered.

Presently, seismic techniques for surface exploration are in limited use, and radar techniques for probing into the coal face are in the research stage (Fowler, 1979). It is reasonable to expect that these and other techniques will be available to the mining industry in the future. Accordingly, the following desirable characteristics are offered for the designer's consideration.

D.10   Surface Exploration: IN SUPPORT OF MORE EFFECTIVE MINE PLANNING, IT IS DESIRABLE THAT THE SYSTEM BE PROVIDED WITH SURFACE EXPLORATION TECHNIQUES THAT ARE CAPABLE OF (1) DETERMINING THE THICKNESS AND PROPERTIES OF A COAL SEAM AND SURROUNDING ROCK, AND (2), DEFINING MAJOR ANOMALIES WITHIN THE SEAM. If such a capability is incorporated into the system, the design must describe its approximate configuration, estimate its precision of measurement, and project costs of usage.

D.11   In-Seam Exploration: IN SUPPORT OF OPERATIONAL PLANNING, IT IS DESIRABLE THAT THE SYSTEM BE ABLE TO IDENTIFY AND DESCRIBE CONDITIONS FAR ENOUGH IN ADVANCE OF THE FACE (OR RIB) TO PERMIT DEVELOPING A SOLUTION TO AN IMPENDING PROBLEM. THUS, THE LOOK-AHEAD DISTANCE MUST CONSIDER THE ADVANCE RATE OF THE FACE, TOGETHER WITH THE TIME NEEDED TO ADAPT TO CHANGED CONDITIONS (SEE REQUIREMENT D.12). ROOF AND FLOOR ROLLS, FAULTS, SPLITS, WASHOUTS, LARGE SULFUR BALLS, AND GAS POCKETS ARE OF PARTICULAR INTEREST. If incorporated into the system, the performance and cost of an in-seam exploration capability are to be projected as in Requirement D.10.

It would be very helpful for the mine planner and operator to have at his disposal the kind of information specified in requirements D.10 and D.11. However, it may not be technically or economically feasible to develop such a capabilty, or the scheme developed may be only partially effective. Thus, an ability to rapidly reconfigure the system to adapt to changed conditions will be valuable in any event.

ORIGINAL PAGE IS OF POOR QUALITY

D.12   Rapid Reconfiguration of Mining Equipment: IT IS HIGHLY DESIRABLE
        THAT THE MINING EQUIPMENT USED BY THE SYSTEM HAVE THE CAPABILITY OF
        BEING RAPIDLY RECONFIGURED TO COPE WITH SUDDEN CHANGES IN MINING
        CONDITIONS. IT IS SUGGESTED THAT THE TIME TO RECONFIGURE REQUIRE NO
        MORE THAN ONE HOUR IN NORMAL CIRCUMSTANCES.

4.6.2.2 Reduction in Underground Personnel. Because productivity is the
ratio of output to personnel, and because the underground component
constitutes the bulk of the work force, it is logical to consider reduced
manning as a way to improve productivity. At first glance, automation appears
to promise exactly this result. In industries where automation has gone so
far as to use robots extensively, substantial reductions have been possible
(e.g. the auto industry's recent experience in automated assembly of complete
vehicles). However, in the early stages of automation, it has generally been
true that the capability of the individual worker has been enhanced
considerably, but the work force shrinks very little. Thus, in view of the
nascent state of automation in mining, it is not reasonable to expect
substantial reductions in the work force.

       Reductions due to automation become even more implausible when one
recognizes that the logical target of automation is the face operation which
typically constitutes less than 1/3 of the total work force for the medium to
large mine (Lynn, 1980). Indeed, Bickerton and Westerfield (1981) project
that evolutionary continuous miner and longwall technology in the year 2000
will require three to four people in support for every person at the face.
Thus, a very substantial reduction in the face labor force would have only a
modest impact on the total mine work force, and consequently on mine
productivity.

       The sheer bulk of the labor force devoted to production support
activity suggests that reduction in this component of mine labor be an
important objective of the system designer. But because the relative
proportions of production, and production support personnel are likely to be
system-specific, a quantitative design goal in this area is not appropriate.

4.6.2.3 Management Improvements. Studies of the underground workplace by
Hill (1980) and Davis (1977) indicate that management can have considerable
impact upon the effectiveness with which a technology is applied. Many
factors are involved, including worker training and experience, quality of
first level supervision, wage incentives, work group structure, degree of
trust between management and labor, etc. Although previous research on these
factors has been rather limited, a recent field study by Akin (1981) draws
some interesting conclusions about the interaction between the psycho-social
environment and the technology of mining. Findings of potential interest to
the designer are summarized in Appendix B.

       Although the designer must have a broad appreciation for the
constraints the technology imposes on the workplace (see Trist and Bamforth
(1951), for a chronicle of misapplied underground technology), the scope of
this project is limited to the management tools which should properly be a
part of an advanced system. A list of the principal mine management
functions, together with needed information and tools is presented in
Table 4-6.

ORIGINAL PAGE IS
          OF POOR QUALITY

Many of the tools identified in Table 4-6 are available commercially (Brezovec, 1980; Coal Age, October 1980; Minetics, 1980), while others are being developed under the sponsorship of the Department of Energy, the Bureau of Mines, and private companies. An effort to combine all the necessary elements into a comprehensive system would provide a very valuable adjunct to an advanced system, and should be a fairly straightforward task.

Table 4-6. A Partial List of Functions of the Mine
Management System in a Large Mine*

1. Planning:

    Inputs: Initial exploration, in-seam exploration, surveys of product demand, sensor data, inventory data.

    Output: Overall plan; daily, weekly and monthly schedules; manpower loading projections; charts; maps; preventative maintenance schedules; transport schedules.

2. Operations:

    Inputs: Planning schedules, foreman reports, shop report, maintenance reports, supply depot reports, production reports, quality control lab reports, equipment breakdown reports.

    Output: Personnel assignments, machine assignments, problems, alerts, purchase orders, payroll, periodic production summaries, health and safety reports, instructions and commands to staff.

3. Communications and Control:

    Inputs: Planning, operations, laboratory reports, customer reports, parts lists, prices, company management instructions, time studies, health and safety audits.

    Outputs: Instructions for plan changes, communications to production management, purchase approvals, cost reports to management, inventory control, health and safety instructions, training instructions, procedural manuals, equipment purchase decisions.

*Smaller mines perform many of the same functions on an informal basis.

M.16   Mine Management System: IT IS MANDATED THAT A COMPREHENSIVE MINE
MANAGEMENT SYSTEM SUPPORTING THE PLANNING, OPERATIONS, AND
COMMUNICATIONS NEEDS IDENTIFIED IN TABLE 4-6, BE A PART OF THE
SYSTEM. THE DESIGN OF A MINE MANAGEMENT SYSTEM MUST DESCRIBE
NECESSARY HARDWARE, SOFTWARE AND COMMUNICATION FACILITIES, AND MUST
PROVIDE ESTIMATES FOR CAPITAL AND OPERATING COSTS.

4.6.3   Reduced Capital Costs

        Mining costs can also be improved by reducing capital-related costs,
especially the costs of the following major capital expenditures:

    (1)   Seam access and initial development.

    (2)   Ongoing development.

    (2)   Underground transport and utility installations.

    (3)   Mining Equipment.

        A number of suggestions are made below about approaches for cost
reductions in each case. It is recommended that the designer review these and
implement as many improvements as practicable.

        The mandatory productivity goal would, most likely, be achieved by
increasing capital expenditures. Thus, specific requirements relating to
capital costs are not formulated. Naturally, the designer must look at life
cycle costs to ensure that the ROI requirement stated earlier is met.

4.6.3.1 Seam Access and Initial Development. Table A-1 in Appendix A
indicates that seam access and initial development contribute less than 10% to
the cost of mining coal. Reduction in the costs of shaft sinking, shaft
lining, optimum design of openings, etc., would produce proportional cost
benefits; a 10% reduction in capital cost will result in about a 1% reduction
in cost of coal.

        Another approach to reduce capital cost contribution is to speed up
the processes of shaft sinking (seam access) and initial development so that
the mine begins to produce coal earlier. Additional analysis of a model room
and pillar mine studied by Bickerton and Westerfield (1981) indicates that
faster shaft sinking and faster initial development can be economically
beneficial even with slight increases in cost. The actual amount of economic
benefit is too mine-specific to be useful in conceptual design. Therefore, no
formal requirement is proposed.

4.6.3.2 Ongoing Development Work and the Costs of Utilities and Transport.
Full-scale production from each panel requires a considerable amount of
development work. For example, longwall panel development requires two to
three continuous miner sections per longwall section. If panel development

ORIGINAL PAGE IS
         OF POOR QUALITY

work is reduced, only one or two continuous miner sections will be sufficient, thus reducing the capital and operating costs. Reductions in entry sizes and the number of entries per panel are classical examples of this approach.

The cost of transport and utility installations are also strongly dependent upon the mine layout. It may be possible to reduce these costs by reducing the lengths of permanent underground openings, and by properly proportioning production and development work. However, we can offer no quantitative guidance to the designer in this matter.

4.6.3.3 <u>Mining Equipment</u>. Although mining equipment is a very visible capital item, Goldsmith and Lavin (1980) indicate that cheaper machines would have a relatively modest impact on the minimum acceptable selling price for the product. Indeed, Table A-2, Appendix A, indicates that reducing the cost of section equipment by ten percent would have only one-tenth the impact of improving output by ten percent. Nonetheless, cheaper mining equipment is certainly a possible way to meet the production cost goal and should, therefore, be considered in any treatment of design requirements.

Unfortunately, it is not possible to give the designer a great deal of guidance in this matter. It is generally true that cost increases with weight and complexity, but lighter, simpler machines are, of course, also desirable from the standpoint of improved reliability and mobility. Perhaps the only advice to be given in cost reduction is to encourage the designer to think beyond conceptual design to visualize how the equipment will be fabricated, operated, and maintained. Fabrication cost must be addressed to some degree in compiling a list of capital items for computation of return on incremental investment. Here again, because the cost of mining equipment is quite system-specific, no design requirement is appropriate.

4.6.4   Reduced Tonnage-Related Costs

Tonnage-related costs include items such as roof bolts, cutter picks, spray nozzles, machine parts, lubricants, electric power, water, a portion of union welfare, etc. The nature and mix of these items in an advanced system may be radically different from that of the present systems. There are several strategies for reducing these costs, including the following:

(1)   Reduce the number and size of permanently supported entries.

(2)   Use improved materials and designs so that parts last longer in normal operation and are protected from overstressing.

(3)   Reduce the need for expendables.

Since these strategies are operative at subsystem and component levels, a requirement for reducing the costs of expendables and other tonnage-related costs is not justified at this stage.

Tonnage-related costs enter the life cycle costs of the mining system and are thus subject to the ROI restraints mandated earlier. The designer may

find it useful to develop trade-offs for capital costs vs. tonnage-related costs, and manpower costs vs. tonnage-related costs for his system.

4.6.5   Increased Value Added to the Product

Finally, a direct means of improving economics is to enhance product quality and, therefore, value, and to make economical use of by-products. Three design approaches for increasing product value are presented below.

Reduced Coal Contamination

There are a number of contaminants in run-of-the-mine coal. Ash in coal reduces its heating value, increases handling problems, and may cause fouling of boiler tubes. The release of sulfur compounds into the air by power plants is regulated by environmental laws and so is the emission of oxides of nitrogen. Coal combustion products also contain a large number of toxic chemicals. Thus, coal beneficiation to remove these impurities can increase the value of coal significantly. Reduction in ash and sulfur content should be stressed in any beneficiation approach.

D.13   Beneficiation: IN ADDITION TO MEETING THE PRODUCT QUALITY STANDARDS SET FOR PHYSICAL CLEANING IN REQUIREMENT M.15, IT IS HIGHLY DESIRABLE THAT THE SYSTEM INCORPORATE TECHNOLOGY FOR CHEMICAL CLEANING WHICH PERMITS THE PRODUCT TO COMPLY WITH APPLICABLE ENVIRONMENTAL STANDARDS FOR COMBUSTION PRODUCTS.

Since the cost and effectiveness of chemical cleaning together with the amount of value added to the product will determine the feasibility of complying with D.13, this requirement is listed as a desirable system characteristic.

Selective Mining: A technique which can selectively mine and segregate coal from rock strata, at or near the face, is particularly valuable because of the likelihood of favorable impacts on transportation and preparation costs. However, a quantitative requirement about selective mining and underground coal clean-up cannot be justified.

Elimination of Spillage: Knowledgeable observers state that 0.5% to 1% of the coal mined never reaches the surface due to spillage by the haulage system and to fines blowing away. If this coal is saved, it will add significantly to the net profit. Given that net profit averages about 10% of sales (Tomimatsu and Johnson, 1976), elimination of spillage may add 5 to 10% to profit! Furthermore, coal spillage increases labor costs, and contributes to unsafe working conditions. Advanced techniques such as slurry transport may eliminate spillage.

Methane Usage: Predrainage of methane ahead of mining is being practiced at some mines in Appalachia. Predrainage techniques include the use of vertical wells drilled from the surface or horizontal in-seam bleed holes; the geology of the seam dictates the method used. For example, industry sources state that the Pittsburgh seam is suitable for vertical drainage while the horizontal technique is better for the Pocahontas seam, where the overlying strata must be drained also (Lynn, 1980). A recent study by Arthur D. Little (1975) suggests that methane extraction and usage can be profitable. The safety aspects of methane drainage are obvious.

ORIGINAL PAGE IS
OF POOR QUALITY

D.14   Methane Usage: IT IS HIGHLY DESIRABLE THAT METHANE PREDRAINAGE BE
        INCORPORATED INTO THE SYSTEM AND PROVISION MADE FOR CAPTURE AND USE
        OF THIS GAS. If methane usage is incorporated into the system
        design, credits for the economic benefits must be applied to system
        costs.

