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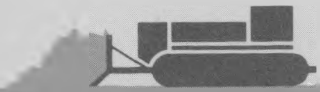
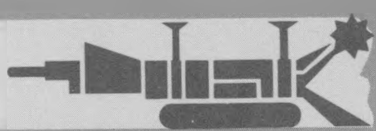


Built-In Test Equipment for Front-End Loaders

Final Technical Report
Contractor—Skelly and Loy

January 1980

Contract No. U.S.D.O.E. AC01-79ET11268



U. S. Department of Energy
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BUILT-IN TEST EQUIPMENT FOR FRONT-END LOADERS

FINAL TECHNICAL REPORT

U.S. DOE Contract No. DE-AC01-79ET 11268
Task Order No. 001

Prepared for:
UNITED STATES DEPARTMENT OF ENERGY
Mail Stop D-107
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January 1980

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ABSTRACT

The objective of this study was to evaluate the feasibility of using "Built-In Test Equipment" (BITE) on front-end loaders (FEL) to increase their availability and productivity. Coal mining productivity is constrained in many operations due to the low availability of FEL. BITE systems allow for reductions in unscheduled maintenance downtimes and implementation of efficient preventative maintenance practices. This report illustrates the feasibility of the concept from a technical and economic viewpoint. It provides a representative system hardware description and a preliminary system specification.

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EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The Department of Energy has initiated this study, "Built-In Test Equipment for Front-End Loaders," due to the necessity of increasing front-end loader availability in coal mining environments. This study resulted from one of the conclusions of an earlier study, "Constraints Limiting the Availability of Front-End Loaders." The current study had as its objective the evaluation of the feasibility of using on-board testing and monitoring equipment to improve the availability and productivity of front-end loaders. This study develops a conceptualization for an electronic, microprocessor controlled, monitoring system capable of meeting these objectives in a coal mine environment. Figure 1 shows an artist's conceptualization of this system.

The initial efforts in this project centered on a determination of the major causes of front-end loader lost/downtime. The areas causing significant decreases in availability, and therefore productivity, were engine failure, drive train failure, hydraulic system failure, damaged tires, and cracked loading buckets. One contributing factor to these failures is environmental. The coal mine operating environment is extremely harsh and causes accelerated wear patterns on the machine. A second factor results from those situations where comprehensive preventative maintenance programs are not enforced.

Another causative agent for significant amounts of lost/downtime is operating methodology. Hydraulic cylinders and loader buckets are often broken due to the impact loads generated when the operator rams the material

Figure 1 - Artist's Conception - BITE Display

to be loaded at excessive speed or when he attempts to generate excessive breakout forces in consolidated materials. Operator abuses such as these are termed "negative productivity" factors since they usually occur when the operator is seeking shortcuts to increase his productivity. The results of actions such as these only serve to reinforce the poor availability percentages generated due to harsh operating environments.

Additional efforts during this study were targeted at developing a concept for a "Built-In Test Equipment" (BITE) system. The basic function served by this system addresses the aforementioned availability constraints. When fully populated with all available options, BITE can supply design data on actual operating conditions and operating loads for manufacturers. It can also supply comprehensive maintenance data on operating conditions and component life so as to allow improved preventative maintenance procedures to be generated. The combination of these data should enable an improvement in the availability percentages of front-end loaders (FEL). Previous studies (Source 42) have shown that without good preventative maintenance, availabilities can fall as low as 30 percent. With aggressive preventative maintenance, the same study shows average availabilities of 75-80 percent. The incorporation of BITE systems on FELs will allow operators to upgrade their preventative maintenance programs and achieve the latter percentages at a very low incremental cost. Additionally, BITE will allow operators to anticipate unscheduled maintenance activities and further increase the availability percentages. With development costs amortized over several years' production, the consensus of manufacturers contacted feel that the BITE system described herein would add only five to twenty-five thousand dollars to the cost of a new FEL. The net effect of this incremental cost would be to allow the availability percentage to approach the theoretical maximum of approximately 95 percent. The savings in operating costs alone could amount to two dollars per ton of coal produced for a typical mining operation. Obviously, the savings will be dramatic for operators using only minimum preventative maintenance procedures or operating in harsher environments.

Aside from addressing availability constraints, the BITE system described in this report also addresses the constraints on productivity. The "negative productivity" factors mentioned in the previous section on availability are the first example of productivity constraint reduction. The BITE system cues the operator with audible warnings whenever his operating mode imposes unnecessary strain on the machine which will lead to premature breakage and the concurrent loss of production. Other components of the system allow the operator to obtain data on his actual production. Additionally, in those operating modes utilizing repetitive sequences, he can obtain feedback on his cycle times and their consistency.

A key factor in the generation of the BITE system specification was quickly realized to be the operating environment. Computers are notorious in their demands for a stable, well-defined operating environment. Since this type of environment never exists on FELs, the system to be developed was necessarily a special type — totally different from the BITE systems currently used on draglines (Source 31) that use commercial computer components. The most obvious specialty BITE systems currently available are those used by the military. These were quickly rejected due to their costly nature. The computers and their associated transducers were developed without cost constraints due to their environmental reliability requirements. Consequently, their solutions negate their use in a cost-conscious market. Fortunately, the revolution occurring in the semiconductor industry in supplying components for the industrial process control and automotive industries is generating the types of system components needed for BITE.

The system outlined in this report is based on the employment of a central microprocessor module to supply intelligence and memory; a personality module containing sufficient read-only memory (ROM -- see glossary in Appendix E) for storage of the operating algorithm tailored to the machine type and use; and data channels comprised of analog transducers, signal conditioners, short-run analog signal lines feeding long-run digital signal lines, and analog to digital converters. The data channels are configured according to the function being monitored and the data analyzed by the microprocessor according to the algorithm. Full details and specifications are reviewed in subsequent sections of this report.

The remaining efforts of this project were dedicated towards market research on the feasibility of this system. Research indicates that equipment manufacturers are instituting changes to their FEL. On models such as the Caterpillar 980C, the first vestiges of BITE systems, even though rudimentary in nature, are being installed. This is a direct result of the need of a manufacturer to supply a more reliable machine and the operator's demand for the same. The survey conducted during the course of this study confirmed the need and the demand.

The objective of this study was to determine the feasibility of using

BITE on FELs. It has been shown that operators feel a strong need for BITE systems. A number of manufacturers are responding in various ways to that need. At present, there is no unity in the approaches these responses provoke. The contents of this report show a representative system that will achieve more uniform results and its economic feasibility.

The system shown in this report was developed to address the needs of potential BITE users while using currently available technologies. The specification is preliminary in nature due to the unavailability of some information. Further work is needed to establish the best match of available technologies and environmental envelope parameters to be delineated in the prototype specification. It is necessary to establish conclusively that components available today will survive in a mine environment before monies are committed to prototype development.

Therefore it remains for further specification development to be undertaken. In this manner, higher confidence levels can be established in system costs and savings. A set of recommendations in this report details the actions needed. It is our belief that this developmental action will yield a refined set of specifications that can be easily and cost effectively met by current technology. The potential information on mine environments and machine characteristics alone garnered from such a system development would justify its undertaking. The resultant increased production and lowered operating costs resulting from its widespread employment adds increased impetus to its necessity.

INTRODUCTION

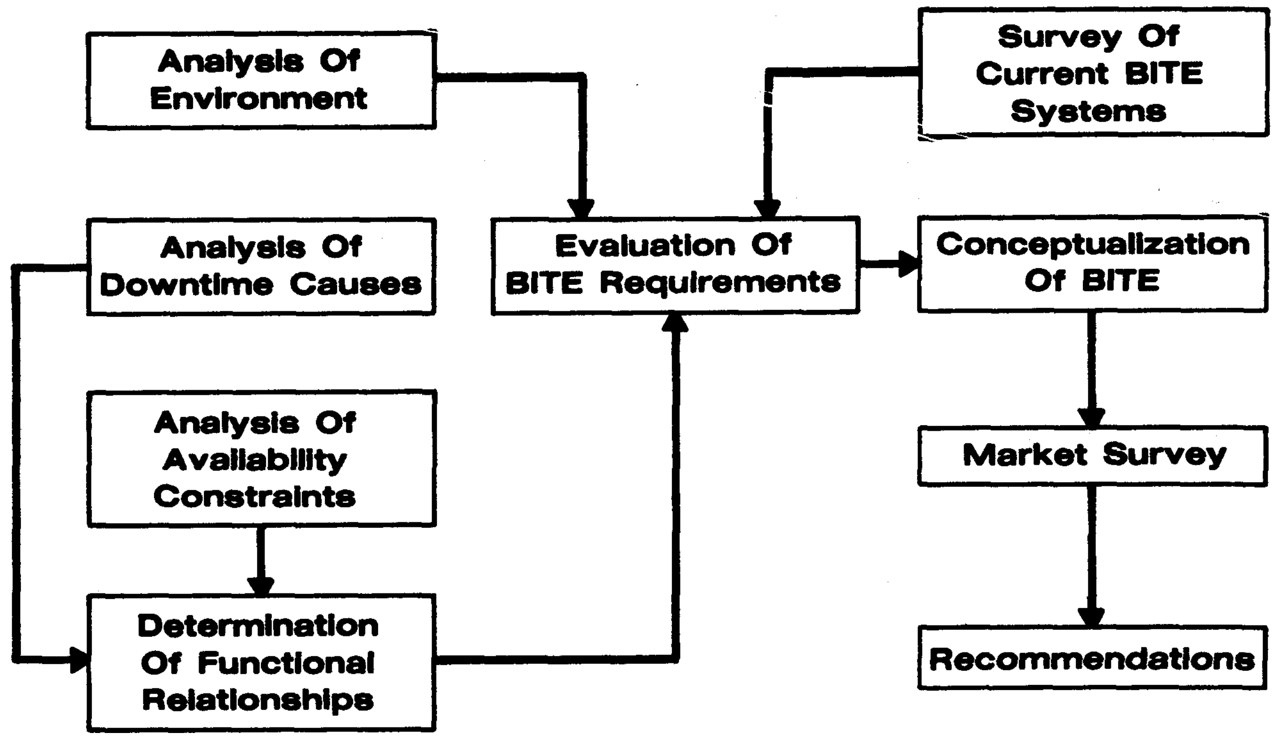
INTRODUCTION

This report and its appendices comprise the documentary output of the study "Built-In Test Equipment for Front-End Loaders." The study was performed by the Energy Division of Skelly and Loy during the last half of 1979 for the U.S. Department of Energy under contract number DE-AC01-79ET11268. Figure 2 shows the sequence of the study.

The objective of the study was to evaluate the feasibility of using on-board testing and monitoring equipment to improve the availability and the productivity of the front-end loader (FEL).

Previous studies have dealt with the constraints to the availability of FELs (Source 42), and the standardization of FEL controls (Source 6). As will be seen later, the constraints are sometimes due to an operating environment which causes mechanical breakage regardless of the level of preventative maintenance. Coal dust, being extremely fine and abrasive, has the propensity for penetrating even the best of seals. Once inside of the various systems, it scores cylinders and ruins pumps. Electric motors also draw the dust inside and create very serious fire hazards. The operating environment subjects the components to temperature swings from below zero to well past boiling, taxing the vehicle's various fluids and often rendering them ineffective. Pulsating diesels and rough benches create vibration spectrums which induce fatigue and machine breakage. Rocky benches also create accelerated tire wear and damage.

Other major causes of breakage arise from improper operating procedures. The operators aggravate these environmental problems by forcing the machine to work beyond its limits. Excessive speed, culminating in high



ORGANIZATION AND SEQUENCE OF THE STUDY

FIGURE 2

impact loads to the bucket mechanism upon contact with a pile of material, increases bucket breakage. Attempts to break out consolidated materials overload hydraulics, straining pumps into submission and overheating the fluids until they break down. Bucket overloading tips FEL's to accident-causing angles and wears tires dramatically.

To aggravate these environmental and operational factors, a lack of emphasis of good preventative maintenance procedures sometimes allow conditions to go uncorrected that may lead to premature breakage. Combinations of these factors yield FEL availabilities ranging from 30 to 80 percent.

Studies on control standardization emphasize the need for standardization in order to reduce accidents. These efforts, spurred by the rapid increase in the use of rubber-tired FELs in the coal mining industry, were initially restricted to the man-machine interfacing aspects of the operating controls. Display, maintenance procedure and operator training standardization studies were not included to prevent the multitude of safety-critical, productivity, and availability factors associated with these from reducing the emphasis on the man-machine relationships. BITE inclusion on FELs as a standard component will aid in removing this restriction by allowing automatic monitoring of machine functions and status, and by allowing feedback in real time to the operator. The monitoring and feedback actions will allow the operator to check and improve his productivity. They will also allow him to insure that his operating procedures are not injurious to his machine or himself.

These same studies have shown that an aggressive preventative maintenance procedure can dramatically increase machine availability. BITE can act as a complement to these maintenance activities by providing statistical data on the operating characteristics and life of individual machine components. A similar concept has been successfully utilized on draglines to increase productivity (Source 44). The work completed in the current contract has been a logical extension of the dragline concepts to the unique characteristics and environment of the front-end loader.

What is presented herein is a summary of the progress in this field to date. It encompasses work done on standardization; work done on other mine equipment; work done on other equipment types; and work done in fields such as the aerospace industry. It presents a concept for a BITE applicable not only to FEL, but also to other equipment with analogous functions. It must be noted though that standardization cannot be accomplished by reason of analogous function alone. Real differences exist between machines in their usage of operational procedures. The concept presented allows for the tailoring of a basic unit to different usages. The system is designed to function as a cost-effective base unit, supplying sufficient intelligence and flexibility to adapt to these differences. The presented concept also factors in work being done by those manufacturers who did not consider their findings to date proprietary. Also, to the extent feasible, it includes the recommendations of standards organizations such as S.A.E. and includes basic ergonomic principles in the displays.

Only through the awareness of the existence of problems can improvements be made. Until we have reliable information on operator efficiencies, we cannot create programs to improve them. Only when we have firm data on availability constraints and their causes can we design better machines and implement comprehensive preventative maintenance programs. BITE is aimed at a low cost solution to obtaining all of the above data without creating hardships for the operator or forcing maintenance and management personnel to endure test programs and complicated instrumentation systems.

AVAILABILITY CONSTRAINTS

AVAILABILITY CONSTRAINTS

The low mechanical availabilities of front-end loaders often restrict the productive capabilities of surface mining operations where these machines are used for essential stripping and coal loading functions. Availabilities of 50 to 60 percent are fairly common in harsh rocky environments due to the method of operation inherent to the loader. In a continuous "loading mode", the loader must perform a considerable amount of manuevering and gear changing per cycle. "Load and carry mode" operations require travelling long distances at maximum load capacity over usually less than desirable surfaces. These conditions accentuate the stresses on several critical loader components and eventually lead to fatigue and failure.

MECHANICAL CONSTRAINTS

Several components exhibit high failure rates. The following material is based on previous case studies. It delineates those components most often found to fail and the causes for the said failure.

Engine

Typical loading operations often develop excessive amounts of airborne particulate matter. These dust particles infiltrate and overload air filters, eventually finding their way into cylinder bores. Accumulation of these particles on cylinder walls results in scoring, seal failure and compression loss. Excessive accumulations may cause engine seizure. Although these failures are serious, dust creates even more hazardous situations.

The fine coal mixes with any grease or oil covering the machine to create an extremely flammable substance. The presence of this substance can be detrimental to engine components. Its ignition can be disastrous. Frequent washing of the machine and strict attention to filter replacement schedules can alleviate most of these problems.

Engine life is also abbreviated due to component fatigue from fluctuating peak loads. As the loader travels through its cycle, the demands on the engine vary from idle to near maximum horsepower output. This places great stress on all moving parts in the engine and occasionally some fail. Proper lubrication and a careful watch on engine temerature can help to extend the usable working life of the engine.

Drivetrain

As mentioned previously, the loading operation requires several stops and starts in addition to numerous gear changes per cycle. The inertia forces caused by these motion changes are transferred through the planetary drive units, the differential, the transmission and the torque converter. As the load on the machine increases, a greater amount of torque must be transferred through the drivetrain. These torque loads place continual strain on drivetrain components and occasional failures result. Machine abuse is a major cause of drivetrain failures. Ramming the bucket into the digging face and allowing the tires to spin freely creates undue stresses on drivetrain components. Just as do overloaded vehicles, ballasted tires add to the strain on the drivetrain. It is essential that transmission and torque converter fluids remain clean and at a working temperature low enough to prevent fluid degradation. Adherence to proper loading and operating techniques can alleviate many drivetrain failures.

Hydraulics

The reliability of a hydraulic system is totally dependant on the condition of the fluid within the system. Hydraulic components operate under high pressures with close tolerances. Dirty or contaminated fluids erode and destroy critical surfaces causing inefficiency and component failure. Fluid contamination occurs in two forms. They are (1) dirt or particulate matter and (2) fluid degradation. The majority of the particulate contamination is introduced during maintenance procedures and while refilling the fluid. Fluid degradation is a chemical process that deteriorates the lubricating qualities of the fluid and creates thick sludges and varnishes that erode component surfaces and clog critical orifices. The chemical process is called oxidation and is accelerated by heat. Proper filter maintenance and temperature control are essential for the elimination of failures due to fluid conditions.

The most persistant problem plaguing hydraulic systems is leakage. High pressures erode minute openings until a leak develops. These leaks reduce the efficiency of the system by draining essential pressure. Pumps also cause many problems for hydraulic systems. Since hydraulics pumps require close tolerances for proper operation, worn internal pump parts cause inefficiency and heat buildup. This heat degrades the oil and destroys the pump. Pressure spikes also occur frequently in hydraulic systems. Caused by the rapid closing of valves, these spikes can be three times the rated pressure of the system and can shear pump shafts.

Hydraulic cylinders actuate the forces supplied by the fluid. They require finely polished surfaces and effective seals. Often these seals develop leaks and the efficiency of the cylinder is reduced. Dirt and abrasive particles from the fluid score polished surfaces. This, in turn, destroys seals. Bent rods and cracked end plates are two mechanical failures caused by operator abuse and misapplication of equipment. He can encourage pump failure and fluid heating by overloading the bucket lift mechanism (such as by trying to break out consolidated material). Forcing the pump to work beyond its rated capacity for extended periods leads to its quick deterioration. Pressure relief valves do not cure this since they still allow the working of a pump at its maximum. Proper operating procedures and effective operator training are the only ways to cure these problems.

Tires

The length of a tire's life relates to the surface conditions over which the loader must operate. Rockey and slippery surfaces greatly reduce tire life by cutting, chipping and abrading the tread until failure is imminent. Tire spinning, usually on slippery surfaces, wears tread and causes excess heat buildup in the tire carcass. This heat buildup destroys the bonding between the tread and the plies, and causes rubber degradation.

Another major cause of tire failure is overloading. Overloading may result from carrying too heavy of a payload or from improper inflation pressures. The effects of overloading include overheating, over-stressing, and crushing the tire carcass. Under-inflated tires yield the same effects as overloading. The tire does not contain the pressure required to adequately support the load so it is, in effect, overloaded. Daily inflation maintenance, effective working surface maintenance and proper operating techniques prove to significantly lengthen tire life.

Bucket and Lifting Mechanisms

The major cause of failure in buckets and lifting mechanisms is stress cracks. These cracks start very small and propagate into large cracks that weaken the structure of the bucket or boom. Cyclic compression and tension within the metal forms the small cracks and causes their expansion during normal operation. Operator abuse is also a factor contributing to cracking. Ramming the bucket into the bank too rapidly will cause an excessive impact load and crack the bucket or teeth in addition to the boom and its pivots. Proper care during operation and frequent inspections can alleviate many of these stress cracks.

Electrical Systems

Electrically driven front-end loaders incorporate two to four high-voltage electric motors and a high capacity alternator or generator. These components are subject to overheating from the combination of high ambient temperatures and normal component operating temperatures. To cool these units, a blower system is often utilized to force air inside the motor housing. Although this air is filtered, dust and dirt frequently enter the motor housing. This results in abrasion, scoring, and a potential fire hazard. Armatures and brushes require the most frequent replacement due to wear. Accumulations of coal dust within the housing and current overloads propagate fires which destroy the motor unit. Frequent changing of air filters and current overload protection are most effective in reducing drive motor failures.

PREVENTATIVE MAINTENANCE CONSTRAINTS

A strictly enforced preventative maintenance program is an essential part of effective equipment management. Many serious and costly failures can be foreseen and action taken to alleviate the cause of the problem if a close watch is kept on individual components. Often, a component will exhibit signs of malfunction that can be recognized long before a failure occurs. The time lost to periodic preventative maintenance is small compared to the losses incurred due to the need for an engine replacement. For example, an excessively hot hydraulic pump can be diagnosed and rebuilt before pump seizure or breakage can damage other parts of the hydraulic system. This type of preventive repair can save money and increase availabilities by eliminating costly repairs for severe damage and by avoiding unscheduled downtimes.

Accurate recordkeeping is an important part of effective preventative maintenance. Judging component conditions over a series of inspections will alert the maintenance personnel of deteriorating equipment or impending chronic failures. This information can then be used to improve system designs where necessary.

The correlation between loader availability and the extensiveness of preventative maintenance procedures was examined in a U.S. DOE study entitled, "Constraints Limiting the Availability of Front-End Loaders." It was determined that, even in severe conditions, mines that employed a thorough preventative maintenance program attained excellent availabilities between 70 to 80 percent. Mines that had superficial or nonexistent programs were constantly plagued with unscheduled downtime and costly repairs. Numerous case studies are illustrative of the value of regular preventative maintenance. They also serve to show the diversity of programs in existence now. They detail only the preventative maintenance programs and are excerpted from previous reports.

Case History Number 1

A full maintenance crew is employed by this mine to repair or replace components and perform preventative maintenance. A well equipped service shop is available on site; however, these facilities are not so equipped to allow engine rebuilding. Engines are sent to the local factory representative for rebuilding. All other repair work, not covered by warranty, is done in the repair shop. Preventative maintenance is performed on a per shift, 125 hour, and 500 hour schedule.