        Reduced Fines: It is desirable to reduce the amount of fines in the
product because its market value is increased, and at the same time wind and
spillage losses are decreased. Fewer fines also reduce capital and operating
costs of the prep plant. A quantitative requirement, however, cannot be
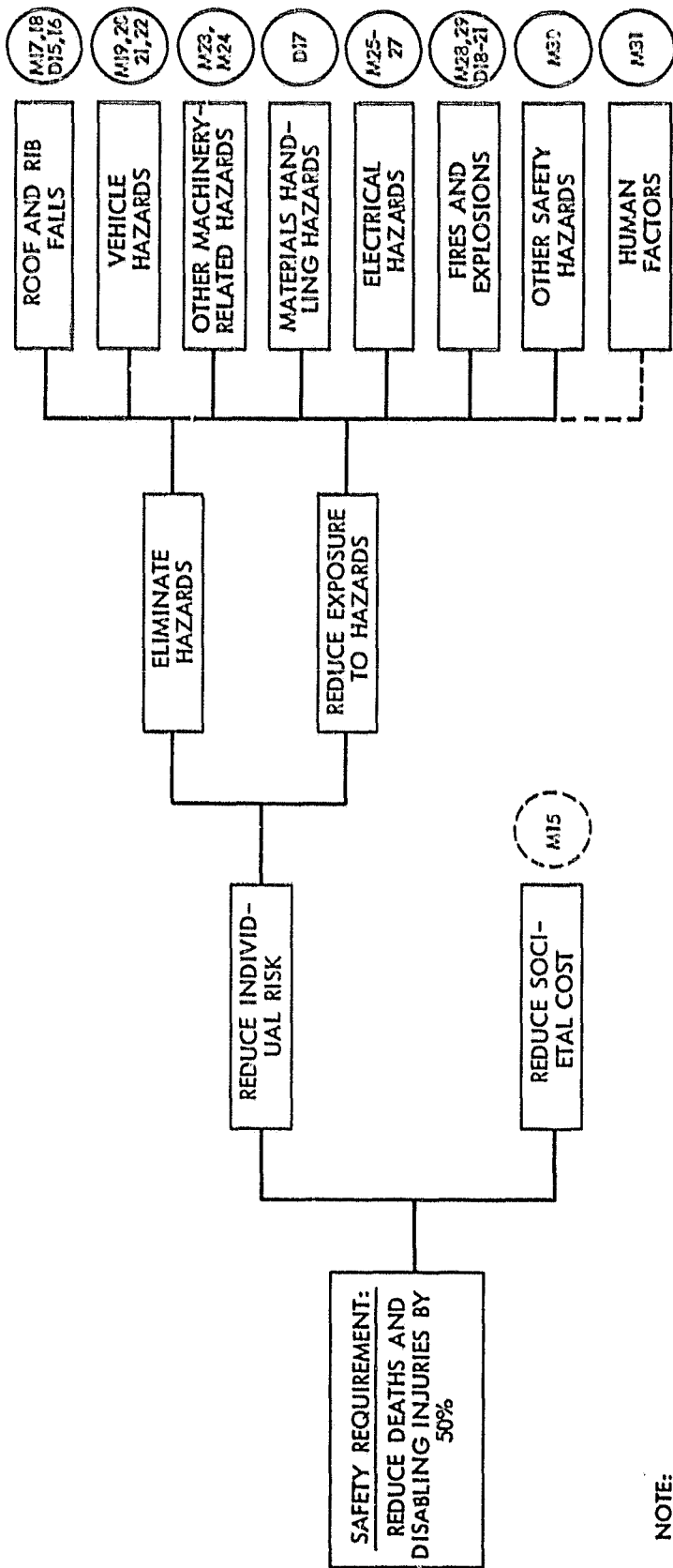justified for the proportion of fines in the product.

4.7   SAFETY AND HUMAN FACTORS REQUIREMENTS

        In the area of safety there are two measures of risk; individual risk
and societal risk. The former is measured in deaths and disabling injuries
per unit time; the latter, in injuries per unit output. The goal is to reduce
each risk by 50%. Mandatory requirements developed below, combined with the
productivity improvement requirements (M.15), will accomplish these twin
objectives. A closely related set of issues deals with the human engineering
involved in making the mining equipment easy to operate and maintain. Figure
4-4 summarizes the approaches to improved safety and human factors.

4.7.1   Individual Risk:

        Individual risk is measured as the risk of suffering a fatality or
permanently disabling injury, termed "serious injuries" for ease of
discussion. Although Goldsmith and Lavin (1980) indicate that total injuries
per million man-hours appear to be declining in underground coal mining,
Table 4-7 suggests that the incidence of serious injuries has not decreased
definitively over the 10 years since the passage of the 1969 Health and Safety
Act. A number of factors have been isolated as major safety hazards. Table
4-8, from Zimmerman (1981), groups accidents into nine causal categories
listed in order of decreasing severity. Since roof/face/rib falls, haulage,
machinery, and handling material accidents account for about 80% of serious
injuries in contemporary underground mining, the safety requirements emphasize
these four areas. The bulk of the ideas presented in this section are adapted
from Zimmerman (1981).

4.7.1.1 Roof and Rib Falls. Statistical evidence indicates that falls of
unsupported roof is the principal safety problem, especially in the face
area. Thus, an advanced system must provide means for eliminating this
hazard. This may take the form of providing temporary support, devising means
of continuous roof support, or making entries inherently safe when human
presence is required for any reason. For the sake of convenience or in
response to production pressures, miners often go under unsupported roof and
as a result, many are injured. For example, in order to set up temporary
supports, contemporary practice requires that one work under, or in close
proximity to unsupported roof for brief periods. What is required is to
"preclude" the need for anyone to go under unsupported roof, even under
abnormal working conditions.

SAFETY REQUIREMENT:
REDUCE DEATHS AND
DISABLING INJURIES BY
50%

REDUCE INDIVID-
UAL RISK

REDUCE SOCI-
ETAL COST

M15

ELIMINATE
HAZARDS

REDUCE EXPOSURE
TO HAZARDS

ROOF AND RIB
FALLS

VEHICLE
HAZARDS

OTHER MACHINERY-
RELATED HAZARDS

MATERIALS HAND-
LING HAZARDS

ELECTRICAL
HAZARDS

FIRES AND
EXPLOSIONS

OTHER SAFETY
HAZARDS

HUMAN
FACTORS

M17,18
D15,16

M19,20
21,22

M23,
M24

D17

M25-
27

M28,29
D18-21

M30

M31

NOTE:
NUMBERS CORRESPOND TO
REQUIREMENTS STATEMENTS
IN TEXT

Figure 4-4. Overview of Safety and Human Factors Requirements

ORIGINAL PAGE IS
OF POOR QUALITY

Table 4-7. Trends in Deaths and Disabling Injuries in Underground Coal Mines Since the Passage of the 1969 Coal Mine Health and Safety Act

Year	Productivity Tons/Man-shift	Rates for Deaths and Disabling Injuries per Million Man-hours	Deaths and Disabling Injuries per Million Tons
1969	15.61	45.00	18.4
1975	9.54	31.4	19.0
1979	7.90	56.3	48.4

Table 4-8. Breakdown of the Major Causes of Fatalities and Nonfatal Disabling Injuries

Source: MSHA Injury Statistics, 1972-1978

Accident Causal Category (in order of severity)	Average % Contribution to Serious Injuries	
	Fatalities	Nonfatal Disabling Injuries
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

The regulations prepared by the Mine Safety and Health Administration (MSHA) are primarily aimed at preventing miners from being exposed to unstable roof. This is accomplished by describing approved roof control plans, providing for periodic testing of support structures, regulating the buildup of explosive gas and dust, and establishing rules which prohibit workers from going under unsupported roof. In addition, all face machinery is required to have falling object protection to protect operators from small falls, rib sloughing, and from roof which has been reinforced. Typically such falls involve a rock fragment of the order of 1 ft^3 in volume dislodged from the wall of a cavity that was excavated and stablized within the previous 24 hours.

M.17   Roof Support: THE SYSTEM SHALL SUPPORT THE ROOF IMMEDIATELY AFTER MINING, IN ALL AREAS WHERE MINERS MAY HAVE ACCESS. THIS SUPPORT MAY BE TEMPORARY OR PERMANENT, BUT MUST BE INSTALLED AS THE SYSTEM ADVANCES.

D.15   Restricted Entry Under Unsupported Roof: IT IS HIGHLY DESIRABLE THAT THE SYSTEM BE DESIGNED TO PREVENT ANYONE FROM GOING UNDER ANY UNSUPPORTED ROOF, INCLUDING OPENINGS NOT INTENDED FOR HUMAN PRESENCE.

M.18   Falling Object Protection: ALL MACHINERY OPERATING UNDER RECENTLY SUPPORTED ROOF WITH PERSONNEL ON BOARD MUST PROVIDE PROTECTION AGAINST SMALL FALLS OF ROOF OR RIB, OR DISLODGED GROUND CONTROL STRUCTURES. RECENTLY SUPPORTED ROOF MEANS ROOF WHICH HAS BEEN REINFORCED WITHIN THE PREVIOUS 24 HRS OF OPERATION. A SMALL FALL REFERS TO A FRAGMENT OF ROOF ROCK (SANDSTONE OR SHALE) HAVING A VOLUME OF 1- TO 2-FT^3 OR AN EQUIVALENT VOLUME OF RIB COAL.

D.16   Robustness of Ground Control Components: IT IS DESIRABLE THAT THE SYSTEM UTILIZE PERMANENT AND TEMPORARY GROUND CONTROL COMPONENTS DESIGNED SUCH THAT THEY CANNOT BE EASILY DISLODGED BY IMPACT RESULTING FROM MACHINERY OR OTHER OBJECTS.

4.7.1.2 Hazards Associated with Vehicles and Other Mobile Equipment. A number of accidents are caused by vehicles running over personnel or crushing them against the rib or face. Often poor design is to be blamed. Contributing causes include poor operator visibility, sudden starts without warning to those in the vicinity, loss of control by the operator, and equipment designs which require the operator to walk or crawl alongside the vehicle as it trams. A major thrust of the current regulations in this area is to warn workers of an impending 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. To ensure better operator control of haulage vehicles, two independent brake systems are required. Finally, vehicle traction and controllability are regulated by requiring sanding devices for slippery areas and specifying that haulage ways be kept clear of debris.

M.19   On-Board Operation of Vehicles: THE SYSTEM SHALL BE DESIGNED SO THAT THE OPERATORS OF ALL VEHICLES OR MOBILE EQUIPMENT WHICH ARE NOT REMOTELY CONTROLLED ARE REQUIRED TO TRAM OR REPOSITION THE EQUIPMENT FROM A CAB OR OTHER PROTECTED ENCLOSURE ON THE MACHINE.

M.20   Collision Avoidance: THE VEHICLES AND OTHER MOBILE EQUIPMENT EMPLOYED BY THE SYSTEM SHALL BE DESIGNED TO PROVIDE AN UNOBSTRUCTED FIELD OF VISION FOR THE OPERATOR, ILLUMINATION SUFFICIENT TO SEE PERSONNEL IN THE VEHICLE PATHWAY FOR ALL POSSIBLE DIRECTIONS OF TRAVEL, AND DEVICES WHICH GIVE CLEAR WARNING OF APPROACH UNDER THE WORST EXPECTED CONDITIONS OF LIGHTING, MASKING EQUIPMENT NOISE, AND LIMITED ABILITY TO SEE AROUND CORNERS.

M.21   Sudden, Unanticipated Motion: COMPONENTS OF MOBILE EQUIPMENT WHICH ARE FREQUENTLY REPOSITIONED IN THE COURSE OF OPERATION MUST BE DESIGNED TO (1) GIVE AUDIBLE AND OR VISIBLE WARNING OF IMPENDING MOVEMENT, AND (2) START THE MOVEMENT IN A GRADUAL MANNER. ALTERNATELY, THE DESIGN MAY INCORPORATE PEOPLE SENSORS OR EQUIVALENT FAIL-SAFE DEVICES TO AVOID "HIT BY MACHINE" ACCIDENTS.

M.22   Protection Against Collision Impacts: VEHICLES AND OTHER MOBILE EQUIPMENT EMPLOYED BY THE SYSTEM SHALL BE DESIGNED TO PROTECT THE OPERATOR AGAINST IMPACT INJURY IN THE EVENT OF A COLLISION WITH A RIB OR OTHER OBJECT, OR AN UPSET.

The above requirements were formulated because of their wide applicability. However, every system is likely to have unique features which may pose a safety hazard if not corrected. The conceptual designer is required to attempt early identification of such hazards by a safety audit described at the end of this section.

4.7.1.3 Other Machinery-Related Hazards. Another very important source of injuries is impact or entrapment by moving components of a machine which are not associated with the need to tram or reposition the machine. Examples of this class of hazard are entrapment in a moving conveyor or the rotating mechanism of a bolter, being pinched by the forward motion of a chock, or being struck by a vehicle which falls off its jacks while undergoing maintenance or repair. A number of regulations deal with the prevention of impact or entrapment 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 on rotating and moving equipment in conjunction with easily accessible "panic bars" or shut-off switches. Automatic shut-off switches are required on hand-held power equipment. All machinery, and areas around machinery, are required to have illumination to allow workers reasonable vision of activities. The regulations 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, ensuring that precautions are taken to set brakes and completely shut systems down, and requiring the use of jacks and other lifting devices.

M.23 Illumination of the Workplace: THE SYSTEM SHALL BE DESIGNED TO ASSURE THAT THE WORKPLACE AND ASSOCIATED EQUIPMENT ARE ILLUMINATED TO ALLOW UNOBSCURED VISION OF ALL OPERATIONS IN ACCORD WITH THE INTENT OF ALL MSHA REGULATIONS.

M.24 Guards on Moving Machinery: GUARDS SHALL BE PROVIDED TO PREVENT CONTACT WITH ROTATING OR MOVING MACHINERY WHILE THE MACHINERY IS OPERATING. THESE GUARDS SHALL BE DESIGNED TO BE FAIL-SAFE, IN THAT OPERATION IS NOT POSSIBLE WHEN THE GUARD IS REMOVED.

4.7.1.4 Materials Handling Hazards. Many of the materials handling activities in mining are done manually, thus, it is difficult to set standards for performance of these tasks, and as a result, very few regulations exist. Since many of the tasks requiring handling of heavy or cumbersome material are support tasks for ground control or equipment maintenance operations, safe practices associated with these tasks include the material handling aspects as well. Because materials handling is a major contributor to serious injuries, this area warrants the designer's attention on its own merits. Although materials handling needs tend to be system specific, the analysis reported in Zimmerman (1981) suggests one rather general approach to reducing injuries of this type.

D.17 Materials Handling Assistance: IN A SYSTEM WHICH REQUIRES THE HANDLING OF HEAVY, CUMBERSOME MATERIAL, IT IS HIGHLY DESIRABLE THAT THESE TASKS BE MECHANIZED.

4.7.1 5 Electrical Hazards. The present mining environment contains many electrical hazards which constitute an ever present danger of electrocution. These include exposed trolley wires; live, faulted cables; and uncontrolled access to energized electrical terminals. Since electrical hazards are not generally visible, their danger is compounded. Moreover, the danger remains despite both the availability of the means to detect energized equipment and numerous electrical safety regulations. 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. 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 regulations call for periodic testing of circuit breakers to ensure power is cut off under overload conditions.

  The following conceptual design requirements call for conformity to MSHA regulations and directly address the hazard of exposed conductors and terminals. Dealing with other electrical hazards is the proper domain of functional requirements.

M.25 Compliance with Electrical Regulations: ALL MSHA ELECTRICAL REGULATIONS TOGETHER WITH INDUSTRY STANDARDS AND PRACTICES SHALL BE FOLLOWED IN THE DESIGN OF THE SYSTEM.