Prior to the start of every shift, a visual inspection of the machine is performed by a mechanic. Torque converter and transmission seals are checked. Linkage and bands are adjusted. Boom seals and hydraulic cylinders are checked for wear and leakage. Buckets and booms are inspected for stress cracks. All fluid levels are checked. Hydraulic lines are inspected for leakage and clamps are tightened, and tire inflation pressures are checked. At the end of every shift, the engine compartment is steam cleaned. Any problems discovered during this pre-shift inspection are scheduled for repair.

Check lists are followed for the 125 hour and 500 hour inspections. Both inspections are visual and any leaks, loose bolts, cracks, improperly operating components or unsafe conditions are scheduled for repair. All major maintenance areas are checked including the brakes and air system, electrical system, instruments and gauges, cooling system, hydraulic system, engine, filtering system, drive train, steering system, final drive, wheels and tires, bucket and boom, and automatic lubrication system. The unit is then tested for proper operation before being sent back into production. Oil and filters are changed every 250 hours and hydraulic fluid is replaced every 500 hours.

By following a regularly scheduled preventative maintenance schedule and promptly repairing damaged components, the mine has kept availabilities of the three front-end loaders around 85 percent. Operator experience is also a factor in the overall availability of the loaders. The average level of operator experience at this mine is one year. This relative lack of experience could account for some of the mechanical failures.

Case History Number 2

The front-end loaders are the primary coal stripping machines at this mine and therefore, must be kept in operation as much as possible. To obtain this required availability, the mine has implemented a rigorous preventative maintenance (PM) program. All machines are examined every day during the third shift for signs of wear, failure, or impending failure of parts. Fluid levels are checked and any needed fluid is added. Air filters are cleaned and vacuumed. Torque converter seals are checked. Transmission bands and linkage are adjusted. Buckets and booms are checked for stress, and pivots are lubricated. Hydraulic lines are checked for leaks, and clamps tightened. Tire pressures are also checked. Any required repair work is also performed during this four hour PM period. Other periodical PM is also performed to replace engine oil and filters and hydraulic fluid.

Cooperation with the maintenance program is considered excellent. Average availabilities for the loaders range from 67 percent for the Hough H 400 C; 81 and 82 percent for the Dart D 600's; and 82, 87 and 90 percent for the Caterpillar 992 B's. The rigid preventative maintenance program reduces the unscheduled downtime by determining deteriorating components before a catastrophic failure necessitates downtime.

Case History Number 3

This mine employs six 23½ cubic yard capacity front-end loaders for handling coal. Four of the machines are Marathon LeTourneau L-700 A's, one is a Marathon LeTourneau L-800, and the other loader is a Dart DE-620. Availabilities on these machines range from 75 to 87 percent. Several smaller front-end loaders are used throughout the mine for support and clean up. The Dart DE-620 is usually employed in the stockpile area since it was determined that this is the area most suited for this loader. The other loaders are distributed throughout and interchanged between the different pits.

Several years ago, a front-end loader maintenance division was established at the mine in an effort to increase the availabilities of the coal digging loaders. Prior to the implementation of this program, the machine availabilities averaged around 30 percent. Present availabilities are 75 to 82 percent. Rigidly followed preventative maintenance programs and accurate recordkeeping can be credited for the program's success. The division consists of mechanics and electricians. This combination provides the required balance of electrical and mechanical maintenance knowledge that is essential for the repair of these diesel-electric machines.

This mine has an excellent maintenance shop and a good preventative maintenance program. All fluids, oils, and wear points are checked regularly and manufacturers' recommended programs of preventative maintenance are followed. Certain critical wear areas are checked on a daily basis as a part of the mine's preventative maintenance program. Buckets and booms are checked for stress cracks. All fluid levels and tire pressures are checked, and the main steering pivot is greased. Bucket and boom pivot points are checked and lubricated twice per day. This preventative maintenance program also includes changing the engine oil and filters when 200 hours of usage is attained.

From the foregoing material, we can see the benefit of good preventative maintenance programs. From availabilities of 30 percent without a program, we can enhance availability to 80 percent with one at a cost of only a few hours per year on the part of a dedicated maintenance crew.

CURRENT MONITORING SYSTEMS

CURRENT MONITORING SYSTEMS

It is easily recognizable that the revolution in the electronics industry is having a profound effect on many industries. Our quest for increased domestic energy resources is bringing this revolution and its new technologies to the coal mining industry. In the electronics industry, equipment upgraded in capability through advances in technology is characterized as being of a new generation. We may view the instrumentation and monitoring of FEL functions in an analogous manner. The majority of existing front-end loaders in this country use the mechanical and electro-mechanical instruments developed years ago. These are the first generation in the instrumentation/monitoring family tree. The gauges comprising this generation are simple, rugged, and primarily mechanical in nature. They supply information to the operator on various operating conditions in real-time and are of little use to management or maintenance personnel concerned with anything except troubleshooting a defective machine.

A second generation is evidenced in the trend towards inclusion of electronic monitoring systems on several new models of FEL by several manufacturers. These systems are still simple as they do not rely on the intelligence of a computer. However, they do possess hardwired logic that cues the operator on different necessary actions. These systems can discriminate between conditions affecting the operational ability of the machine such as overheating, and safety related conditions such as loss of brake pressure. This new generation, a trend gathering momentum in the industry, still does not address the needs of the maintenance nor management factions. But it does signal the emergence of electronics as a viable instrumentation/monitoring aid for the operator.

The following material describes these two generations. It is illustrative of where the industry has come from and where it is now. The third generation that logically follows these is the subject of this report - the on-board computer capable of addressing the needs of the operator (productivity), the maintenance person (availability), and management (productivity and availability). The course of its development will be the subject of subsequent sections.

EXISTING FEL INSTRUMENTATION

All front-end loaders utilize a number of gauges and warning lights to monitor and indicate the condition of critical systems affecting loader operation. The number of functions monitored on each machine varies with manufacturer and machine size. Larger machines usually incorporate more complex systems with more expensive components; therefore, more extensive monitoring is preferable. Individual manufacturers consider certain functions worth monitoring while others disregard these same functions. Several functions, however, are considered by all manufacturers as critical to loader operations and are monitored on all loaders of the size most commonly used in surface coal mines. These include brake system pressure, engine oil pressure, fuel level, engine water temperature, hydraulic system temperature, and torque converter oil temperature.

The braking systems on front-end loaders can be either full hydraulic, full air, or air over hydraulic. Air system pressures are measured from an air chamber connected to the brake lines. Hydraulic oil pressure is measured from the nitrogen accumulator. Most front-end loaders employ a diaphragm actuated rheostat sending unit that regulates the current flow through an electromagnetic gauge on the dash. The diaphragm is subjected to the pressure in the air chamber or nitrogen accumulator so that increasing pressures cause a higher dial reading. Some loaders utilize a totally mechanical monitoring device to determine brake pressures. A tube connects the dash gauge directly to the air chamber or nitrogen accumulator. The system pressure then acts on a bourdon tube which operates the gauge indicator. This type of monitoring device is not as accurate or reliable as the electrical sending unit type although it is less expensive.

Engine oil pressure is measured using the same devices as for brake pressure except that the sending unit is connected directly to the oil line. A marking on the dash gauge indicates normal operating pressure.

Engine coolant temperature, hydraulic system fluid temperature, and torque converter oil temperature are monitored most often using a thermistor. This device changes its resistivity with varying temperatures. The same type of electromagnetic actuated gauge is utilized in each case. Its face displays green, yellow, and red regions which indicate cold, normal and overheated conditions. The monitoring point for engine coolant temperature is located at the outlet line from the engine back to the radiator. Hydraulic fluid and converter oil temperature measurements are acquired from their respective outlet lines back to the reservoir.

Another temperature monitoring device is utilized in some loaders. It consists of a vapor-pressure operated bourdon tube, mechanically linked to the indicator. This type of gauge is more susceptible to sticky, jumpy or erratic movement than thermistor units and so is less reliable.

The fuel level gauge utilizes a float linked to a slide rheostat sender. The sender regulates the current flow to either an electromagnetic or bimetalic gauge. A calibrated friction brake is usually included in the tank unit to eliminate oscillation due to wave motion.

Other instrumentation common to all loaders includes an ammeter to indicate whether the alternator or generator is charging or not, an electric hour meter to measure the cumulative operating time of the machine, a speedometer, a tachometer, and a parking brake indicator light.

Several loader manufacturers recognize the need for instrumentation in addition to that previously described. The reasoning for this additional monitoring is mostly safety related. Loud warning horns and flashing warning lights alert the operator to malfunctioning equipment, dangerously low fluid levels, or extremely high system temperatures. Often these warning devices are actuated by the maximum range limits for typical monitoring units.

These additional gauges and warning devices are shown by loader manufacturer in Table 1.

TABLE 1
FEL GAUGES

CASE

- Alternator warning light
- Clutch pressure warning light

CATERPILLAR

- Coolant flow warning horn
- Air cleaner service indicator
- Pilot system filter system service indicator
- Engine oil level gauge
- Fuel pressure gauge
- Hydraulic filter service indicator
- Hydraulic system oil level
- Variable capacity torque converter setting

CLARK

- Automatic lubrication system pressure warning light
- Brake system hydraulic oil pressure warning gauge with audible horn

DART

- Balanced boom pressure gauge
- Hydraulic systems high temperature warning light
- Lo-air "wig-wag" warning device
- PTO high oil temperature warning light

FIAT-ALLIS

- Low air pressure warning light and buzzer

HOUGH

- Air cleaner service indicator

TABLE 1 (Cont'd.)
FEL GAUGES

MARATHON LE TOURNEAU

- Engine low oil pressure warning light
- Engine high temperature warning light
- Cooling blower failure light
- Air cleaner service warning light
- Warning light test switch
- Electronic diagnostic meter

TEREX

- Air cleaner restriction gauges
- Three way alarm for low oil pressure, high water temperature, and high torque converter temperature

The growing trend in loader instrumentation is to replace the mechanical type of monitoring devices such as the bourdon tube with more reliable electronic sensors. These sensors are continually being improved and refined and the existing electro-mechanical sensors will soon be replaced with solid state devices. Examples of these solid state devices are strain gauge transducers and monolithic semiconductor pressure transducers. These transducers utilize the properties of semiconductor materials to transform pressure responses into electrical signals to operate displays or microcomputer functions without the need for mechanical elements. Strain gauge transducers are presently being used in industrial equipment applications and avionics applications. The existing trend toward electronics will make the transition to computer monitored equipment much easier.

EXISTING ON-BOARD MONITORING TECHNOLOGY

The use of computerized monitoring devices to provide visual and audio information concerning the condition of a machine to its operator is a new and rapidly expanding technology. The most advanced use of electronics is found in the aerospace and airline industries. Heightened public interest and government funding provided the means for the aerospace industry to develop and utilize complex electronic computer systems and extremely expensive and intricate sensors to accomplish the required monitoring and controlling tasks. Many of these devices were transferable to the airline industry because of the similarity of equipment operation and environment. Presently, the aircraft pilot enjoys the ability to monitor most all mechanical functions and can rely on electronically automated control systems to operate and regulate the most critical aircraft systems.

Recent federal emissions regulations in addition to an increasing realization of the vast potential offered by electronics and computerization has drawn the automotive industry heavily into the development of new electronic technology. Due to exorbitant component costs and incompatability with the automotive environment, a direct transfer of technology from the aerospace industry was not possible. Automotive and electronic engineers proceeded to research and develop new sensor and processor designs using existing technology as a foundation. With cost-benefit limitations on system designs, the use of exotic semiconductor materials and complex processing units was impractical. This dictated the use of common materials and existing manufacturing processes. Other factors also influenced component design. The operating environment of an automobile is much less controlled than that of an aircraft or rocket. Dust, sand, gravel, oil, salt spray, water, frost, shock, vibration, electromagnetic interference, temperature extremes, high power voltage transients, and humidity can contact the components and threaten to destroy the integrity of the system. A far more durable and reliable system is required to withstand this environmental regime and provide the degree of dependability necessary for consumer acceptance.

Many advances have been achieved throughout the years of automotive research. Many of these devices are suitable for usage on off-highway equipment. Microprocessing chips and semiconductor transducers form the backbone for many of the automotive electronic systems. Several manufacturers have developed and are marketing an electronic system to monitor and control engine performance. Developed to comply with new federal emission standards, this device incorporates two temperature sensors, an oxygen sensor, an ignition timing sensor, an intake-manifold pressure sensor, and actuators for the fuel pump, EGR (exhaust gas recirculation) valve and eight injectors. The various sensors monitor the key engine functions and relay the information back to a microprocessor. The data is then analyzed and signals are sent back to the actuators to adjust engine settings when necessary to maintain efficient performance.

Other electronic devices that are being marketed are a wheel-lock control braking system and a traction control system. The wheel-lock control is presently being used on large highway trucks and allows braking without the danger of locking up the wheels. A wheel speed sensor, consisting of a permanent magnet, a pole, and an induction coil, generates an AC current equivalent to the wheel speed. If the wheel speed reduces sharply, a wheel lock situation is assumed and the actuators are signaled to release the brake momentarily. The result is an extremely rapid pumping action and efficient braking. The traction control regulates the power to the drive wheels to keep the rear wheel speed within 10 percent of the speed of the front wheels.

Several other devices are being developed and improved for eventual automotive application. Automated collision avoidance systems (using radar) and vehicle on-board diagnostic systems (with external readout) are two devices which might find applications in off-highway use.

The mining industry has just begun to exhibit interest in the use of computer technology to increase equipment productivity and reliability. Several systems utilizing electronic technology have been introduced. These include an electronic monitoring system for a Caterpillar 980C loader; a draft power sensor for a bulldozer; and two computer systems for draglines. These systems will be detailed in the following sections.

Caterpillar Electronic Monitoring System

The Caterpillar electronic monitoring system is essentially a series of sensors that monitor critical equipment functions. It also has a panel of light emitting diodes (LED) to warn the operator of dangerous conditions or component failure. Its main function is to alert the operator that something is wrong with the machine and in need of attention. The system is designed to provide three levels of warning. The lowest priority level is called "operator awareness." This alerts the operator that either the fuel level is low; the alternator output is low; or the parking brake is engaged while the engine is running and the transmission in neutral. A light on the LED panel corresponding to the problem area flashes to attract the operators attention. The second level of warning is called "operator response." This requires the operator to take appropriate actions to correct the problem being encountered. A flashing red light located directly in front of the operator's bucket controls alerts the operator that a problem is present. The operator must then turn to the LED panel to discern the specific trouble. This level of warning addresses the potentially hazardous situations of high engine temperature, high torque converter temperature, high transmission fluid temperature, and high hydraulic oil temperatures. The highest level of priority warning is the "immediate shutdown" response. In this mode, a loud horn is sounded in addition to the flashing lights in front of the operator and on the LED panel. When a malfunction of this priority level occurs, the operator should turn off the machine as soon as possible to avoid excessive damage or a safety hazard. The immediate shutdown warning alerts the operator of low engine oil pressure, low brake pressure, or an engaged parking brake while the engine is running and the transmission is in gear.

The level of priority or operator response is determined by the severity or expense of the damage that would result from the malfunction of the monitored device. Those causing the most damage or presenting a safety hazard receive the highest priority. Those not creating an imminent danger receive less attention. The selection of functions to be monitored is determined in the same manner. Functions not restricting the efficient performance of the machine are not monitored.

The Electronic Monitoring System uses standard electronic sensors and sending units which relay data back to a central receiving unit. This unit then monitors the level of feedback through hardwired logic and trips the appropriate warning.

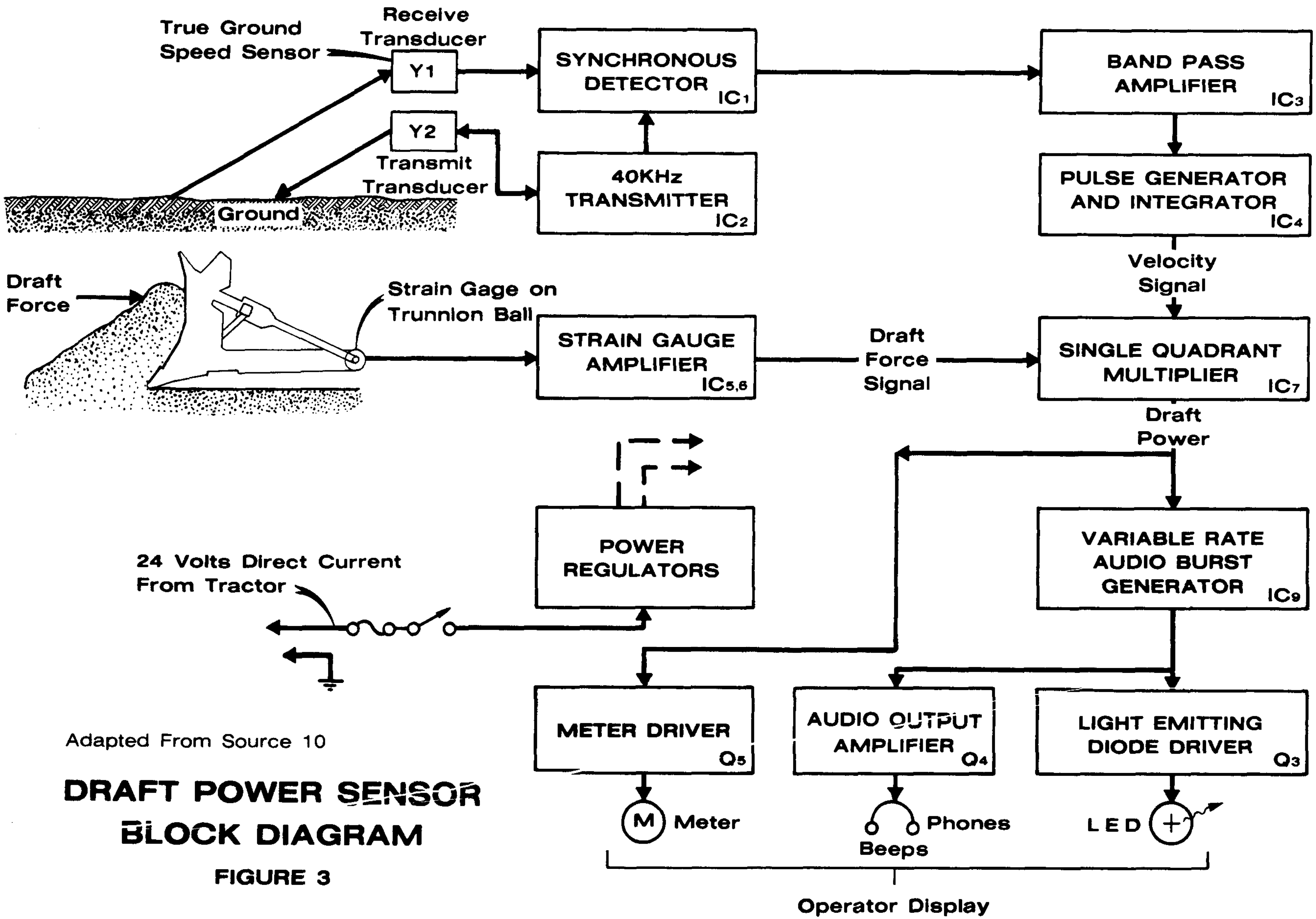
The Caterpillar system relies on the operator to acknowledge a warning and react to it. Therefore, for this system to be effective, operator acceptance is imperative. The entire system has to be designed for better reliability than the existing gauges to justify the cost and augment operator faith. Environmental elements such as extreme temperatures, dust, and moisture are as important as the system introduced constraints of vibration and electromagnetic interference, and all must be adequately protected against electrical transient spikes. To accomplish this feat, military type connectors were used and the entire system was sealed.

Draft Power Sensor

The draft power sensor (Source 10) is a device that was developed by Southwest Research Institute for use on bulldozers to optimize production. It consists of a sensor to monitor true ground speed and a sensor to measure the resistive force acting on the blade. The relationship of these two parameters is used to create a pulsating feedback signal that varies proportionally in frequency with production rate. This signal is presented to the operator so that he may continually monitor the production rate of his machine. This provides the operator with the necessary feedback to correct inefficient and counter-productive methods of operation, and to utilize the maximum potential of his machine.

The true ground speed sensor utilizes the doppler frequency shift effect. A transmitting transducer reflects an ultrasonic signal off the ground surface to a receiving transducer. The difference in signal frequency from transmission to reception is then used to determine vehicle speed. A velocity signal proportional to the doppler signal is produced and sent to a single quadrant multiplier where it is multiplied with the draft force signal. The draft force signal is determined by the use of a strain gauge rosette located on the neck of one of the push arm trunnion balls. The strain gauge produces a voltage proportional to the draft force, which is amplified and sent to the single quadrant multiplier. The multiplier then produces an output wave which is entered into the scaling amplifier powering a meter, an audio-burst generator, and a LED. Figure 3 depicts a block diagram of this system.

The draft power sensor is basically a productive aid for the experienced dozer operator as well as a training device for new and inexperienced operators. The pulsating beeps tell them how close the dozer is working to capacity. Since the draft force/speed ratio is dependent on footing conditions, the draft power sensor can also indicate the optimum digging depth for various surfaces and materials.