M.26   Exposed Conductors and Terminals: EXPOSED TROLLEY WIRES, OTHER
        EXPOSED CONDUCTORS, AND EXPOSED TERMINALS SHALL NOT BE PERMITTED
        DURING NORMAL OPERATION OF THE SYSTEM.

M.27   Electrical Fault Isolation: FAIL-SAFE SHUT OFF OR FAULT ISOLATION
        SYSTEMS SHALL BE PROVIDED TO PREVENT PERSONNEL FROM INADVERTENTLY
        COMING INTO CONTACT WITH AN ENERGIZED CONDUCTOR.

4.7.1.6 Explosion and Fire Hazards. Regulations related to explosion and
fire 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 address: (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 the extent of
fragmentation is controlled to prevent damage to the mine openings. 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. Additional handling
precautions describe the proper storage and labeling of explosives.

        A primary objective of the regulations is control over the size of
the charge to ensure that the detonation force is sufficient to fracture coal
but not large enough to damage the entries. 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
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.

        In spite of the considerable effort to assure safe handling of
explosives, injuries continue to occur as a result of misfires, premature
detonation, misdirected shots, etc. Thus, it is desirable that future systems
employing explosives utilize remote means for charge setting and detonation to
the extent this is both technically and economically feasible.

D.18   Remote Shot Firing: IT IS HIGHLY DESIRABLE THAT A SYSTEM WHICH USES
        EXPLOSIVES TO FRAGMENT ROCK OR COAL INCORPORATE MEANS TO BOTH SET AND
        FIRE THE CHARGES REMOTELY.

        Explosions and fires may also result from the ignition of gas and
dust released from coal. Methane constantly seeps into the mine openings
through the roof, ribs, and floor, and it forms an explosive mixture with air
when its concentration is between 5 and 15%. Although MSHA regulations
require dilution of methane to less than 1%, in mining practice it is
difficult if not impossible to avoid local pockets of methane at the face.
These pockets can and do cause ignitions. Recent research by Kissell et al,
(1981) shows that the use of properly controlled air flow patterns and
directed water sprays can reduce methane hazards significantly. However,
efforts to suppress explosions by sensing ignitions and quenching fires have
not been successful. Thus, dilution is the recommended approach to
safeguarding against gas explosions.

Dust presents dual hazards. Respirable dust particles floating in the air cause pneumoconiosis and other health problems which are discussed in the next section. If not neutralized, dust is also an explosion hazard. Whenever a coal surface is exposed, by whatever means, coal dust resides on the surface in sufficient quantity to constitute an explosion hazard. The principal means of avoiding dust explosions are: (1) cleaning up loose coal and (2) spraying noncombustible limestone powder (rock dust) on roof and ribs, and into the return air stream. The use of water sprays on mining equipment and periodic removal of accumulated dust piles help in controlling dust explosions, but are not a substitute for the explosion barrier provided by rock dust.

Regulations dealing with explosion and fire 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 machines, loading machines, and haulage equipment) since much of the gas is released during the excavation 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 ventilation stoppings.

The need to cope with the explosion hazards posed by methane and coal dust leads to the following conceptual design requirements:

M.28   <u>Methane Explosions:</u> THE DESIGN OF THE SYSTEM SHALL MEET ALL CURRENT REGULATIONS RELATING TO METHANE CONCENTRATION. IN ADDITION, THE DESIGN MUST CONTAIN AN EXPLICIT APPROACH TO REDUCING THE HAZARDS PRESENTED BY LOCAL POCKETS OF METHANE FORMED DURING EXCAVATION.

        <u>Exception:</u> SOME DESIGNS MAY BE BASED UPON AN OXYGEN-FREE ENVIRONMENT IN THE MINE AND THUS NEED NOT COMPLY WITH MSHA REGULATIONS ABOUT METHANE DILUTION. IN SUCH CASES, THE DESIGN SHALL INCORPORATE A FAIL-SAFE APPROACH TO PREVENT EXPLOSIVE MIXTURES OF AIR AND METHANE.

D.19   <u>Benign Excavation Techniques:</u> IT IS HIGHLY DESIRABLE THAT THE SYSTEM EMPLOY EXCAVATION METHODS WHICH DO NOT CAUSE METHANE IGNITION WHILE EXCAVATING.

M.29   <u>Dust Explosions:</u> THE DESIGN SHALL INCLUDE POSITIVE MEANS OF CONTROLLING THE DUST EXPLOSION HAZARD THROUGHOUT THE SYSTEM OVER THE EXPECTED RANGE OF OPERATING CONDITIONS.

D.20   <u>Continuous Monitoring of Dust and Dangerous Gas</u>: IT IS DESIRABLE THAT THE VENTILATION SYSTEM CONTINUOUSLY MONITOR GAS AND DUST BUILDUP AND ALTER THE FLOW TO MAINTAIN SAFE CONCENTRATIONS AS ESTABLISHED BY MSHA. IN ADDITION, IT IS DESIRABLE THAT THIS MONITORING SYSTEM PROVIDE HIGHLY VISIBLE WARNING TO ALL WORKERS IN AN AREA WHERE THE RATE OF INCREASE OF DUST OR GAS THREATENS TO CREATE AN UNSAFE CONDITION.

D.21   <u>Isolation of Fires and Explosions</u>: IT IS DESIRABLE THAT THE SYSTEM QUICKLY SEAL OFF AREAS IMPACTED BY FIRE OR EXPLOSION AND PROVIDE A SOURCE OF BREATHABLE AIR FOR THOSE CAUGHT IN THE SEALED OFF AREAS.

4.7.1.7   <u>Other Safety Hazards</u>. The requirements presented above address the six hazard categories which account for the bulk of the serious injuries in contemporary underground coal mining. Falls of ground, impact with vehicles and other moving machinery, handling materials, electrical shock and electrocution, and explosions and fires are of such a generic nature that these classes of hazards are very likely to be relevant to the design of an advanced system. However, it is probable that each new system concept will pose some unique safety problems which are potentially as severe as known hazards. Generally, the cost of modifying a design increases sharply as it progresses from conceptual design through detailed design and fabrication. For this reason, it is very important that the design be monitored periodically for safety problems as it evolves. The procedure for conducting such an audit has been described by Zimmerman (1981).

M.30   <u>Safety Audit</u>: TO ENSURE COMPLIANCE WITH THE INTENT OF SAFETY REGULATIONS AND SAFETY DESIGN REQUIREMENTS, AND TO IDENTIFY HAZARDS NOT SPECIFICALLY ADDRESSED IN THESE REGULATIONS AND REQUIREMENTS, THE DESIGN MUST BE SUBJECTED TO A SAFETY AUDIT AS DESCRIBED BY ZIMMERMAN (1981), AND THE COSTS OF ANY REQUIRED DESIGN MODIFICATIONS MUST BE ADDED TO THE SYSTEM COST ESTIMATES.

4.7.2   Societal Costs

The safety hazard to the society as a whole can be measured in terms of deaths and disabling injuries per million tons of coal produced. Statistics collected since the passage of the Coal Mine Health and Safety Act of 1969 indicate that the change in the incidence of serious injuries has been much smaller than the decline in productivity over the same period. Thus, the cost to society has grown substantially. Some of the cost is borne by society as a whole in the form of an increased product cost which externalizes the impacts of regulation, insurance, labor contracts, etc. However, the costs of hospitalization, reduced physical capability, and associated loss of income, as well as the personal loss to individual families remain very high. Assuming that the above safety requirements are met, the systems which attain the mandatory productivity requirement of 32 tons/man-day will reduce these societal costs substantially.

4.7.3 Human Factors

Although related to safety, human factors are primarily concerned with efficient operation and maintenance of equipment. A review of the problems typically encountered by the human factors engineer reveals a need to consider the man-machine interface early in the design process even though the complete specification of this interface cannot occur until the detailed design phase. At the conceptual design stage, the important human factors issues are (1) does each worker have adequate space to do his job, and is the layout of equipment such that the worker is comfortable and not subject to excessive physical stress? (2) are the complexities of the human tasks within the physical and mental capabilities of those destined to operate the system? and (3) has the necessary support equipment been identified for maintenance and transport functions? These considerations lead to the following requirements.

M.31   Human Factors: THE SYSTEM DESIGN SHALL DEMONSTRATE THAT ADEQUATE SPACE IS AVAILABLE TO OPERATE AND MAINTAIN THE EQUIPMENT WITHOUT PLACING PHYSICAL STRESS ON THE OPERATOR, THAT THE HUMAN TASKS ARE WITHIN THE CAPABILITY OF THE AVERAGE MINER, AND THAT NECESSARY SUPPORT EQUIPMENT HAS BEEN DESCRIBED AND COSTED.

4.8   HEALTH CONSIDERATIONS

In contemporary coal mining, respiratory disease is the major health problem, with coal dust being the visible cause of illness. However, research has revealed that a certain proportion of those who contract coal worker's pneumoconiosis develop a disease called progressive massive fibrosis which is a mutagenic reaction to substances in the coal and/or the mine workplace (Zimmerman, 1980). Thus, respirable dust, together with carcinogens and other mutagens, are the primary health hazards. Considerable effort has been devoted to defining acceptable levels of exposure to respirable dust, whereas, research on carcinogens and mutagens in coal mining is just beginning. Secondary health hazards include noise, vibration, poor lighting, and the psychological stress caused by working in a dangerous, confined environment. Accordingly, the systems performance goal for miner health is compliance with the intent of all applicable MSHA and OSHA* regulations, with particular emphasis on the hazards identified in Figure 4-5.

The working environment of an advanced system may be so different from contemporary systems that each system would require its own specifications for the control of health hazards. For example, in remotely operated systems, noise specifications may not be so important. On the other hand, very strict standards on chemical exposure may be necessary for solution mining concepts. Accordingly, the designer must make a concerted effort to identify health-related problems in his system, and must show how these hazards will be controlled.

---

* OSHA regulations may apply in instances where equipment or processes from another industry have been adapted to underground coal mining.
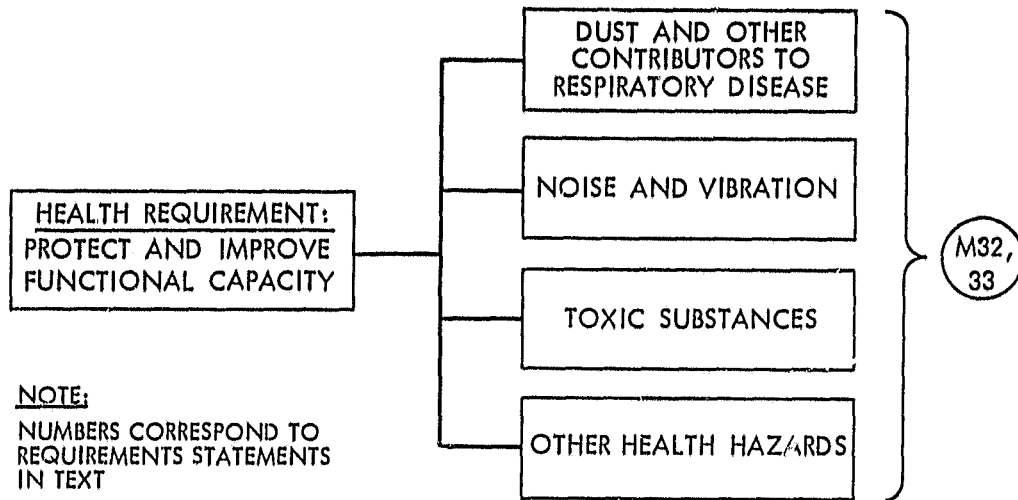
Figure 4-5. Overview of Health Requirements

4.8.1 Technology for Dust Suppression

Respirable dust exposure can be controlled in a number of ways. Recent research by National Research Council (1980) Kissell et al (1981) and Gangal and Banerjee (1979) indicates that a number of techniques are effective in controlling dust, including the following: (a) controlling airflows at the face by the use of directed water sprays; (b) new cutting techniques such as deep cutting and water jet cutting; (c) the use of scrubbers to clean contaminated air; and (d) remote operation of machinery. Where needed, it should be possible to achieve desired low levels of dust by combining two or more of these techniques.

4.8.2 Techniques for Noise Control

Cutters, conveyors, motors, gears and hydraulic pumps all produce noise. Lining pans and large structural plates with vibration damping material has proven to be an effective technique of reducing noise. Still, the noise problem is far from being solved. Salyers (1979) estimates that effective noise control adds about 5% to the cost of a machine.

4.8.3 Exposure to Toxic Substances

As reported by Zimmerman (1980), recent research suggests that there are four generic groups of carcinogenic and mutagenic substances which are present in coal and the surrounding rock:

(1) Aromatic hydrocarbons.

(2) Oxygenated hydrocarbons.

(3)   Nitrogen aromatics (hydrocarbons containing an ammonia complex).

(4)   Metals such as nickel and beryllium which are present in trace amounts.

It is very possible that the mining process will release these substances into the workplace. Moreover, an advanced system may introduce other health hazards in the form of vehicle fuel, hydraulic fluids, liquids used to cut or transport coal, dust suppressants, etc. Accordingly, special measures must be taken by the designer to: (1) identify potentially harmful chemicals produced by or used in an advanced system, and (2) assure the protection of those who may be exposed to these substances in the course of mining. Zimmerman (1980) describes techniques which may be used to identify chemical hazards at an early stage of design.

M.32   Compliance with Health Regulations: THE SYSTEM SHALL MEET ALL APPLICABLE FEDERAL HEALTH REGULATIONS, WITH SPECIAL ATTENTION TO DUST, KNOWN CARCINOGENS AND MUTAGENS, EXPOSURE TO NOXIOUS SUBSTANCES, NOISE, VIBRATION, LIGHTING, AND THE EFFECTS OF WORKING IN A CONSTRAINED SPACE.

M.33   Health Audit: TO ENSURE COMPLIANCE WITH THE INTENT OF HEALTH REGULATIONS AND TO IDENTIFY HAZARDS NOT SPECIFICALLY ADDRESSED IN THESE REGULATIONS, THE DESIGN MUST UNDERGO A HEALTH AUDIT, AS DESCRIBED BY ZIMMERMAN (1980, 1981), WITH EMPHASIS ON LABORATORY TESTS OF SUBSTANCES AND/OR CONDITIONS SUSPECTED OF BEING HARMFUL. SINCE LABORATORY TESTS MAY TAKE A VERY LONG TIME, IF POSSIBLE, THE DESIGNER SHOULD SPECIFY ALTERNATE SAFE CHEMICALS AND ESTIMATE THE COST PENALTY.

4.9   ENVIRONMENTAL IMPACT REQUIREMENTS

The performance goal for environmental impact has two objectives. First, the value of the land overlying and adjacent to the mine site must be maintained at its premining value, and second, the cost of mitigating off-site impacts are to be included in the total mining costs. Implicit in these two objectives is the central idea the that mining activity must not produce any irreparable environmental damage. There are four types of significant environmental impacts: land subsidence, refuse generation and disposal, hydrologic disruption, and water contamination. Measures must also be taken to rehabilitate the site after mining. Each problem is discussed below. An overview of environmental impact requirements is shown in Figure 4-6.