Adapted From Source 10

DRAFT POWER SENSOR BLOCK DIAGRAM

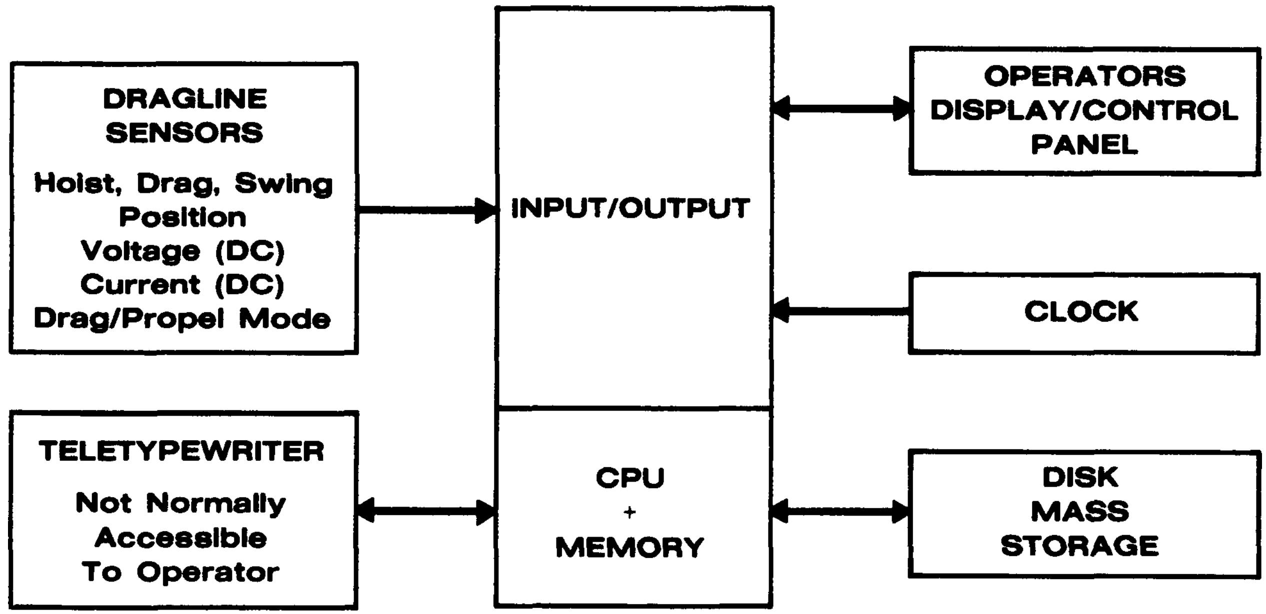
FIGURE 3

Dragline Display and Information Gathering System

This system is presently the most complex application of computer technology in the mining equipment industry. A Digital Equipment Corporation PDP-11/03 microcomputer system with a dual disk memory, solid-state memory, operator display unit, and a teletypewriter was built onto a Marion 8200 dragline (Source 9). This dragline computer system was developed by McDonnell Douglas Electronics Company under a research project for the Department of Energy. It was tested in the 8200 and has since become available on the market.

The computer system monitors and stores a variety of information concerning the operation and performance of the dragline. This information can be displayed to the operator with the entry of the proper code on the keyboard. The system also documents dragline utilization, amounts of and reasons for downtimes.

The dragline computer, like the draft power sensor, is basically a system to monitor production efficiency. Digital readouts, bargraph (thermometer type) displays and alert indicators provide the operator with up to 30 types of information concerning performance. This information is shown in Table 2. Shaft encoders attached to the drag drum, the hoist drum, and the swing gearing collect this information in conjunction with voltage and current sensors on motors. These sensors and encoders send the information back to the computer to be processed and stored. A teletypewriter is available to print out the information on a cyclic, hourly or daily basis for managerial purposes. A block diagram of this system is depicted in Figure 4.



Adapted From Source 31

DISPLAY AND INFORMATION GATHERING SYSTEM FLOW DIAGRAM

FIGURE 4

TABLE 2
PERFORMANCE INFORMATION READOUTS

CODE	DISPLAYED DATA	UNITS
Totals		
1	Time of Day	Hr. Mn.
2	Cycles	Cyc
3	Yardage	Yds
4	Carry Back	Yds
5	Target Strip Rate	Yph
6	Strip Rate	Yph
7	Bench Height	Feet
Averages		
8	Yardage	Yds
12	Load Distance	Feet
13	Load Time	Sec
14	Load Energy	Kwh
15	Swing Angle	Deg
16	Swing Time	Sec
17	Swing Energy	Kwh
18	Cycle Time	Sec
19	Cycle Energy	Kwh
Last Cycle		
21	Yardage	Yds
22	Load Distance	Feet
23	Load Time	Sec
24	Load Energy	Kwh
25	Swing Angle	Deg
26	Swing Time	Sec
27	Swing Energy	Kwh
28	Cycle Time	Sec
29	Cycle Energy	Kwh
30	Steps Moved	Step

The display console contains several bargraphs which indicate height and depth of bucket, bucket reach, and cycle times. Cycle time includes dig time, swing to dump time, dump time and swing to dig time. The cycle times are compared against a reference cycle and displayed on an efficiency basis. Height, depth, and reach measurements are indicated as the distance from the bench upon which the dragline is setting. A circular gauge indicates the swing angle from an inputted reference point.

Two alert indicators are also located on the display console and warn the operator of potential static or dynamic tightlining and of a multiple pass situation where the operator has exceeded five multiple passes in a five minute span. An audible alarm is also sounded for imminent dynamic tightlining situations where the bucket is approaching a collision with the boom.

The PDP-11/03 computer and teletypewriter are housed in a special compartment below the main equipment deck. The isolated location of this installation allows the control of dust, temperature, humidity, and vibration. The display console is located adjacent to the operator's controls in the cab. This allows convenient reference for displayed information and easy access for data input. The analog to digital converter is mounted in the power control room on a vibration dampening base.

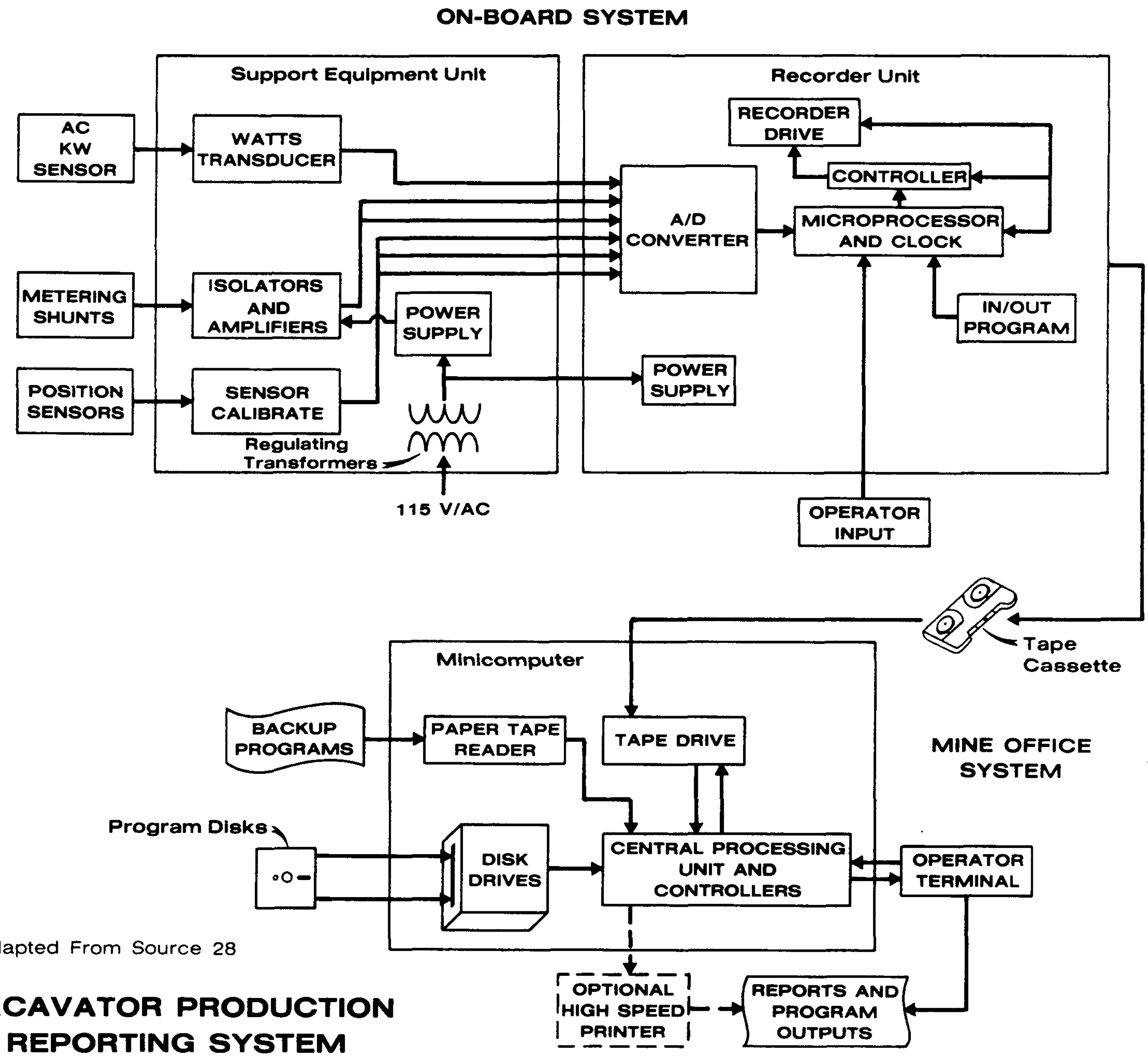
The primary functions of this computer system are to act as a training device for new and inexperienced operators, and to provide performance information to boost the output of seasoned veterans. Operator acceptance and cooperation is, therefore, essential for system effectiveness. Testing on the 8200 dragline proved that operator response was favorable as long as an adequate explanation of the system was provided and the operator had access to recorded information.

Excavator Production Reporting System

The excavator production reporting system, developed and marketed by General Electric Company (Source 28), records production parameters of draglines and stripping shovels onto magnetic tape cartridges for report generation by an off-board mini-computer. This system was originally designed to act strictly as a monitoring device for dragline and shovel production rather than as a tool to increase production. For this reason, the first production models did not include displays for operator access to the recorded information. Only recently has an option called DIGMATE, providing real-time access to information, become available.

The system collects analog signals from position sensors, metering shunts, and kilowatt consumption meters to provide an information base. These signals are calibrated, isolated or amplified as required in a support equipment unit and then transferred to an analog to digital converter (A/D). This A/D converter is housed in the same cabinet as the microprocessor and recorder. The microprocessor evaluates the output of the A/D converter once each second and stores the data in a temporary random access memory (RAM). When 60 samples of data are stored (one minute of monitoring), the microprocessor diverts the data into a second RAM, while this second RAM is being filled, the microprocessor collects the time of day, the operator input code, and the first RAM data samples. It then feeds this information to the recorder to be permanently stored on magnetic tape cassettes. This procedure is alternated so as one RAM is being filled the other is being emptied. Using this process, no information is lost to recording delays except for the time required to change the tape.

Each magnetic tape cassette possesses the capacity to store approximately 64 hours of data. Once filled, the tape must be removed and carried to an off-board mini-computer, usually located in the mine office, for processing and report generation. A block diagram of the on-board and off-board systems is illustrated in Figure 5. The data is used to generate a



Adapted From Source 28

EXCAVATOR PRODUCTION REPORTING SYSTEM

FIGURE 5

standard report detailing cycle information, average bucket fills, downtime reasons and power consumption information. Special reports can also be generated by altering the program instructions in the mini-computer.

As previously mentioned, an operator display is now available to complement the production reporting system. This display consists of a cathode ray tube monitor and an input keyboard. The display outputs include average and last cycle information; total cycles, total yards moved and total power consumed; graphic displays including performance, cycle time, KW demand, and strip rate charts; and operating codes. Each display output must be called for individually and will remain on the screen until another request is inputted or a priority warning is activated. Priority warnings alert the operator to unsafe conditions. Each warning triggers a sonic alert, and the reason for the warning flashes on the CRT. Typical warnings include operator "wake-up," demand limit, stall warning, static tightlining, dynamic tightlining, and multipass.

The Excavator Production Report System is designed to offer the mine management a means to measure real time productivity. It can be installed on draglines, stripping shovels, and any other equipment with analogous operation. Several pieces of equipment can be equipped with this device in any mine, and production records can be generated from the same mini-computer. Effective use of this system by mine management, with respect to maintenance planning and continually updated pit layout decisions, is essentially the only way to provide the production increases necessary to establish and confirm economic feasibility.

Other Devices

Clark Equipment Company is in the process of developing a monitoring system to aid in the design of front-end loader structures. Several sensors located throughout the major load bearing areas of the machine measure the stresses absorbed by the structure during loader operation. This data is then stored in a memory unit for extraction by the engineers. Since this device has limited application for a BITE system and detailed information is considered proprietary, an in-depth investigation was not possible.

Rockwell International has developed an instrumentation system for use on industrial truck fleets. This system, called Trip Master (Source 24), consists of an on-board instrumentation computer, a sensor set, a data monitoring display unit, and a Data Link information transfer unit. Each system has been programmed to gather, preprocess, select and compact, and store required information on fuel economy and vehicle performance. The vehicle parameters monitored by this system are given in Table 3. These monitored parameters are made available for use in two methods. As the data is gathered by the sensors, it is processed and recorded by the instrumentation computer. This data can then be transferred onto magnetic tape cassettes using the Data Link Unit which taps into the microprocessor's memory. The cassette can be carried to an available computer for use in report generation. The second means of information access is supplied by the data monitoring display unit. This unit is mounted inside the cab within convenient reach of the operator and provides one operator selectable and two continuous displays. The continuous displays include

TABLE 3

TRIPMASTER DATA AQUISITION SYSTEM
(Parameters Monitored)

Engine: • RPM • Oil Temperature • Coolant Temperature • Load Factor	Environmental: • Ambient Temperature • Barometric Pressure • Road Grade • Wind Direction
Transmission: • Oil Temperature • Clutch Activation	Fuel: • Consumption • Temperature • Remaining
Vehicle: • Speed/Distance • Brake Application • Axle Temperature • City/Highway Operation	Electrical: • Battery Voltage • Alternator Load • Ignition
Vehicle Options: • PS Pump Pressure • A/C Compressor • Air Compressor • Radiator Fan - Clutch - Viscous	Time: • Real Time • Date

vehicle speed and engine RPM. The operator selectable data is given in Table 4. Each of these selectable displays is given a designated button on the input keyboard which allows quick and simple access to the data.

The information stored within the microprocessor should ideally be transferred to the cassettes on a daily basis. This reporting interval can be extended to allow storage of four day's worth of data if the truck is going to be used for long trips. After the data is transferred to the tapes and entered into the off-board computer, it can be used to generate reports

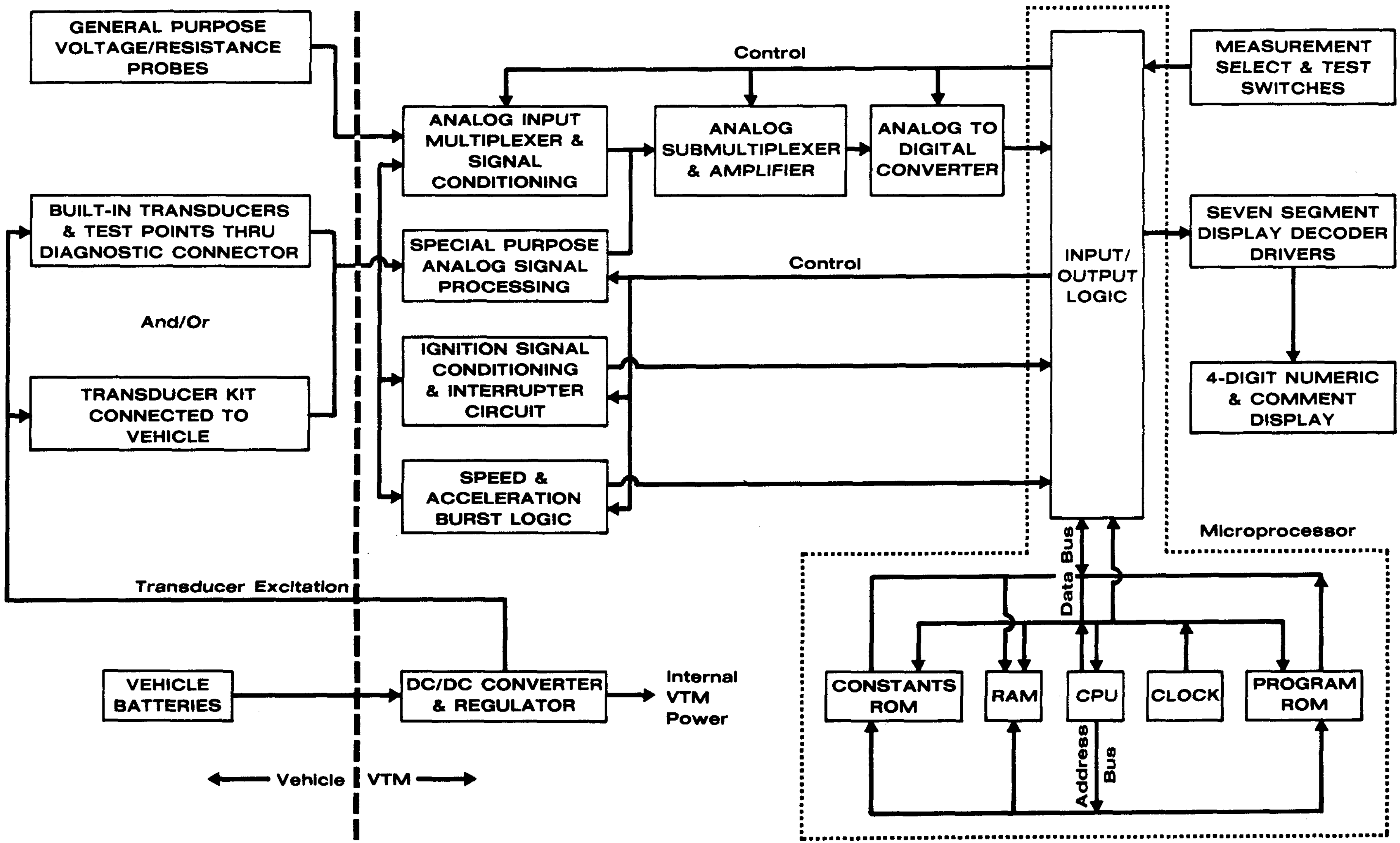
TABLE 4

TRIPMASTER MONITOR
(Parameters Displayed)

• Vehicle Speed	• Engine RPM
• Ambient Temperature	• Time of Day
• Coolant Temperature	• Fuel Consumption
• Engine Oil Temperature	• Fuel Remaining
• Transmission Oil Temperature	• Wind Velocity
• Axle Temperature	• Wind Direction
• Fuel Temperature	• Barometric Pressure
• Battery Voltage	• Road Grade
• Alternator Current	• Manifold Vacuum, Rail Pressure or Exhaust Temperature

detailing fuel efficiency and vehicle performance using histograms and charts.

A related form of vehicle diagnostic test equipment utilizing on-board sensors with a single diagnostic connector assembly is being developed by the U.S. Army for use on military vehicles (Source 40). The Simplified Test Equipment for Internal Combustion Engine Powered Material (STE/ICE) is designed to provide more efficient and less costly vehicle malfunction diagnosis. Its main objective is to assist the in-field mechanic, having no access to maintenance facilities, with an effective means of pin-pointing equipment malfunctions. The STE/ICE consists of a set of sensors that are tied to a diagnostic connector. This connector allows the use of a portable vehicle test meter (VTM) that is connected to the sensor output. This VTM is a microprocessor based device that measures the monitored parameters and displays the results as either a pass/fail message or a digital value. A block diagram of the VTM and its interface to the vehicle is illustrated in Figure 6. A simplified transducer kit can be utilized for vehicle interface in place of the diagnostic connector if this is more feasible for the



Adapted From Source 40

VEHICLE TEST METER INTERFACE

FIGURE 6

application. This device is presently in early production stages and utilizes MIL-SPEC components.

Marathon LeTourneau has recently announced a monitoring system reminiscent of the BITE concept developed later in this report. The primary difference between the BITE concept and the LeTourneau system lies in the location and type of intelligence used to analyze the data gathered on the vehicle's status. The BITE concept is developed around the idea of using an on-board microprocessor to coordinate data gathering, data processing, and generated results dissemination to the operator directly. The LeTourneau system utilizes a telemetry link to transmit immediately all data gathered from the various transducers to a remote location for analysis by staff engineers. The operator can then obtain feedback from the engineers over a CB radio link from the mobile telemetry van back to the piece of equipment being monitored.

Utilizing the latest available telemetry FM transmitting equipment and a corresponding receiver mounted in a mobile van, engineers remotely monitor the components of a LeTourneau machine while it is in its normal working mode. A portable telemetry transmitter is connected to a selected machine's test panel in order to allow engineers to monitor various components or functions of a working machine. The data sent to the mobile van over the telemetry link is then recorded on one of several possible media for analysis by the engineers. Systems most often monitored include engine rpm and horsepower; machine speed; electrical motor current, voltage and speed parameters; control system signals; hydraulic pressures;

and strain gauges monitoring localized stresses. Should any communication with the operator be necessary, a CB radio link is used between the engineers in the van and the operator in the machine.

Research has also uncovered a concept for a BITE system developed for construction type haulage vehicles. As described below, it embodies many of the tenets of the BITE concept applicable to FELs and heavy-duty mining equipment. Although much of the information available is proprietary, we did learn several key items. The concept has been evolved from a military system and most probably lacks the flexibility needed for a FEL application. Projected unit costs, based on a military heritage and ruggedized components, are several orders higher than the projections of the current study. Nevertheless, the concept lends credence to the feasibility of the current study.

The originators describe their concept in the following manner. The monitoring system is a computer-operated, data-acquisition system whose purpose is to monitor the operation of a complex machine. The system detects deviations from normal operation, establishes whether a current or future need for corrective action exists, and notifies the operator and maintenance personnel of that need. Some of the parameters of operation monitored are temperature, pressure, RPM, voltage, current, position and vibration. The data gathered from these parameters can identify abnormal wear and can predict a catastrophic failure before it happens. In addition, it can localize the potential failure item and provide an operating history of the machine to establish maintenance schedules. The objective of this system is to provide the operator and maintenance personnel a real-time operating status of the machine without inundating them with paper. Output comes only when a parameter is trending toward a pre-defined warning limit via an alarm or when requested. The computer which operates the system is suited for a harsh environment. It is a high reliability machine of the type used by the military in similar applications. Included with the computer is an output port for a printer and a display. A printer is used to provide hard copy to the operator. An alarm event is shown on the display. The display output indicates what is out of limit and other effected system parameters at the time of the alarm. The display ranges from annunciators which indicate a system problem (essentially warning lights) to a digital display on which the message appears. At the same time the system detects a fault, an audible alarm sounds. The computer makes its decision based on data gathered from key parameters selected throughout the system.