4.9.1   Subsidence

If coal recovery is kept low, via small and widely spaced excava-tions, there will be little or no immediate surface subsidence. With increas-ed extraction, ground subsidence occurs following the approximate angle of influence (Saxena, 1979). In longwall mining, panel dimensions induce uniform subsidence over an extensive surface area. Uniform or full subsidence will result in fewer post-mining land-use problems than the uneven subsidence produced by room and pillar mining, particularly in undeveloped rural areas. The transition zone between subsiding and stable ground is likely to encounter the greatest land-use problems.

4-41
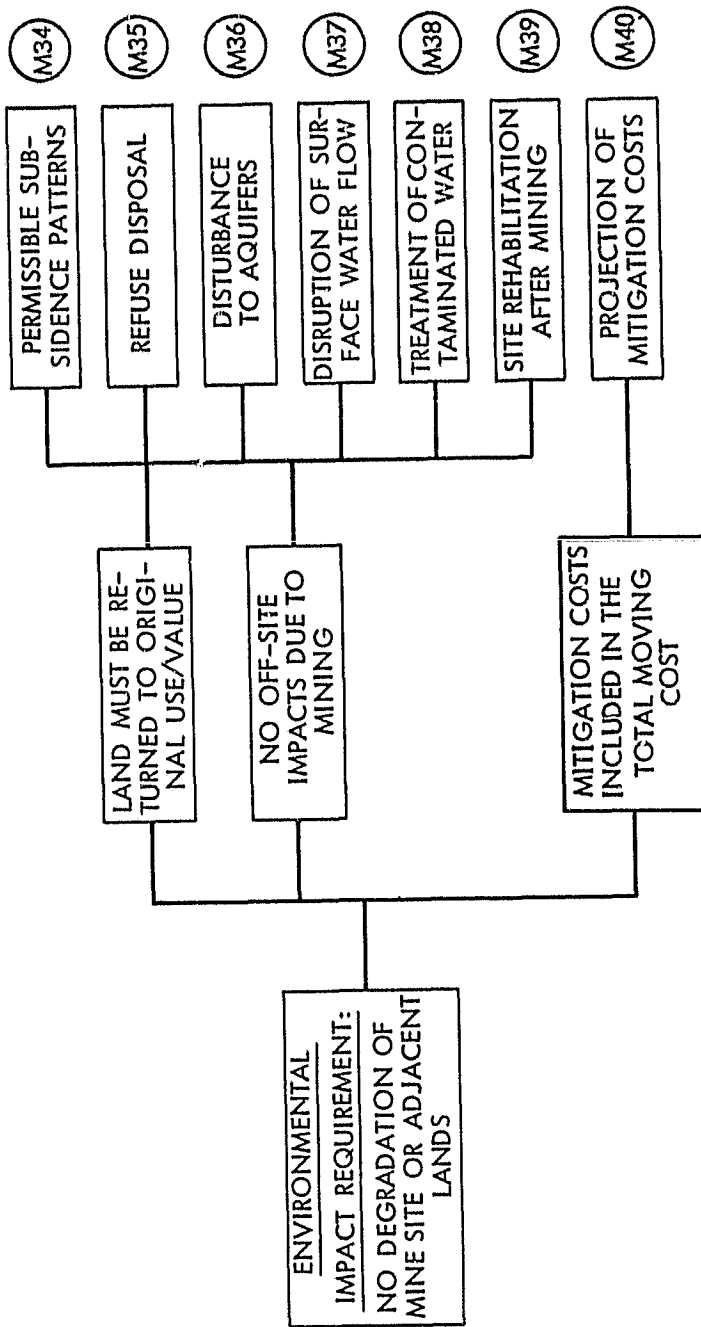
Figure 4-6. Overview of Environmental Impact Requirements

In Central Appalachia, the alluvial valleys are typically 500 to 1000 ft wide. If the surface features caused by subsidence have dimensions comparable to the land forms, the subsided land will blend with the natural landscape. In an undeveloped area, such subsidence will result in minimal changes in post-mining surface use of the land. However, uneven subsidence of farmland will disrupt cropping patterns, hamper the use of agricultural equipment, and distort drainage and irrigation systems. If the land above the mine is devoted to housing or commercial uses, subsidence can be disastrous. Subsidence may be a slow process and take many years to express itself, precluding development of the land for a long time following mine closure. Clearly, uneven subsidence cannot be permitted in areas where surface land use is an important factor. In order to avoid undue restriction on future applications of an advanced system, it is desirable to accommodate the dual needs of preventing any surface subsidence or creating uniform subsidence where permissible.

M.34   <u>Subsidence</u>: THE SYSTEM SHALL BE CAPABLE OF HANDLING TWO MODES OF SURFACE SUBSIDENCE, DEPENDING UPON FUTURE LAND USE: (1) NO SURFACE SUBSIDENCE IN SOME REGIONS OF THE MINE* DURING MINING AND AFTER THE CESSATION OF MINING ACTIVITY; (2) UNIFORM SUBSIDENCE OVER DISTANCES OF THE ORDER OF 500 FT. THE PATTERN AND EXTENT OF SURFACE SUBSIDENCE SHALL BE ESTIMATED FOR BOTH MODES FROM A REPRESENTATIVE MINING PLAN (REQ. M.42).

4.9.2   Refuse Disposal

Refuse storage is also a major problem. Often, several acres of surface area may be covered by refuse dumps and silt basins (Sullivan and Lavin, 1981). Not only are the waste dumps unsightly, they also result in destruction of surface vegetation, sediment runoff, polluted water, hydrologic impacts, unstable slopes, and spontaneous combustion hazards. The measures to control these impacts are not always effective. Some state and local authorities who deal with the refuse impact problem urge that this waste be stored underground (Sullivan et al 1980). Moreover, underground disposal may solve the problem of uneven subsidence under valuable surface property. Although it may be desirable, underground refuse storage may be too costly and may result in an aggravated water pollution problem. Thus, the designer is encouraged to consider underground waste disposal; however, the requirement for waste disposal accommodates surface disposal as well.

M.35   <u>Refuse Disposal</u>: ALL GROUND WASTE PRODUCED DURING THE PROCESS OF MINING MUST BE DISPOSED OF IN A MANNER THAT AVOIDS SEDIMENT RUNOFF INTO STREAMS; CONTAMINATION OF SURFACE OR GROUND WATER BY ACID DRAINAGE OR OTHER POLLUTANTS; UNSTABLE SLOPES, IN VIEW OF REGIONAL PRECIPITATION PATTERNS; AND SPONTANEOUS COMBUSTION OF REFUSE CONTAINING COAL. MOREOVER, THE DESIGN OF ANY SURFACE DISPOSAL SITES MUST COMPLY WITH STATE AND FEDERAL REGULATIONS.

---

*   Especially while mining under houses, schools, and other important areas.

4.9.3 Hydrologic Disruptions

The third major environmental concern is possible change in the natural hydrology. Some settling of the overburden is almost inevitable because of the voids typically created by the mining process. Thus mining usually disturbs overlying aquifers to some degree even when surface subsidence is minimal. If subsidence is severe and uneven, damage to aquifers may be extensive. Aquifer impacts under conditions of uniform subsidence are not well known but are thought to be intermediate between the extremes indicated above. Disruption of surface drainage networks is, of course, an inevitable consequence of substantial subsidence.

Because of the complex nature of the physical phenomena involved, it is difficult to predict the extent of either type of hydrologic impact even for a particular mine site. Thus, it is reasonable to require that an advanced system be no more disruptive to aquifers than existing systems under each of the two allowable subsidence modes.

M.36   Disruption of Groundwater Aquifers: THE SYSTEM SHALL PERMIT FRAGMENTATION AND CONTAMINATION OF OVERLYING GROUNDWATER AQUIFERS WHICH IS NO MORE SEVERE THAN EXISTING SYSTEMS UNDER CONDITIONS OF BOTH (1) SOME AREAS OF NO SURFACE SUBSIDENCE AND (2) UNIFORM SUBSIDENCE OVER DISTANCES OF 500 FT. THE SUBSIDENCE CHARACTERISTICS OF THE SYSTEM (REQ. M.34) WILL BE USED TO JUDGE COMPLIANCE WITH THIS REQUIREMENT.

M.37   Disruption of Surface Water Flows: THE SYSTEM SHALL MINIMIZE DISRUPTION OF RIVERS, STREAMS, LAKES, AND OTHER SURFACE WATER BODIES SUCH THAT THE QUANTITY AND USABILITY OF THE SURFACE FLOWS REMAIN UNCHANGED. THE APPROXIMATE COST OF PREVENTION OR MITIGATION MEASURES MAY BE ESTIMATED FROM SULLIVAN AND LAVIN (1981) OR EQUIVALENT DATA.

4.9.4 Contaminated Water

Since the discharge of contaminated water off the mine site cannot be permitted, contaminated water from the mine and refuse storage areas must be treated to comply with applicable water quality standards. Most drainage from underground mines in Appalachia is unacceptably acidic, and other polluting or toxic substances may be present depending upon local physical characteristics of the mine site (Hill and Bates, 1978). Although current methods of treament and control are regarded as adequate, the costs of water treatment are too site-specific to be determined at the conceptual design stage. However, Dutzi, et al (1980), indicate that costs of water treatment may be as high as a dollar per ton in Central Appalachia.

M.38   Treatment of Contaminated Water: THE SYSTEM SHALL PROVIDE FOR CAPTURE AND TREATMENT OF ALL CONTAMINATED WATER WHICH IS IN A POSITION TO DRAIN OFF THE MINE SITE INTO ADJACENT LANDS OR SURFACE WATERS. THE METHOD OF TREATMENT SHOULD ASSUME THAT ACID IS THE PRINCIPAL CONTAMINANT AND MUST PRODUCE AN EFFLUENT WHICH COMPLIES WITH APPLICABLE STATE AND FEDERAL WATER QUALITY GUIDELINES. COST OF TREATMENT MAY BE ESTIMATED AS $1.00 PER TON (IN 1980 DOLLARS) UNLESS JUSTIFICATION IS PRESENTED FOR AN ALTERNATIVE FIGURE.

4.9.5   Land Reclamation After Mining

Following closure of the mine, current regulations require that all surface areas disturbed by mining operations must be reclaimed. Necessary procedures include removal of access and haul roads, regrading of disturbed areas, soil replacement, and revegetation in order to restore the land to a condition capable of supporting the uses which existed prior to mining.

M.39   Site Reclamation: THE MINING SYSTEM SHALL COMPLY WITH ALL APPLICABLE LOCAL, STATE, AND FEDERAL ENVIRONMENTAL REGULATIONS CONCERNING RECLAMATION OF THE SITE FOLLOWING MINE CLOSURE. THE COST OF RECLAIMING THE LAND SHALL BE ESTIMATED IN CONJUNCTION WITH PREPARING A MINE PLAN (REQ. M.42).

4.9.6   Environmental Impact Mitigation Costs

The costs associated with mitigating the environmental impacts of a mining system in compliance with applicable regulations, both during active mining and following mine closure, tend to be closely related to the unique geologic and hydrologic characteristics of a site, specifics of the mining system, and planned land use following mine closure. Mitigation costs must be estimated in the preliminary planning stage, and should be based upon detailed knowledge of the characteristics of a representative site.
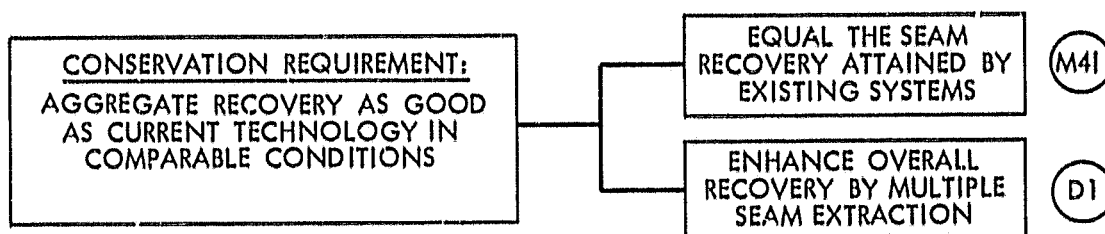
M.40   Projection of Mitigation Costs: COSTS FOR MITIGATING ADVERSE ENVIRONMENTAL IMPACTS DURING AND AFTER MINING, IN CONFORMANCE WITH APPLICABLE REGULATIONS, SHALL BE DETERMINED USING THE MINE PLAN PREPARED FOR REQUIREMENT M.42. THE COST FOR ENVIRONMENTAL IMPACT MITIGATION SHALL NOT EXCEED THE COSTS FOR EXISTING TECHNOLOGY OPERATING IN COMPARABLE CONDITIONS.

4.10   CONSERVATION REQUIREMENTS

Coal recovery currently averages only 50% of the available resource and in addition, mining often seriously disrupts closely adjacent seams. However, the abundance of coal in the ground compared with projected production over the next few decades suggests that conservation of the resource will not be an urgent problem. Accordingly, Goldsmith and Lavin (1980) were unable to justify a conservation performance goal which exceeds the capability of contemporary technology. Since coal recovery will vary with mining conditions, and the mining technique used (caving or non-caving), Goldsmith and Lavin set recovery minimums based upon the suitability of room and pillar or longwall systems to particular sets of mining conditions. These minimums focus on recovery from a single seam or a group of closely adjacent seams mined as one entity. As noted above in requirement D.1, the design of a system to accommodate multiple seams will greatly enhance aggregate recovery from a mining property (Figure 4-7).

Because a new system will undoubtedly be applied in a variety of conditions, it will be useful to know both what its conservation performance will be on the average, and what range of recovery to anticipate as conditions improve or worsen. Such calculations must be based on analysis of representative mining plans.

```
┌─────────────────────────────┐              ┌─────────────────────────┐
│  CONSERVATION REQUIREMENT:  │          ┌───│    EQUAL THE SEAM       │  (M41)
│  AGGREGATE RECOVERY AS GOOD │          │   │ RECOVERY ATTAINED BY    │
│  AS CURRENT TECHNOLOGY IN   │──────────┤   │   EXISTING SYSTEMS      │
│   COMPARABLE CONDITIONS     │          │   ├─────────────────────────┤
│                             │          │   │   ENHANCE OVERALL       │  (D1)
└─────────────────────────────┘          └───│ RECOVERY BY MULTIPLE    │
                                             │   SEAM EXTRACTION       │
                                             └─────────────────────────┘
```

NOTE:
NUMBERS CORRESPOND TO
REQUIREMENTS STATEMENTS
IN TEXT

Figure 4-7. Overview of Conservation Requirements

M.41   Coal Recovery: THE SYSTEM SHALL HAVE A CONSERVATION PERFORMANCE AT
        LEAST AS GOOD AS EXISTING EQUIPMENT OPERATING IN COMPARABLE
        CONDITIONS. THE RECOVERY MINIMUMS SET FOR EXISTING SYSTEMS ARE GIVEN
        IN TABLE 4-9. GUIDANCE IN THE USE OF THESE MINIMUMS MAY BE FOUND IN
        GOLDSMITH AND LAVIN (1980).