FUNCTIONAL RELATIONSHIPS

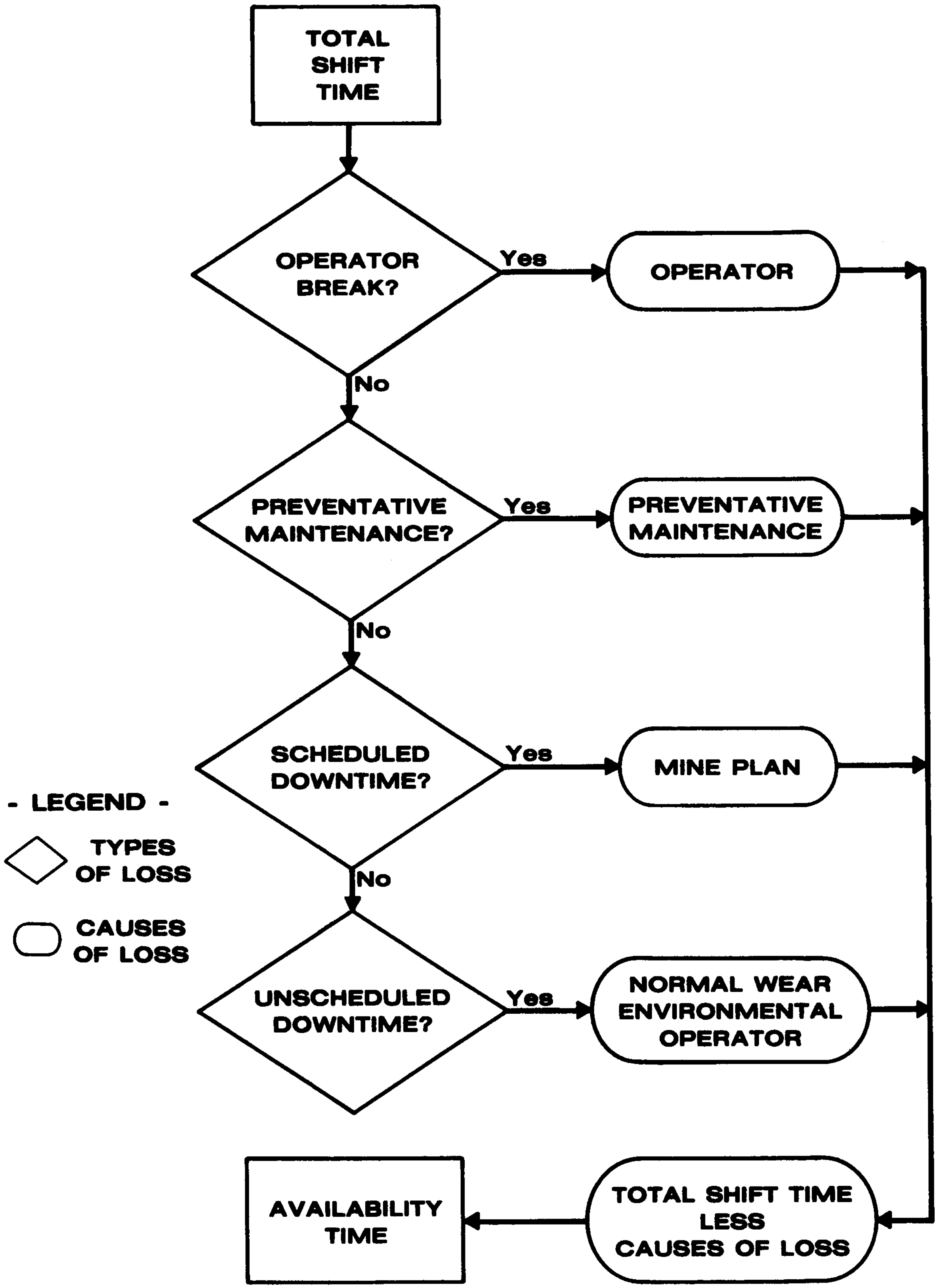
FUNCTIONAL RELATIONSHIPS

The determination of the most feasible BITE system depends on the functions the system is to serve. For the purposes of this study, we desire the system to address two objectives - to increase availability and to increase productivity.

AVAILABILITY

Availability may be defined as the percentage of the total shift working time that a FEL is capable of performing useful work. Typically, an eight hour workable shift is reduced by operator break times, preventative maintenance time, scheduling delay times, and unscheduled downtime (see Figure 7). No on-board monitoring system can influence the first of these factors. On the other hand, BITE can influence the remaining three items. Preventative maintenance time can be reduced at those mines already using this procedure by virtue of the substitution of a centralized monitoring and readout point for a maintenance man crawling all over the machine. A central, computerized unit can check more machine status indicators quicker and more accurately than any maintenance man. What may require 15 to 30 minutes per shift for the maintenance man or operator to check can be duplicated by the computer in 1 to 2 minutes. Only those functions not readily checked by remote sensors, such as checking tires for cuts or abrasions, are left for the maintenance man.

Scheduling delays are a function of the mine unit operations plans. Since this is the province of management, BITE must be capable of supplying



AVAILABILITY FLOWCHART

FIGURE 7

data for minimizing these delays if availability is to be increased. A common example of this delay would be a FEL sitting idle in the pit awaiting a haulage truck. BITE can indirectly influence this through the generation of reports detailing the amounts of time spent in various modes of action. A loader sitting idle or performing pit maintenance is not available for production of coal. Management must take action to cure this situation based on time study type data generated by BITE.

Unscheduled downtime arises principally from mechanical failures. As shown in Table 5, there are direct relationships between the causes of the mechanical failures and factors which BITE can influence. Two agents appear to be the majority causes - normal wear and operating conditions. As was shown in other portions of this report, the FEL is subjected to very high and frequent mechanical loads. Constant starting, stopping, loading, direction reversing and impact shocking all cause accelerated fatigue and ultimately breakage. Loaders have evolved over the years. One manufacturer related to us that these machines are built very crudely. They were designed initially with a safety factor and then beefed wherever breakage occurred. Incorporation into BITE of concepts such as statistical analog monitoring (STAM - see Source 14) will provide reliable design information for the first time. Although it considers all of its information proprietary, Clark Equipment Company has developed a BITE system for this purpose.

The agent named "operating conditions" refers to the manner in which the loader operator performs his duties. An operator who constantly uses "jackrabbit" starts, excessive speed during manuevers in the pit, or

TABLE 5

DOWNTIME CAUSATIVE AGENTS

FAILURE	AGENTS	
Engine Failure	E	N
Drive Train Failure	O	N
Hydraulic System Failure	O	N
Hydraulic Cylinder Failure	E	O
Tire Failure	O	N
Bucket & Boom Failure	O	N
Machine Rollover	O	N
Electric Motor Failure	P	E

KEY:

E = **Environmentally Accelerated Wear**
N = **Normal Time Dependent Wear**
O = **Operating Technique**
P = **Lack of Preventative Maintenance**

rams into piles of consolidated materials increases the loading on vehicle components and induces breakage. Operator actions such as these have been gathered under a heading of "negative productivity" factors. Sensors attached to the BITE system can easily detect these factors and aprise the operator. In this manner, operator efficiency can be increased and the loads the machine is subjected to lessened. This should allow for a reduction in unscheduled downtime.

Unscheduled downtime can also result from environmental conditions such as excessive dust clogging filters and being ingested into components. One operator reported that in a large western mine, dust often rolls off the windshield like water - it behaves like a "fluid solid"! BITE can reduce the chances for conditions like these causing component failures by monitoring filters and warning the operator in real-time of overloading.

In summary, BITE can be configured to address the major constraints on availability. Depending on economic considerations and information desired, it can address any number of availability functional components.

PRODUCTIVITY

Productivity for front-end loaders is difficult to comprehensively define. A dragline is relatively stationary with well defined components to its working cycle. Therefore, its productivity can be defined as available time x cycle rate x productive tons per cycle. A front-end loader, on the other hand, is a very mobile piece of equipment. It is used for a wide variety of tasks (overburden removal, coal loading, topsoil handling, general maintenance) and in a number of different modes (loading trucks, loading material and carrying it to a remote location, etc.). As such it has no standard operating procedure nor defined cycle time. Relationships could be developed for each of the types of operations and operating modes. A large matrix would be needed to correlate the large number of variations possible with the combination of task, mode, and mine type. This sort of effort becomes counterproductive quickly and not of use to any significant sector of mine operators.

The most widely adaptable functional definition is that developed from restricting productivity measurements to a specific loading operation. Appendix A shows that loaders are most often used for overburden removal and coal loading. Therefore, we will restrict our definition to situations where a FEL is moving unconsolidated material (coal or overburden) to a haulage vehicle or conveyor. In this manner, the dragline productivity functional relationship is applicable. We may now use the intelligence of a BITE system to determine productivity through measurements of percent of bucket fill and cycles completed per unit of time. This information can then be given to the operator so that he may improve his efficiency. It may also be used by management to determine mine plan effectiveness as long cycle times may indicate poor truck placement or poor blasting. They may be also used to indicate operator effectiveness or the need for operator training. Ultimately, as more categories of mining equipment receive the benefits of BITE technology, a mine can be planned and monitored by efficiently matching the productive capabilities of all machines to each other.

In summary, BITE can influence productivity through increased operator efficiency. By providing feedback to operators and management alike on the amount of material moved in a given amount of time, efficiency and productivity should increase.

BITE systems must serve three factions if they are to positively influence the function of FEL. The operator needs real-time status information of the condition of his machine and his efficiency in operating it. The maintenance man needs real-time information for troubleshooting a down machine. He also needs historical data in order to efficiently plan his preventative maintenance program and reduce downtime. Finally, management needs information on operator efficiency (for training); on productivity (for efficient mine planning); and on reliability (for reducing operating costs). The BITE system developed in the next section addresses these separate factions.

BITE SYSTEM DEVELOPMENT

BITE SYSTEM DEVELOPMENT

Front-end loaders have rapidly evolved from small support machines to large capacity stripping units. This evolution has greatly enhanced their importance to the mining industry in addition to creating areas of machine design that require improvement. Current instrumentation does not reflect the complexity to which loader systems have grown. Mechanical and electromechanical gauges can only provide a visual indication of the status of a limited range of machine functions. Their limited scope leaves many areas of the loader unprotected. Persistant failures in these areas, such as hydraulic pumps, can become extremely expensive to repair as well as increase the amount of downtime and lost production experienced.

Recognizing the inadequacy of current monitoring equipment, BITE systems are being developed. When we review the functional relationships developed earlier, we find that FEL availability has a profound impact on productivity. Productivity cannot be increased if a machine is not available for production. Interviews with maintenance personnel have shown that unscheduled downtimes constitute their biggest problem and the largest loss of availability. Because the causes of these downtimes are easily monitored, BITE can dramatically reduce their occurrences. It is a consensus opinion that a minimum ten percent reduction in downtime and increase in availability is feasible. Knowing this, the need for continually monitoring and evaluating the performance of front-end loaders through the use of BITE is easily argued. As shown in the scenario that follows in another section, a ten percent increase in availability will increase production and lower the cost per ton of coal produced by several dollars! Cost reductions of this magnitude must be fully explored.