        To assure that the system will meet this conservation requirement,
the designer must perform an analysis of a mine plan representative of typical
mining conditions (see Section 4.12). In addition, the designer must estimate
how recovery will vary with conditions by projecting (1) a maximum value for
very favorable geology and (2) a minimum value for marginal geology.

4.11   PREPARATION OF A MINE PLAN

        In given geological and geographical settings, mining engineers
develop detailed strategies, or mining plans, for mining coal economically,
safely, and without damaging the environment. Thus, mine plans tend to be
very site-specific. On the other hand, many aspects of conceptual design can
best be understood via the preparation of a mine plan. Accordingly, we
require the designer to develop a representative mine plan for the purpose of
evaluating the design point performance of his system.

M.42   Mine Plan: THE DESIGN SHALL INCLUDE A REPRESENTATIVE MINING PLAN
        SUITABLE FOR IMPLEMENTING THE SYSTEM IN A TYPICAL CENTRAL APPALACHIAN
        SETTING. THE RECOMMENDED SETTING IS THE MINE SITE DESCRIBED BY DUTZI
        ET AL (1980). THIS PLAN SHALL DESCRIBE AND ILLUSTRATE THE PHYSICAL
        PLANT LAYOUT, DETAILS OF UNDERGROUND CONSTRUCTION, PLANS FOR PROPER
        DEPLOYMENT OF EQUIPMENT AND PERSONNEL, PROCEDURES TO BE USED FOR
        GROUND CONTROL AND VENTILATION, PROPOSED MEASURES TO CONTROL

Table 4-9. Target Recovery Ratios for Each
Major Mining Technology

Source: Goldsmith and Lavin (1980)

Technology	Production Panels		Mains & Submains		
	Fraction of Mine Area	Recovery Factor	Fraction of Mine Area	Recovery Factor	Aggregate Recovery Factor
Room and Pillar, Continuous Miner: Full Pillar Extraction[a]	0.7	0.7	0.3	0.4	0.6
Room and Pillar, Conventional Mining: Partial Pillar Extraction[a]	0.7	0.5	0.3	0.4	0.5
Longwall[b]	0.8	0.7	0.2	0.4	0.7[c]
Shortwall[b]	0.8	0.7	0.2	0.4	0.6

[a]250,000 ton/year mine

[b]1,000,000 ton/year mine

[c]Differences are due to rounding off to one significant digit.

UNDESIRABLE ENVIRONMENTAL IMPACTS, AND TREATMENT OF RELEVANT HEALTH AND SAFETY ISSUES. THE PLAN SHALL ALSO PRESENT THE TEMPORAL DEVELOPMENT OF THE MINE FROM EXPLORATION TO CLOSURE. ANY NONCONVENTIONAL APPROACHES EMPLOYED IN THE PLAN SHALL BE JUSTIFIED BY ANALYSIS AND SHOWN TO BE FEASIBLE AND SAFE. THIS PLAN SHALL THEN BE USED BY THE DESIGNER AS THE BASIS FOR ESTIMATING THE DESIGN POINT PERFORMANCE OF HIS SYSTEM.

4.12   GENERAL COMPLIANCE WITH REGULATIONS AND STANDARDS

The design of mining equipment, mine openings, and working procedures is subject to a number of regulations. Since these regulations were introduced to prevent unsafe conditions, the design must comply with all applicable regulations. It is admissible that an advanced system may be designed to comply with the intent rather than the letter of the regulation. In such a case, the designer must justify his approach.

M.43   <u>Regulations and Standards:</u> THE DESIGN SHALL COMPLY WITH ALL APPLICABLE FEDERAL, STATE, AND LOCAL REGULATIONS, AND INDUSTRY STANDARDS. EXCEPTIONS TO THE REGULATIONS AND STANDARDS MAY BE PERMITTED PROVIDED THAT THE DESIGNER MEETS THE INTENT OF THE REGULATIONS. SUBSTANTIAL JUSTIFICATION WILL BE NEEDED FOR THE ACCEPTANCE OF EACH EXCEPTION.

SECTION 5

CONCLUDING COMMENTS

This document has presented a consistent set of requirements to guide the conceptual design of advanced underground coal mining systems which will meet the broad performance goals previously established for this project. Requirements are set in seven areas: target resource constraints, mine size, production cost, miner safety, miner health, environmental impact, and coal conservation. These requirements are divided into two sets: (1) mandatory requirements which are deemed essential to meeting the system performance goals, and (2) desirable characteristics which identify highly attractive opportunities to obtain improved performance. However, incorporation of these desirable features into a design must be justified in terms of dollars and cents.

A good deal of discussion and debate accompanied the formulation of the requirements presented here. In the end, we found that requirements fall into two groups: (1) a totally new capability for which strong justification exists, and (2) a quantified performance goal or constraint which can be substanti- ated empirically. It did not suffice to say, "one must do better." Three examples help elaborate the point. A productivity goal of 32 clean tons per man-shift is based on a thoughtful extrapolation of contemporary mining tech- nology, together with a consideration of what would constitute a meaningful separation between advanced and evolutionary technology. Two requirements were set in the area of exploration because of the obvious impact this new capability would have on non-productive time if cost-effective technology could be developed. In contrast, we were unable to justify any quantitative goal for reduced manning and so elected to propose no requirements in this area.

Finally, it should be emphasized that these requirements are meant to be a guide and should be used in that spirit. Undoubtedly, the designer will wish to make certain compromises and adjustments to the performance levels set above. This is expected and totally appropriate, so long as he continues to focus on the ultimate goals of making the underground workplace substantially safer and more productive than it is today.

APPENDIX A

TRANSLATION OF THE PRODUCTION COST
GOAL INTO A DESIGN REQUIREMENT

APPENDIX A

Appendix A is devoted to translating the stated systems level requirement into more detailed cost guidance for the conceptual designer. The logic of developing detailed cost guidance requires a treatment of the following questions:

(1) How may the economic performance of a mining system be characterized in terms which are technology-independent?

(2) Given the "design space" implied by the answer to (1), what quantitative performance goals are appropriate to focus the designer's efforts?

(3) What are the attractive opportunities to meet the stated performance goals?

In the course of responding to these questions, this report develops one mandatory requirement and a number of desirable system characteristics. The formulation of the mandatory requirement is described in this appendix; desirable system characteristics are treated in Section IV of the text.

I. DETAILED CHARACTERIZATION OF ECONOMIC PERFORMANCE

Because the system boundaries extend from property assessment and mine planning through mine close, the cost figure of relevance is the minimum acceptable selling price (incorporating normal industry profit) based on a projection of all material cash flows over the mine life cycle. This cost —called "life cycle cost," for convenience— is entirely analogous to a minimum mills/kwh projection produced by a revenue requirements analysis of a proposed power generation plant. There are two obvious ways to break down the costs of a mining venture: (1) by resources, or (2) by activities. Let us explore each in turn.

II. RESOURCE BREAKDOWN

Traditionally, manufacturing costs are divided into fixed costs and variable costs. Fixed costs result from irreversible commitments of resources at the beginning of a venture, such as the construction of a plant and the purchase of production machinery. Variable costs, such as labor, energy, and other consumables are viewed as occurring more or less in direct proportion to output. Indeed, for process industries which specialize in adding value to a bulk commodity (e.g., metallurgy, petroleum refining, paper production, electric power generation, etc.) the variable cost is often further subdivided into an hourly or labor component, and a consumables component which is incurred only when the manufacturing process is actually in motion. Lavin and Borden (1978) have indicated that an underground coal mining operation exhibits the cost structure which is characteristic of those industries

processing a bulk commodity. The cost for one unit of output can be expressed as follows:

$$c = \frac{K_o + M}{T} + E \qquad (1)$$

where

c: Unit cost, including profit and all tax-related impacts

K_o: capital cost of the production facility, comprising all structures and equipment

M: total manpower-related cost associated with some production level, say, T

E: unit cost of all consumables, which vary directly with output

T: the level of output for which the unit cost is calculated, typically the capacity of the facility.

Usually the utilization rate (percent of time the facility is up and able to produce product) is a very important consideration. Thus, it is useful to rewrite Eqn (1) as:

$$c = \frac{K_o + M}{u\, T_o} + E \qquad (2)$$

where

T_o: The nameplate or rated capacity of the facility when "up"; and

u :   the average utilization of the plant and equipment.

Consider two mining systems: (1) An advanced system suitable for a well defined resource, say flat-lying Appalachian coal of moderate thickness, under moderate cover, and (2) a competitive system, embodying evolutionary technology projected ahead to the year when the advanced system will become commercially available (see Bickerton and Westerfield, 1981, for some representative projections). For convenience of comparison, let us further assume that the "advanced" and evolutionary systems are sized to have an identical annual production capability, T. After some simplification of the treatment of fixed charges, the systems level cost requirement may be restated as the following linear constraint on the cost performance of the advanced system:

$$\frac{C_1 K + C_2 M}{u\, T_o} + C_3 E = C_4 \qquad (3)$$

Where

K: The present value of the aggregate initial investment in mining plant and equipment

M: The total number of hourly and salaried personnel required to operate the mine

E: The proportion of unit operating cost which depends directly on tonnage produced (e.g., mining supplies, power and water, royalties, tonnage component of union welfare, etc.)

T_0: The annual capability of the mine, assuming 100% utilization of the mining equipment and other capital

u: The utilization factor for mine capital

C_1: A constant which embodies all of the impacts of taxes and periodic replacement of capital equipment

C_2: A constant which translates headcount into a fully costed hourly expense, including all labor expense which is not identified as tonnage-related

C_3: The tonnage-related unit cost multiplier

C_4: A constant which embodies both the return on incremental investment required of the _advanced_ system, and the aggregate cost performance of the competitive _evolutionary_ system.

The above expression can be represented by the tetrahedron OABC, shown in Figure A-1. This tetrahedron depicts admissible combinations for mine capital, manpower, and consumables, which satisfy the systems performance goal for production cost, and effectively define a "design space" for the economic performance of an advanced mining system. Examination of the detailed structure of the Eqn (3) (not shown here) reveals that points inside the tetrahedron, which are successively closer to the origin, imply correspondingly higher rates of return.

Eqn (3) and Figure A-1 clearly identify the resource categories relevant to production cost improvement at the mine level. Let us now examine a cost breakdown by major mining function to see what additional guidance may be obtained for the designer of advanced systems.

III. BREAKDOWN BY MINING ACTIVITY

Table A-1 presents a breakdown of production cost by major mining activity, for a 2 million ton/year shaft mine using room and pillar technology. The figures are based on the illustrative example in Lavin and Borden (1978), and are judged to be very similar (in terms of percent contribution to cost) to an activity breakdown of cost for Bickerton and Westerfield's year 2000 projections. Table A-1 includes all major mining activities including ongoing environmental mitigation and mine close, treated here as a contingency.
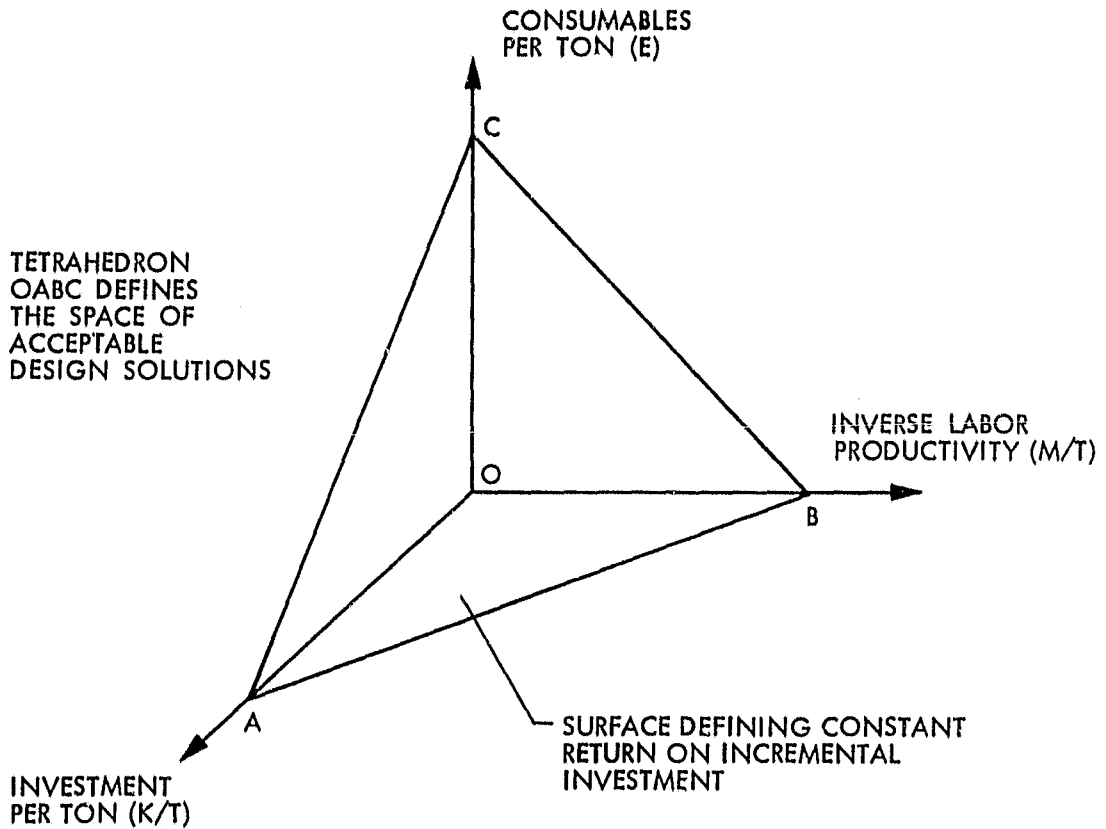
Figure A-1. Geometric Interpretation of Cost Combinations Satisfying
the Systems Level Goal for Production Cost

Table A-1. Activity Breakdown of Life
Cycle Underground Mining Cost

Activity	Unit Cost as a % of Total Cost
Initial Planning and Mine Opening	7.2%
Surface Construction and Initial Development	1.9
Operating Cost during Capacity Production	54.8
Direct Production Costs	
Cutting — 13.4	
Coal Transport — 11.9	
Roof Control — 6.5	
Ventilation — 2.8	
Other Support — 11.1	
Crew Unavailable — 9.1	
Administration and other Indirect Costs	28.6
Mine management and administration — 3.8	
Local taxes and insurance — 2.9	
Federal taxes — 4.8	
Tonnage portion of union welfare — 7.3	
Royalty to land owner — 4.7	
Other indirect — 5.1	
Coal Preparation	5.0
Mine Close and Site Rehabilitation	2.5
	100%

In the course of developing system performance goals, Goldsmith and Lavin (1980) have shown that environmental costs incurred over the mine life cycle are typically less than one dollar per ton, without any downward adjustment for discounting these cash flows. Examination of Table A-1 reveals that 88% of cost (excluding mitigation of environmental impact) is attributable to the capacity production era of a mine life, and that 55% of the cost is consumed in production or production support activities. The remainder of the expense during capacity production includes managerial overhead, the various impacts of state and local taxes, and two tonnage-based royalties -- one paid to the landowner, and one paid to the union. The cost of preparation, estimated to be 5% of total unit cost, is called out as a separate item both because it is a well identified and distinct technology,

and because a substantial fraction of the industry is expected to persist in its practice of selling raw, unwashed coal.

Table A-1 points to two findings bearing upon the production cost performance of an advanced mining system. First, the opportunity for the greatest impact lies in improved effectiveness of the production effort, i.e., the core mining functions. In other words, substantial improvement in mine opening and initial development is possible, and potentially very attractive from the standpoint of return on incremental investment; however, these improvements are likely to have only a modest impact on the life cycle cost. Second, in examining the costs attributable to the production activities, it is not possible to identify a predominant cost driver; all of the five production functions listed are more or less of equal importance, except perhaps for ventilation, which accounts for only one-fifth the expense of cutting. Appendix B explores in greater depth the cost implications of the manner in which men and machines are currently applied to underground production tasks.

To obtain additional insight into the structure of the production cost, a sensitivity analysis was performed for a representative room and pillar mine with costs projected to the year 2000. The results are presented in Table A-2 as price influence coefficients. For example, a price influence coefficient of 0.0456 for initial development means that a dollar reduction in this expense category will result in a 4.6¢ reduction in the life cycle cost of coal.

Table A-2 corroborates conclusions drawn above in two areas, and adds to the picture in several other aspects. The influence coefficient for "initial construction and non-section equipment" provide additional evidence about the relatively limited opportunity for impacting life cycle cost via system improvements here.* The influence coefficient for tons per machine shift points to the comparatively large impact obtainable by boosting the productivity of the mining equipment and the people who operate it. This result confirms the overall cost structure presented above in Eqn (3). Additionally, Table A-2 points to the salience of hourly labor and mining supplies, with influence coefficients of 0.31 and 0.25, respectively.

In sum, examination of costs broken down by mining activity leads to the following conclusions:

(1) The capacity production era presents the greatest opportunity for production cost improvement, and this fact should be reflected in the design requirements.

(2) Analysis of contemporary technology reveals that capital, labor, consumables, and production rate are all important, with cost being the most sensitive to changes in production rate and labor costs, as indicated by the structure of Eqn (3).

---

* Since the mine depicted in Table A-2 has drift access to the seam, no conclusions can be drawn about sensitivity to the cost of shaft construction.

Table A-2. Price Influence Coefficients for a 1.37 Million ton/yr Room and Pillar Mine in the Year 2000 (Percent Change in Price Due to Percent Change in Factor)

TONS/MACHINE SHIFT		0.7661
LABOR RELATED EXPENSE:		
HOURLY PERSONNEL	0.3050	
WELFARE RATE/MAN-HOUR	0.0350	
SALARIED PERSONNEL	0.0900	0.430
TONNAGE RELATED EXPENSE:		
SUPPLIES AND MATERIAL/TON	0.2475	
UNION WELFARE RATE/TON	0.0699	
POWER COST/TON	0.0085	
ROYALTY COST/TON	$\leq 10^{-4}$	0.3259
PRODUCTION SECTION AND HAULAGE EQUIPMENT:		
PRODUCTION SECTION EQUIPMENT	0.0748	
PREPRODUCTION HAULAGE	0.0225	
PRODUCTION HAULAGE	0.0140	0.1113
FINANCIAL FACTORS:		
INTEREST RATE ON BORROWED CAPITAL	0.1259	
PORTION OF CAPITAL BORROWED	-0.0657	
RATE OF RETURN DESIRED	0.043	0.1082
INITIAL CONSTRUCTION & NON-SECTION EQUIPMENT:		
OTHER SURFACE CONSTRUCTION	0.0511	
HEAVY EQUIPMENT	0.0195	
PRODUCTION SITE AND VENT. CONSTR.	0.0158	
PREPRODUCTION SITE PREPARATION	0.0049	
VENTILATION EQUIPMENT	0.0030	
EXPLORATION	0.0006	
SHAFTS, MINE ENTRIES, ABANDONMENT	$\leq 10^{-4}$	0.0949
INITIAL DEVELOPMENT EXPENSE:		
DIRECT AND INDIRECT DEV. COST	0.0438	
DEVELOPMENT TIME	0.0018	0.0456
TAXES:		
FEDERAL TAX RATE	0.0389	
STATE TAX RATE	0.0019	0.0408
SEAM RECOVERY FACTOR		-0.0140
OTHER EXPENSE:		
COMMUNICATIONS EQUIPMENT	0.0018	
FIRE AND SAFETY EQUIPMENT	0.0012	
DEWATERING SYSTEM	0.0012	
MISCELLANEOUS ITEMS	0.0024	0.0066

(3) Finally, within the capacity production era about two-thirds of the cost can be impacted by fundamental changes in technology; the remaining third is governed by tax law, contractual arrangements, and administrative overhead, all of which are effectively beyond the designer's control.

These three findings tend to focus the designer's attention on the mining activities within the capacity production era. Let us now consider what additional guidance can be developed: in particular, whether it is possible to identify a quantitative design goal within the feasible space depicted in Figure A-1.

IV. Formulation of a Design Goal

A desirable formulation of a design goal requires (1) an analytic representation of the system performance envelope and, (2) an empirically based judgment for where to set the performance target. At the highest level, we have an analytic representation of system cost performance (Eqn (3) and Figure A-1). Moreover, in the case of annual production (uT) this model can be elaborated somewhat because of easily observable physical relationships:

$$uT = \frac{n w_\infty H_o}{(1 + a_u + a_x)(1 + a_c)} \qquad (4)$$

where

n : Number of operating sections

w_∞ : Maximum sustainable section production rate while up (tons/hr)

H_o : Available working hours in a year (hrs/yr)

a_x : Fraction of working time lost due to scheduled downtimes exclusive of equipment moves and set-ups

a_u : Fraction of working time lost due to unscheduled downtime of all sorts

a_c : Fraction of the available productive time lost due to set-ups moves, adjusting machinery, etc.

No comparable elaboration of mine capital, mine labor, or consumables is possible on physical grounds. For example, it is clear that every mining system will require a certain number of people in support for every man at the working face. However, the relative proportions of the two types of labor is a complicated function of how the core mining functions of cutting, haulage, ground control, ventilation, etc. are accomplished. Similarly one could argue that there is a well defined relationship between non-section capital equipment (e.g., rail lines and other underground utilities, maintenance equipment, prep plant and loading facilities, etc.), and both the annual tonnage produced and the areal extent of a mine. Yet examination of a variety of different technologies reveals that any such relationship is bound to be

very system-specific. Contrast, for example, the non-section capital requirements of single-entry longwall with slurry transport and hydraulic stowing, with the requirements of cut and shoot served by electric shuttle cars. In sum, we see no firm basis for elaboration of Eqn (3) beyond the simple expression for annual tonnage given above in Eqn (4), which by itself, is little more than an obvious accounting for the sources of system downtime.

An economist would argue that what is really needed is an engineering production function for underground mining, with the factor inputs of capital (K) and labor (M) treated in a rather aggregate fashion. In fact, Chenery (1949) describes such a production function for the deep coal mining industry in Great Britain. However, examination of such a model reveals that it can do little more than help explain (and possibly extrapolate) productivity trends over some period of interest. In consequence, design goals must be set for cost performance using the broad cost structure defined above in Eqns (3) and (4). In other words, any additional guidance given the conceptual designer must be based on engineering judgment about the relative attractiveness of various opportunities for system improvement.

Let us now reexamine Eqn (3) to ascertain if there are good reasons for focussing the design effort on one or more of the factors in that expression. In the aggregate, Eqn (3) dichotomizes cost into two terms: a tonnage-related term, and a term containing all of the costs which are incurred whatever the tonnage produced.

The tonnage-related term is itself divided into two portions: (1) mining supplies, power, and other consumables, and (2) royalties, severance taxes, contributions to union welfare, and other contractual obligations. Clearly, the contractual obligations are outside the purview of the design requirements. Mining supplies and other consumables are relevant to design, but as argued above, this cost factor tends to be system-specific, as indicated by Table A-3. If one reviews the technological evolution of coal mining over the past hundred and fifty years, it is evident that as hand work was replaced by machines, consumables per ton did increase. Interestingly enough, a comparison of cut and shoot, continuous mining, and longwall does not corroborate this trend (assuming longwall to be the most advanced technology), possibly because less consumables per ton are used in extracting the longwall panel itself. This merely reinforces the point that consumables are very system-specific. Moreover, consumables although related to the technology, are not the mos. salient consideration in pondering how to improve system performance; one tends to think first about new ways of excavation, materials handling, and ground control, with other issues being decidedly secondary. Thus, it is apparent that setting a cost goal for consumables per ton is not appropriate for directing conceputal design effort.

The term in Eqn (3) concerned with tonnage-independent effects is composed of three factors: capital, labor, and production rate. Historically, the industry has focussed on a combination of two of these factors, the figure of merit being tons per man-day. More recently, with the increased mechanization of the mining process, interest in section performance as an entity has led to a new measure -- tons per machine shift. Lavin and Borden (1978) suggested a new measure: the productivity of capital. Studies by J. J. Davis (1977), Marrus et al. (1976), and others imply that improvements in system utilization would have most significant impacts and

Table A-3. Comparative Production Costs for Room and
Pillar, Longwall, and Shortwall
Source: Bickerton and Westerfield (1981)

	Production Cost Expressed as a Percent		
	Room and Pillar	Longwall	Shortwall
Labor	30.9	28.1	28.8
Supplies	30.0	26.5	27.7
Power	2.0	1.3	1.5
Union	6.4	8.1	7.6
Royalties	1.3	1.7	1.6
Capital-Related	29.4	34.3	32.8
	100.0%	100.0%	100.0%

could, therefore, be taken as a primary design goal. Are any of these
suggested performance indices appropriate for a design goal, or must yet
another be devised? The argument which follows, concludes that labor
productivity in terms of tons per man-shift, considering all personnel at the
mine site, is a quite acceptable and suitable measure for focusing conceptual
design effort.

One would like to identify an input-output ratio or a performance
measure because of its obvious pertinence to the effectiveness with which a
system deploys resources. This argues against focussing solely on the
numerator or denominator of the capital-labor term, and effectively eliminates
system utilization as a candidate. Because it impacts the effectiveness with
which both capital and labor are applied, utilization is very important. Yet
a primary focus on utilization would bypass the cost of the measures employed
to secure a higher operating rate, a most important consideration for the
designer. A similar objection could be raised against the use of either the
section or mine production rate as the primary performance measure.

This then leaves three choices: (1) the capital-labor term as an
entity, i.e., the life cycle cost less the tonnage-related term, (2) the ratio
of capital to output; or (3) the ratio of labor to output, i.e., the
traditional expression for labor productivity. The capital-labor term is not
an attractive choice because it is so aggregate; use of the capital-labor term
as the performance goal is virtually equivalent to setting a target for the
life cycle cost.

It could be argued that a viable alternative is the direct cost of the face operations, i.e., a dollar per ton target for all activity inbye the first transfer point or its equivalent. At first glance, this option appears attractive. However, it becomes less attractive when one recognizes that such a measure would provide no incentive for reducing production support activity per ton, which can account for over half the labor effort in a large mine (Bickerton and Westerfield, 1981; Lynn, 1980).

The ratio of capital to output is a more appealing measure, both because it is more focussed, and because it can be put on an empirical basis. There is little question that over a long period of time, say fifty years, the investment per annual ton has grown substantially, and has been the primary cause of the observed productivity increase in underground coal mining during the first part of this century. However, the variation about the trend line in capital per ton is judged to be too great to provide useful guidance to the conceptual designer. In particular, one can observe two very different technologies working side-by-side (longwall and continuous mining equipment) which have comparable production costs, but a per ton investment in mining equipment differing by an order of magnitude (Mabe, 1979).

Thus, we are left with the ratio of output to the labor input -- the widely accepted measure of tons per man-day. This choice is very attractive for several reasons. First, labor productivity is a widely accepted measure of production efficiency and technological progress not only in coal mining but in the economy as a whole. Since labor is the crucial input to any manufacturing (or service) organization, it is natural to measure growth in overall efficiency by tracking increases in labor productivity. Second, setting a goal for increased labor productivity motivates the designer to place much more productive equipment at the disposal of the mine workforce without imposing an arbitrary target for capital investment per man or per annual ton. Mechanization of manual functions, followed by automation where possible, is the pattern of progress in industry after industry. The ultimate is the substitution of a robot for a man, now a reality on the automobile production line and discussed by Yonemoto (1978) as a near-term possibility in underground mining. Third, a performance goal for output per man at the mine site provides strong incentives for improvement in system utilization and in the effectiveness of labor effort devoted to production support activities -- both regarded as prime opportunities for system improvement. Fourth, as indicated in the discussion of mine safety in Section 4.7, the societal cost of underground coal mining is large and growing. Over the past twelve years, deaths and disabling injuries per ton have doubled as labor productivity has declined by 50%. Moreover, as coal production continues to expand through the end of the century, serious injuries will grow in absolute terms unless there are meaningful gains in labor productivity. Thus, selecting labor productivity as the design focus for production cost contributes directly to the other important system performance goal -- substantially reducing deaths and disability injuries. Fifth, and finally, labor productivity is a measure for which extensive historical data exists, and labor productivity is an easy performance measure to compute once the conceptual designer has completed his projections for production rate and manning; in other words, labor productivity is a measure for which it is simple to set a quantitative target easily verifiable by a designer.

In sum, labor productivity has been chosen as the production cost performance goal because it

(1) Is a widely accepted measure of industrial efficiency.

(2) Provides a clear incentive for additional mechanization and automation where appropriate, this being the traditional avenue of technological progress.

(3) Encourages the designer to impact the core mining functions via the more effective use of the entire mine labor force together with structural options that promise higher equipment utilization.

(4) Contributes directly to the system performance goal of reduced deaths and disabilities per ton.

(5) Is easy to convert into an operational performance measure, usable by all involved in system design and development.

In the statement of design requirements, a minimum rate of return on incremental investment (ROI) is combined with a goal for labor productivity as necessary and sufficient conditions for a system to be "advanced" in the area of production cost. Because these two requirements are not derived from a self consistent set of economic and physical laws, it is possible that the productivity goal may conflict with the requirement on ROI. In particular, the numerical values chosen may be such that simultaneous compliance with both requirements is not possible or is very onerous, thus exposing the need for a redefinition of "advanced system". Moreover, because labor productivity is, in economic terms, an "average product," it is not clear what conditions must hold (primarily the relative prices of labor and capital) to assure that there is a feasible set of design solutions. In the next section, a quantitative goal for labor productivity is developed with these caveats in mind.

V.   QUANTITATIVE DESIGN GOAL FOR PRODUCTIVITY

Choice of a quantitative design goal for labor productivity breaks down into two topics: (1) selection of a point of reference for productivity in the year 2000, and (2) determination of how much better an advanced system must do in order to represent a meaningful advance in technology. The following paragraphs discuss each topic in turn.

VI.   PROJECTION OF LABOR PRODUCTIVITY TO YEAR 2000

Past projections of labor productivity have been done in very aggregate terms (Griffiths, 1977; Mabe, 1979; Terasawa and Whipple, 1980). Most of these studies anticipate a recovery of labor productivity to a level approximating the historical peak of 16 tons/man-day attained in 1969. However, these expectations are based on a qualitative assessment of factors, such as, technological innovation, a more skilled labor force, less restrictive regulation, more effective labor incentives, etc. No attempt is generally made to translate these qualitative judgments into a defensible quantitative impact on labor productivity.

Bickerton and Westerfield (1981) recently published a set of technological projections for three mining systems presumed to have important roles in the year 2000: room and pillar with continuous mining equipment, longwall, and shortwall. In contrast to the so-called "top down" projections which treat productivity very grossly, Bickerton's projections were predicated on a series of judgments about how equipment design would evolve and how this equipment would be operated. In making these projections, Bickerton considered two sets of mining conditions: "average" and "ideal." Average conditions represent values for roof and floor quality, ventilation requirements, partings, and other anomalies which the technology is expected to face in a typical mine appropriate for this equipment. Ideal conditions, on the other hand, embody a set of geological and operating factors which would permit sustained peak production (but not a world's record, which generally reflects little of the unavoidable downtime built into the usual mining operation). Thus, Bickerton and Westerfield were able to project a plausible range of equipment performance for the year 2000.

Table A-4 presents Bickerton and Westerfield's projections for labor productivity, adjusted to reflect conditions in a 50-in. seam. This seam height is judged to be more representative of Central Appalachian deep mining in the year 2000 than the 6-ft seam used throughout Bickerton and Westerfield's calculations. A value of 50 in. was selected after comparing Young's (1967) statistics on coal production with a histogram of virgin resources (Figure A-2) and the range of seam heights projected by the National Coal Model for the year 2000 (Kaplan, 1981).

For average conditions, Table A-4 suggests a recovery of productivity to the mid-teens, in line with industry hopes to recapture the 1969 peak of 16 tons by the end of the century. Under ideal conditions, these same three technologies are seen as achieving a productivity in the range of 22 to 26 tons/man-day.

VII. LABOR PRODUCTIVITY GOAL FOR AN ADVANCED SYSTEM

In setting a cost performance goal for an advanced system, we shall require that the labor productivity be significantly better than the productivity projected for evolutionary systems in the year 2000. In view of the projections presented above, it appears that the industry average for evolutionary systems should be approximately 15-17 tons/man-day. How much better should an advanced system do?

To answer this question, we shall utilize the logic underlying the two-sample difference of means test from statistics. Thus, the first order of business is to obtain an estimate for the standard deviation (σ) of labor productivity. Table A-5 presents estimates of mean section production (m) and σ for room and pillar technology in 1976 and longwall in 1980. Since data are not available for estimating the standard deviation of total labor productivity, data on section production (face productivity) must suffice. However, since we are interested only in the ratio (σ/m), this is not a serious problem.

Although intuition argues for a decreasing ratio of σ/m with increasing m, these data indicate that σ/m appears to vary relatively little with large changes in m, and suggest that a σ/m of about 0.5 should be a good approximation for evolutionary technology.

Table A-4. Extrapolated Technologies Operating in a
50-in. Seam for the Year 2000

Source: Bickerton and Westerfield (1981)

Item	Average Conditions			Ideal Conditions		
	Room & Pillar	Longwall	Shortwall	Room & Pillar	Longwall	Shortwall
	1,026,700	1,283,300	1,031,250	2,823,300	2,433,750	1,851,667
Personnel: Hourly	270	318	285	428	392	323
Salaried	67	70	68	96	89	75
Subtotal	337	388	353	524	481	398
Less Prep	(24)	(24)	(24)	(30)	(30)	(24)
Labor Total	313	364	329	494	451	374
Man days @ 220/year	68,860	80,080	72,380	108,680	99,220	82,280
Tons/man-day	14.91	16.03	14.25	25.98	24.53	22.50

* Figures for annual capability were obtained by multiplying Bickerton and Wester-
field's raw tonnage projections by (50/72). A direct proportionality between
productivity and seam height was documented in Mabe's (1979) comparison of long-
wall with room and pillar.

Table A-6 applies this rule of thumb to (1) compute standard deviations
for Bickerton and Westerfields's evolutionary technologies in average condi-
tions, and then (2) infers the difference between average and ideal
performance in terms of the standard deviation. When viewed from this
perspective, Bickerton and Westerfield's adjusted projections for ideal
conditions appear rather conservative. Room and pillar exhibits the widest
range, with a difference of 1.5 between ideal and average; longwall and
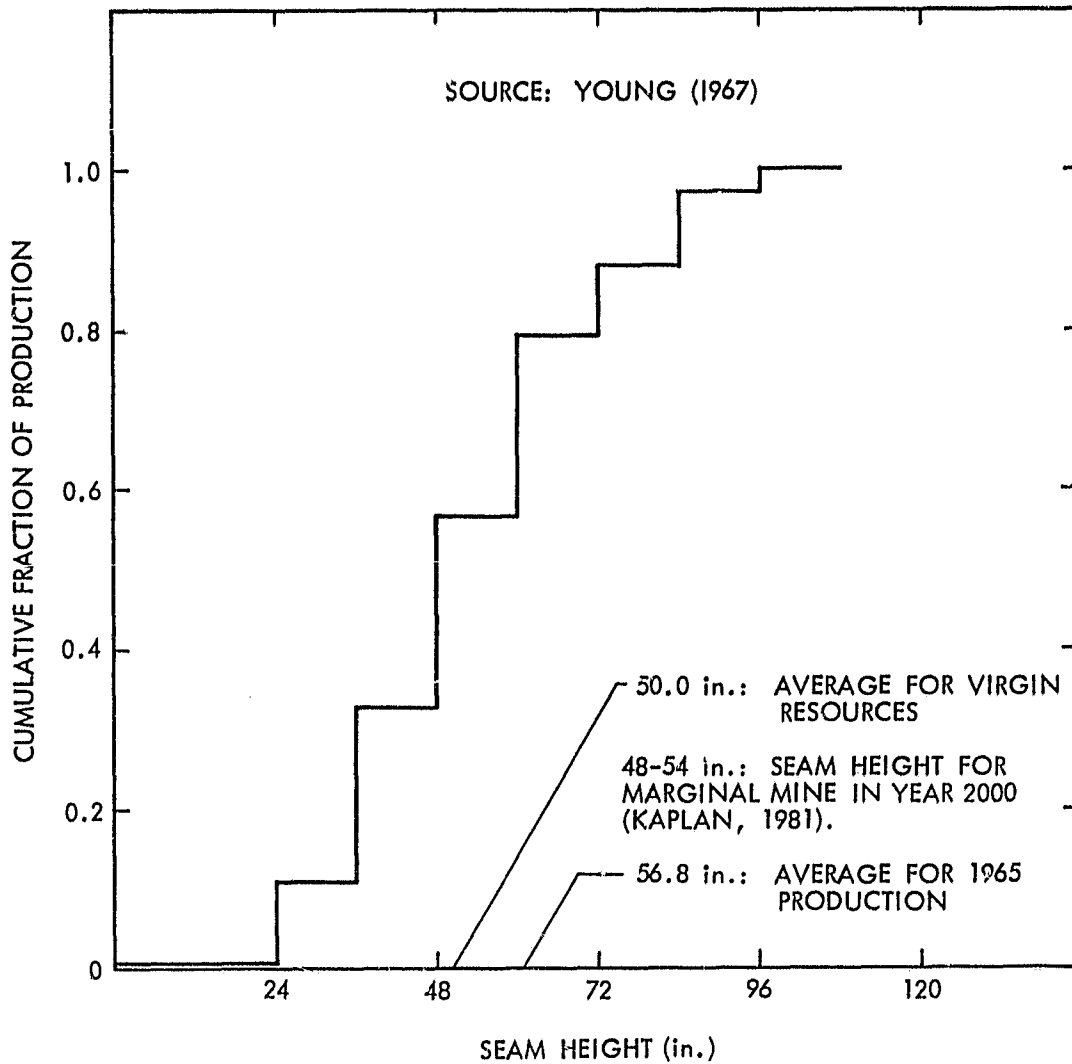shortwall both exhibit an ideal-average difference of a bit over 1.0 σ.

Figure A-2. Seam Height Distribution of 1965 Coal Production from Central Appalachia

Table A-5. Estimates of the Mean and Standard
Deviation for Labor Productivity

	Mean (m)	Std. Devn (σ)	σ/m
Room and Pillar (from Suboleski, 1978):	281	147	0.523
Longwall (from Merritt and Brezovec, 1980):	1005	554	0.551

Table A-6. Parameter Study of the Confidence Level Implied by
Various Deviations from the Mean Labor Productivity
(raw tons/man-day)

Source: Table A-4

	Room & Pillar	Longwall	Shortwall
Ideal Productivity	26.0	24.5	22.5
Average	14.9	16.0	14.2
Difference	11.1	8.5	8.3
Estimated Standard Deviation*	7.45	8.0	7.1
Difference/Standard Deviation	1.49	1.06	1.17

*Estimates were prepared under the assumption that the standard deviation
 will be one half of the mean for average conditions.

A design goal should be set in view of the likely variance about the mean of both evolutionary and advanced technology. Accordingly, let us define the following variables:

x_A, x_E: system labor productivity for the advanced and evolutionary systems, respectively (tons/man-day).

m_A, m_E: mean labor productivity for the advanced and evolutionary systems.

σ_A, σ_E: standard deviation about the mean productivity for the advanced and evolutionary systems.

Let us assume that x_A and x_E are normally distributed, or formally

$$x_A \sim f_N (x_A \mid m_A, \sigma_A)$$

$$x_E \sim f_N (x_E \mid m_E, \sigma_E) \tag{5}$$

where $f_N (x \mid m, \sigma)$ denotes the normal probability density function for the random variable x whose mean is m and standard deviation is σ. Now define a new random variable z such that

$$z \equiv x_A - x_E \tag{6}$$

Since the normal distribution is regenerative, it is a straightforward matter to show that z is also normally distributed, in particular

$$z \sim f_N \left[z \mid (m_A - m_E), (\sigma_A^2 + \sigma_E^2)^{\frac{1}{2}} \right] \tag{7}$$

To establish the superiority of the advanced system, the relationships among m_A, m_E, σ_A and σ_E must be such that $P_r (z \leq 0)$ is very small. Examination of Eqn (7) reveals that the condition on $P_r (z \leq 0)$ is formally equivalent to computing a two-sample difference of means test.

In order to calculate the indicated probability (or perform the difference of means test), one must determine values for σ_A, σ_E and the tail-probability θ, and then solve the following equation for $(m_A - m_E)$:

$$(m_A - m_E) = k (\theta) (\sigma_A^2 + \sigma_E^2)^{\frac{1}{2}} \tag{8}$$

where $k (\theta)$ is the distance from the mean to the beginning of the tail of the probability density function, measured in units of standard deviation. Now the data in Table A-5 suffice to determine σ_E, however, we have no really satisfactory way of estimating σ_A. One could extrapolate the observed relationship between m and σ to much higher values of m, but this is regarded

ORIGINAL PAGE IS

as highly speculative, and in the end, likely to be rather inaccurate. A less speculative approach is to assume that

$$\sigma_A = \sigma_E \qquad\qquad (9)$$

and to choose a value of θ small enough to ensure a sharp separation between the advanced and evolutionary systems in the event that σ_A is somewhat larger than σ_E. Table A-7 presents the results of a sensitivity analysis on θ.

Table A-7. Sensitivity of Mean Tons Per Man-Day for the Advanced System (m_A) to the Probability of Separation Between Advanced and Evolutionary Technology

P_r ($x_A \geq x_E$)	$k(\theta)$	m_A (tons/man-day) Raw Coal	Clean Coal
0.980	2.05	39.7	29.8
0.990	2.33	43.3	32.4
0.995	2.57	46.2	34.6
0.998	2.88	49.8	37.3
0.999	3.09	52.3	39.2

The clean coal productivities listed in Table A-7 are predicated on a reject rate of 25% -- a value consistent with both the analysis of Bickerton and Westerfield (1981), and recent conversations with a sample of Appalachian coal operators (Lynn, 1980).

Examination of Table A-7 suggests that a separation at the 99% level would be adequate to ensure superiority of the advanced system under the conditions described above. Note that a separation at the 99% level implies a design goal of 32 tons of clean coal per day, which is equivalent to approximately a fourfold increase over the industry average for 1980, and a doubling of the 1969 peak productivity of 16 tons.

Finally, it is informative to relate the design goal of 32 clean tons/man-day to the performance goal for return on incremental investment. Figure A-3 indicates how return on total investment varies with increased productivity for two different conditions: (1) fixed manpower, variable output; (2) fixed output, variable manpower. The mine studied was Bickerton and Westerfield's (1981) room and pillar mine operating under average conditions in 1980 and producing 574,000 clean tons/yr. Since the value plotted is return on total investment, return on incremental investment would be correspondingly higher, depending upon the degree to which the entire mining system is redesigned.
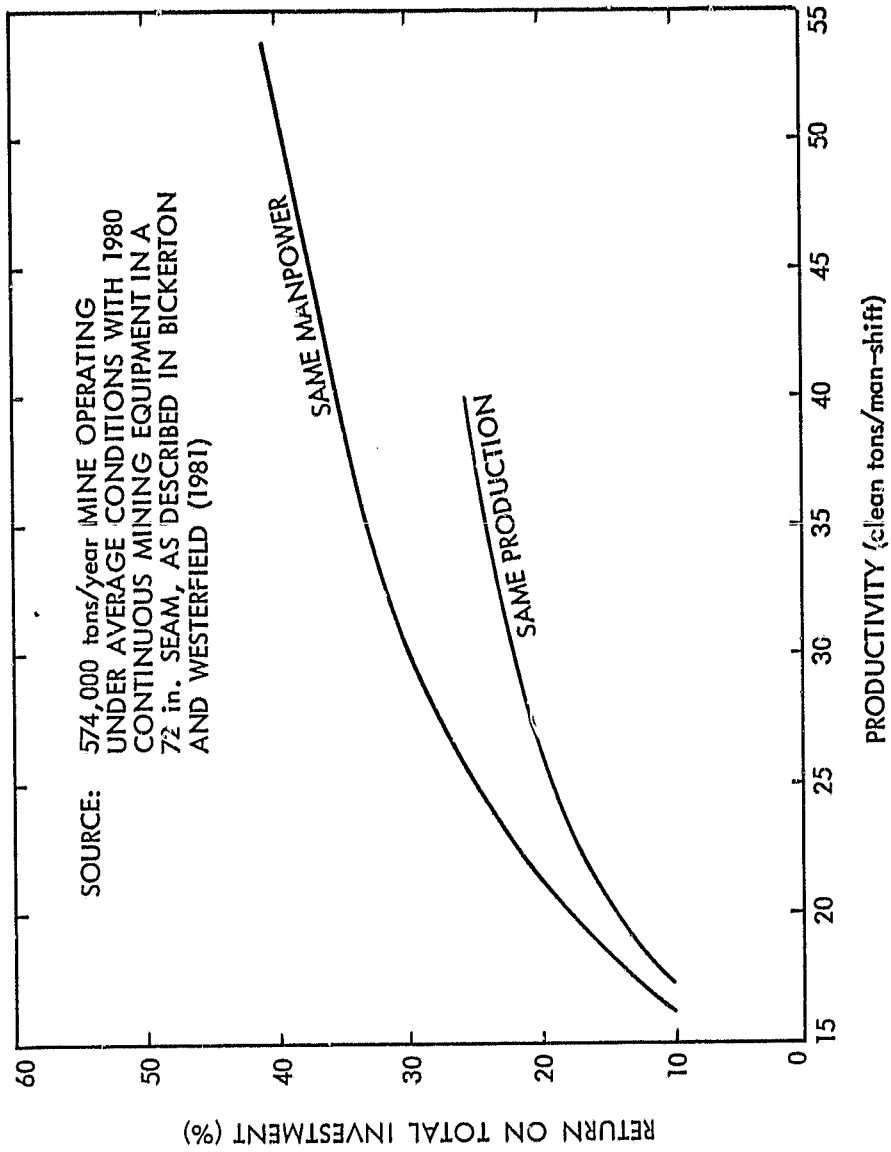
ORIGINAL PAGE is
OF POOR QUALITY

Figure A-3. Return on Total Investment vs. Productivity for a Contemporary Coal Mine

APPENDIX B

PSYCHO-SOCIAL ASPECTS OF SYSTEM DESIGN

APPENDIX B

PSYCHO-SOCIAL ASPECTS OF SYSTEM DESIGN

The following recommendations for the design of advanced coal mining equipment are taken from a study by Akin (1981) of the psycho-social aspects of productivity in underground mining. All of the recommendations are grounded in the assumption that it is desirable to retain and enhance the psychological and social variables that currently contribute to high productivity, and that it is important not to precipitate disruptive and discontinuous change in the culture of coal mining.

I. The equipment used for underground mining must be able to be "run" by the workers. That is, the pace and structure of the accomplishment of the work of getting coal must be primarily determined by the miners at the face and not by the structure of the equipment. This rules out equipment such as that constituting large assembly lines where there is a clear technological imperative with regard to accomplishing production. The miner must run the machine, rather than the machine running the miner. Following are five concrete implications:

(1) The equipment must have a psychologically manageable size. As miners relate personally to the equipment with which they work, knowing it by manufacturer name and model number, and having clear preferences about which kind of equipment is best, the machinery must be of a size so that individual pieces of equipment are readily identifiable as such. A continuous miner is of an acceptable size, while a longwall machine approaches the upper limit, beginning to look more like an assembly line. The machinery must remain a personal tool for the miner to use in running coal.

(2) The equipment must be modifiable by the user. This means that the operator of the equipment must be able to make changes to suit his particular operating style and to adapt the equipment to the particular environment in which it is being used. Equipment which cannot be "played around with" and personalized by the users will not support the meanings that the miner relies upon to generate high productivity.

(3) The equipment must allow for skill differentials and learning in its operation. How efficiently and how effectively the equipment performs must be in part due to the skill of the operator. In this sense, the equipment can be very complex from the operator's standpoint, requiring a great deal of learning to become a skilled user of the equipment, and allowing for the possibility of different operating styles.

(4) The design of the equipment must let the miner himself make decisions about how to mine and how to solve problems in the process of running coal. Decisions may involve equipment placement, equipment speed, or strategies for use, as well as the performance of non-routine maintenance. To the extent that there is more decision making at the coal face, there will be greater learning by the miners, and subsequently greater problem solving

PRECEDING PAGE BLANK NOT FILMED

ability available to meet the inevitable contingencies of underground production.

(5) <u>The equipment must be designed in a way so that the miner at the face can directly judge his own productivity.</u> Feedback on performance should come directly from doing the task. The miner should be able to continuously assess his performance.

II. <u>The design of the technical system must allow the maintenance of a social system which will support continued productive effort.</u> The preliminary work identified three structural features of a viable social system in the mine:

(1) <u>Work teams should be composed of six to twelve men to form face-to-face groups with a common task.</u> Groups larger than twelve will have a tendency to form independent subgroups, and groups smaller than six are unlikely to be able to maintain a strong identity and effective norms for productivity.

(2) <u>The technology must allow for continuance of working in pairs.</u> The "buddy system", helping and watching out for one another, is crucial. The design of underground tasks should not require a man to work alone.

(3) <u>The technology must be flexible enough in the way it is used to allow for discretion with regard to task assignment at the face.</u> That is, it must be possible for workers in a crew to trade jobs and to make daily decisions about how the operation will be run by that particular crew. Further, it must be possible for a crew to run short-handed by realigning some of the tasks within the crew. Fill-ins for absentees should be provided by extra effort within the crew rather than by bringing someone in from outside. This kind of flexibility must also allow for a member of the crew to apprentice to a more skilled member in order to learn new tasks. This will not be able to take place if a strict technological requirement for a particular crew size is present.

In the largest sense, the equipment must allow for discretion, control, and problem solving by miners working in cohesive groups at the face.

BIBLIOGRAPHY

Akin, G., 1981a, personal communication, May 1981.

Akin, G., 1981b, Psycho-Social Aspects of Productivity in Underground Coal Mining, JPL Publication 81-113.

Arthur D. Little Inc., 1975, Economic Feasibility of Recovering and Utilizing Methane Emitted from Coal, NTIS Report No. PB 249 728/AS.

Bickerton, C. R. and Westerfield, M. D., 1981, A Moving Baseline for Evaluation of Advanced Coal Extraction Systems, JPL Publication 81-31.

Brezovec, D., 1980, "Computer Terminals Go Underground," Coal Age, November 1980.

Camilli, F. C., et al, 1981, Geologic Considerations in Underground Coal Mining System Design, JPL Publication 81-74.

Chenery, H. B., 1949, "Engineering Production Functions," Quarterly Jour. Econ. 63:507-531.

Chironis, N. P., 1981, "R&D Projects Paying Off in 1981," Coal Age, February 1981.

Coal Age, 1980, "Management Systems Aid Operations," October 1980.

Diamond, W. P. and Levine, J. R., 1981, Direct Method Determination of the Gas Content of Coal: Procedures and Results, U. S. Bureau of Mines, Report of Investigation No. 8515.

Davis, J. J., Associates, Inc., 1977, Industrial Engineering Study of Continuous Mining Systems, Final Report USBM Contract No. J0357096.

Dutzi, E. J., Sullivan, P. J., and Hutchinson, C. F., 1980, The Environmental Assessment of a Contemporary Coal Mining System, JPL Publication 80-99.

Ferm, J. C., 1981, University of Kentucky, Lexington, personal communication, April 1981.

Ferm, J. C. and Muthig, P., 1982, A Study of the United States Coal Resources, JPL Publication 82-14.

Fortune Double 500 Directory of 1977, Time Inc.

Fowler, J. C., 1979, Subsurface Reflection Profiling Using Ground Probing Radar, AIME Preprint 79-341.

Fowler, R. L. and Troll, W. C., 1975, Feasibility of Remote Control and Development of Remote Control Devices and Sensors: Shuttle Car Sensor System, Bendix Corp., NTIS Report No. PB-248 830.

Gangal, M. D. and Banerjee, B. R., 1979, Deep Cutting Miner Production Task, Final Report on Contract No. J0177019, U. S. Bureau of Mines, by Ingersoll-Rand Research, Inc., Princeton, New Jersey.

Gangal, M. D., 1981a, report of a visit with mine operators and equipment manufacturers, February 1981.

Gangal, M. D., 1981b, report of a visit to Ingersoll-Rand Research, Inc., Princeton, New Jersey, May 1981.

Goldsmith, M. and Lavin, M. L., 1980, Overall Requirements for an Advanced Underground Coal Extraction System, JPL Publication 80-39.

Griffiths, W. R., 1977, draft input to the Market-Oriented Program Planning Study, Energy Research and Development Administration.

Hill, F. E., 1980, "Causes for the Productivity Decline in U. S. Coal Mining," Mining Congress Journal, September 1981.

Hill, R. D. and Bates, E. R., 1978, Acid Mine Drainage and Subsidence: Effects of Increased Coal Utilization, U. S. Environmental Protection Agency, Report No. EPA-600/2-78-068.

Kalvinskas, J., 1980, Final Report, Coal Desulfurization by Low Temperature Chlorinolysis Phase II, JPL Publication 80-15.

Kaplan, S., 1981, Energy and Environmental Analysis, Inc., Arlington, Virginia, personal communication, June 1981.

Kissell, F., et al, 1981, Reducing Dust of Longwall Shearers by Confining the Dust Cloud to the Face, U. S. Bureau of Mines, Technical Progress Report No. 111.

Kohler, J. L., et al, 1981, Impact of Advanced Development Techniques on Mine Design, Final Report on Contract No. 77-C-01-891519, U. S. Dept. of Energy, Ketron Inc.

Krynine, D. P. and Judd, W. R., 1957, Principles of Engineering Geology and Geotechnics, McGraw-Hill.

Lavin, M. L., 1980, report of visits to mines in Utah, November 1980.

Lavin, M. L. and Borden, C. M., 1978, A Life Cycle Description of Underground Coal Mining, U. S. Department of Energy, Report No. FE/9036-1.

Leonards, G. A. (editor), 1962, Foundation Engineering, McGraw-Hill.

Lynn, A., 1980, report of visits to mines in W. Virginia, December 1980.

Mabe, W. B., 1979, Economic Baselines for Current Underground Coal Mining Technology, JPL Publication 79-122.

Mansfield, E., 1968, Industrial Research and Technological Innovation, W. W. Norton.

Manula, C. O. and Rivell, R., 1974, "A Master Design Simulator," presented at the Twelfth International Symposium on the Applications of Computers and Mathematics in the Minerals Industry, Colorado School of Mines, Denver.

Marrus, L. D., McGinnis P., and Ronge, C., 1976, Logistic Performance of Continuous Miners, NTIS Report No. PB-255 971.

Merritt, P. C. and Brezovec, D., 1980, "Longwalling Aims for Bigger Slice," Coal Age, December 1980.

Minetics Corp., Pittsburgh, 1980, product brochure titled, "Mine Monitoring and Control."

MSHA, 1976, Code of Federal Regulations Title 30, Mineral Resources, United States Department of Interior, revised July 1, 1976.

Nielsen, G. F., 1981, "New Coal Capacity Surges Ahead," Coal Age, February 1981.

1980 Keystone Coal Industry Manual, Mining Information Services, McGraw-Hill, New York.

National Research Council - Committee on Measurement and Control of Respirable Dust, 1980, Measurement and Control of Respirable Dust in Mines, National Academy of Sciences, Report No. NMAB-363 Washington D.C.

Peng, S. S. and Chandra, U., 1980, "Getting the Most from Multiple-Seam Reserves," Coal Mining & Processing, November 1980.

Petzinger, T., 1980, "Major Oil Companies Increase Their Share of U. S. Coal Output," Wall Street Journal, December 22, 1980.

Phen, R. L., 1981, report of visits to mines in Colorado and Wyoming, February 1981.

Salyers, E. F., 1979, "The Use of E-A-R Energy Absorbing Products for Noise Control on Mining Equipment," paper presented to the 1979 Canadian Institute of Mining and Metallurgy, Winnipeg.

Saxena, S. K., 1979, Evaluation and Prediction of Subsidence, American Society of Civil Engineers, New York.

Smith, B., 1980, "Subsidence Control Project Set for Fairmont, West Virginia," Department of Interior, News Release, August 5, 1980.

Suboleski, S. C., 1978, "Effects of Physical Conditions on Continuous Miner Production in Underground Coal Mines," Ph.D. Thesis, Pennsylvania State University.

Sullivan, A. M. and Cawley, J., 1980, "Communication Improves Mine Safety," Coal Age, October 1980.

Sullivan, P. J., 1981, Ball State University Muncie, Indiana, personal communication, April 1981.

Sullivan, P. J., et al, 1980, A Methodology for the Environmental Assessment of Advanced Coal Extraction Systems, JPL Publication 79-82.

Sullivan, P. J. and Lavin, M. L., (1981), "Environmental Cost of Underground Mining Technology," paper presented at the Conference on Energy in the Man-Built Environment, Vail, Colorado, August 3-5.

Terasawa, K. L and Whipple, D. W., 1980, Regional Price Targets Appropriate for Advanced Coal Extraction, JPL Publication 80-91.

Tomimatsu, T. T. and Johnson, R. E., 1976, "The State of the U. S. Coal Industry: A Financial Analysis of Selected Coal-Producing Companies with Observations on Industry Structure," Bureau of Mines Information Circular 8707.

Toth, G. W., 1981, Underground Coal Mining Cost Model, EPRI Report No. EA-1273, vol. 1.

Trist, E. L. and Bamforth, K. W., 1951, "Some Social and Psychological Consequences of the Longwall Method of Coal-Getting," Human Relations, 4:3-38.

United Mine Workers of America, 1981 Bituminous Coal Wage Agreement, to be published.

U. S. General Accounting Office, 1981, Low Productivity in American Coal Mining: Causes and Cures, Report No. ERD 81-17.

Windes, S. L., 1949, Physical Properties of Mine Rock, part 1, United States Bureau of Mines, Report No. RI 4459.

Young, W. H., 1967, "Thickness of Bituminous Coal and Lignite Seams Mined in 1965," Information Circular No. 8345, U. S. Bureau of Mines.

Yonemoto, K., 1978, "The Present Status and the Future Outlook of Industrial Robot Utilization in Japan," a publication of the Japan Industrial Robot Association.

Zimmerman, W. F., 1981, A Safety Methodology for the Evaluation of Advanced Coal Extraction Systems, JPL Publication 81-54.

Zimmerman, W. F., 1980, Health Requirements for Advanced Coal Extraction Systems, JPL Publication 80-72.