Analysis also reveals that of the three factions benefiting from BITE implementation, the operator's needs predominate. He directly controls productivity and indirectly availability through the manner in which he operates his machine. Erratic cycle paths, half-full buckets, and long breaks decrease production. Rough-house treatment enhances the possibility of an unscheduled downtime. Therefore, the operator's acceptance and use of the BITE system is mandatory. The supplying of real-time operating status information is of first priority. Additionally, the operator must use the system and not ignore or attempt to defeat it. The experience of two manufacturers has shown that all data gathered must be accessible to the operator. Without this condition, the system is viewed as a "tattle-tale" and operators actively try to defeat it. Consequently, the BITE system development concept actively addresses the needs of the operator and gives him full access to its data.

The basic system described herein is the simplest approach feasible. It suplants existing instrumentation and allows a phased approach to complete monitoring. It is intended to be used by manufacturers as a replacement or enhancement to existing gauge packages. It is a minimum cost, first generation computer system. In this manner, a new technology can be introduced to the field without overpowering or frightening people. Once operator acceptance has been gained, the options can be implemented to allow the needs of maintenance and management personnel to be addressed. The options will generate the data each needs as finances and need dictate.

ENVIRONMENTAL CONSIDERATIONS

A major area of concern for any electronic system is operating environment. Commercial computer systems impose strict climatic requirements on the user. They require a cool, dry, dust free atmosphere for proper operation. Military or so-called "ruggedized" systems overcome these conditions by using special components and climate controlled enclosures at the expense of a substantially increased system cost. The cost of these systems and their counterpart sensors effectively rules them out of consideration in this project.

A critical factor in the design of this system is envelope size. Commercial computer systems such as that used on the dragline project require a small room. Owing to the scarcity of available space on FELs, attention is attracted to the specialty computers used by the military. Aside from the cost constraint imposed by these systems, they also only come in specified cases. The configurations revealed by research could not be placed anywhere convenient on a loader. The most hospitable location for a computer on a FEL is inside the operators cab. Available space here is extremely limited. The conclusion reached is that a system will have to be designed in cooperation with manufacturers to fit whatever space they can make available.

One of the major design considerations for BITE implementation concerns the effects of the surrounding environment on the system. Front-end loaders must operate under many environmental extremes throughout the coal producing regions of the United States. These conditions will destroy the reliability of the BITE system if they are not adequately protected against. Temperature variations occur frequently during normal operations. Ambient temperatures may range from a low of -70° to a high of 120°F. Loaders working on the coal surface may experience even higher temperatures due to the heat absorbing qualities of the coal. Machine generated heat from normal operation also increases the total heat energy to which the system will be exposed. These temperatures may approach the boiling point. Many mines are located in mountainous regions and on high plateaus. At these elevations, cold weather is predominant and loader components must start at freezing temperatures and rise to operating temperature. Adequate insulation is essential to withstand these extremes.

Humidity is a major problem that plagues all electronic systems. Moisture penetrates and corrodes the metal surfaces of contacts and connectors, destroying the effectiveness of the entire system. Humidity is present in all mining situations in varying degrees. Eastern mines may experience humidity in excess of 90 percent, while western mines might average around 30 to 40 percent. Humidity is usually higher during the winter months.

A BITE system installed on a front-end loader will often be exposed to moisture through precipitation. Direct contact with rain or snow or contact from splashing surface water will ultimately destroy electronic components if they are not protected. Standing pools of surface runoff are common in many pit areas where front-end loaders are employed. Another source of moisture infiltration originates from normal maintenance. Cleaning a vehicle periodically to remove dirt and coal dust build-up is a standard practice. The frequency of machine washings depends on the amounts of dust generated by the mine. During these washings, the entire machine is hosed down including the interior of the operator's cab. This practice exposes the components that would normally be protected to large amounts of high force water. This necessitates the sealing of the processing unit inside the cab against moisture.

Dust infiltration presents many problems for an electronic system. Particles can enter the device and destroy the integrity of the contacts. This makes dust a major problem if concentrations are high. The nature of the earth moving process readily creates airborne dust. The levels of concentration are dependant on the moisture content of the material being moved. Western mines typically experience higher dust levels due to the dry and semiarid conditions of the overburden in those areas. Several western mines have airborne dust concentrations so high that visibility is obscured and operations hampered. Coal dust presents an additional fire hazard should it infiltrate hot electronic componets. Lower grades of coal create more dust.

Natural phenomena are not the only environmental constraints to the implementation of the BITE system. Machine generated vibration and electromagnetic interference (EMI) also require consideration and protection. Vibration can be produced by many sources on a front-end loader. Normal engine operation transmits vibration through the machine structure. This vibration usually fluctuates with increased engine RPM. Since the front-end loader possesses no suspension other than the pneumatic tire air cushion, impact shocks created from travel over rough surfaces are transmitted through the axle to the frame and eventually to the BITE system. These shocks and vibrations interrupt electrical circuits by jarring contacts open during impact. Electromagnetic interference is created by the operation of electrical equipment. This interference will affect signals from the transducers if it is sufficiently strong. EMI may come from electrical devices on board the loader, such as an alternator, or it may be introduced from the surrounding environment by devices such as CB radios. Shielding must be incorporated to protect the signals if the EMI levels will affect system operations. Consideration must also be given to reduce the levels of EMI produced by the BITE system so as not to adversly affect other loader electrical systems.

EQUIPMENT CONSIDERATIONS

In determining the functions to be monitored by a BITE system, we must match user needs to equipment capability. The three users have disparate objectives even though their information sources sometimes overlap. A breakdown of objectives would be as shown in Table 6.

TABLE 6
BITE USER OBJECTIVES

A. Operator Objectives

1. Vehicle and Operator Performance

- Engine operational status
- Machine (systems) operational status
- Operational efficiency (cycle times, percent of bucket fill)
- Negative productivity warnings
- Fuel consumption
- Fluid levels (oil, water, hydraulics)

2. Failure Notifications (Imminent)

- Filter loads
- Fluid temperatures and pressures
- Hydraulic pump temperatures

3. Safety

- Braking system condition
- Steering system condition
- Stability

B. Maintenance Personnel Objectives

1. Preventative Maintenance

- Fluid levels
- Fluid conditions (length of service, temperature)
- Engine condition
- Hydraulic systems condition
- Torque converter condition
- Transmission condition

2. Histograms

- Component life
- Failure rates
- Temperature variations
- Pressure variations

TABLE 6 (Cont'd.)

BITE USER OBJECTIVES

C. Management Objectives

1. Efficiency of Available Time Usage
   - Mode of operation elapsed time
   - Downtime; reason and length
   - Cycle times
2. Economics
   - Fuel consumption
3. Production
   - Cycle time and percent of bucket fill
   - Mode of operation elapsed times

The operator has the highest need for a BITE system. Electronic components are available to monitor temperatures, pressures, flow rates, and fluid levels. From this basic parametric data, the microprocessor can analyze the status of the loader. Currently, the complement of gauges on existing machines provide the operator with data and allow him to process it based on his experience. Existing instrumentation gives the operator readings on machine temperatures, pressures, and fluid levels so that he may judge whether to continue operating or not. BITE will replace this interface with another which allows the machine to possess intelligence through its state of the art transducers and microprocessor controller. In this manner, the machine can selectively apprise the operator of his machine's status (complementing and expanding the information currently available) while allowing him more freedom to concentrate on efficiently and safely operating his machine.

The operator also needs information on imminent failures to prevent unnecessary damage and extended downtimes from occurring. Formerly, an operator would only recognize failure-causing agents when he noticed a rising temperature or falling pressure and stopped the machine to investigate. Due to the attention needed for operating the machine, he might overlook the presence of such conditions. Similarly, a filter might clog during a shift without his knowing. Any of these types of conditions could cause a machine failure. BITE can address these issues by allowing an automatic monitoring of a multitude of checkpoints. As machines become more complex, the operator is faced with information overload. He cannot hope to efficiently monitor dozens of dials and lights without confusion. BITE will be used to reduce the required monitoring to a few readouts or lights that signify unacceptable conditions. These will be discrete signals occurring when operator attention is needed, and not continuous readings of a normally functioning machine.

The issue of automatic monitoring of safety-related parameters is complex. Microprocessor systems inherently possess the ability to intervene and prevent operation in the presence of unsafe conditions. The question of when should the monitor be allowed to prevent or cease machine operation is beyond the scope of this project. Shutting down an engine when it overheats might prove to be more hazardous to an operator negotiating a grade with a full bucket than allowing it to continue overheating. Consequently, this system only defines several safety-critical parameters (such as no air pressure) and warns the operator of their existence - allowing him to take discretionary action with a manual override.

It is felt that the greatest benefit of a BITE system can accrue to maintenance activities. Using the same transducer system installed for the operator, the maintenance personnel can perform a complete check of the machine in reduced time. Additional, historical data can be gathered in the form of histograms and functional elapsed times for use in projecting availability and reducing unscheduled downtimes. The use of the microprocessors real-time clock and keyboard allow the maintenance person to check all systems and components. Component life and failure rates can also be statistically determined by examining the memory of the BITE unit. The computer can be instructed through its operating system to track the elapsed time between installation and replacement of specified components. Although this can be done manually at present, BITE will save manpower and increase the scope of such practices by automating the process. It will also allow a single unit to be programmed to function on numerous different machines.

The management objectives are satisfied by the analyses of the wealth of information available from the BITE system. Elapsed times, downtime codes, cycle information, and histograms (see glossary) can be gathered by the BITE operating system to generate reports in any desired format. The details of this cannot be specified as each machine and manager may need different handling. The intelligence and programmability of the basic system will allow the necessary customization.

Considering the technology available, the recommendations shown in Table 7 are made for matching transducer to application. These are general classifications only. It is recognized that each application will need analysis in order to specify the correct transducer.

TABLE 7
TRANSDUCER APPLICATIONS

A. Semiconductor Pressure Transducer

- Oil pressure
- Fuel pressure
- Other low pressure applications

B. Strain Gauge Transducer

- Hydraulic pressures
- Air pressures
- Other high pressure applications

C. Thermistor or Thermocouple Temperature Transducer

- Engine oil temperature
- Hydraulic oil temperatures
- Torque converter and transmission oil temperatures
- Pump temperatures
- Coolant temperatures

D. Automotive-type Level Sensors

- Oil levels
- Hydraulic fluid levels
- Coolant levels
- Other fluid levels

E. Differential Vacuum or Pressure Transducer

- Air filter quality
- Oil filter quality
- Hydraulic fluid filter quality

F. Automotive-type Sensors (Electrical Output)

- Ammeter
- Tachometer
- Speedometer
- Hourmeter

TABLE 7 (Cont'd.)

TRANSDUCER APPLICATIONS

G. General

- Proximity switches for parking brake engagement
- Tachometer generators for tire spin
- Flowmeters (turbine) for fuel consumption
- Load cells for bucket fill and overloading
- Accelerometer for impact loads
- Air pressure gauge for tire inflation
- Mercury tilt sensor for vehicle tipping

Two factors influence the selection of BITE components - reliability and cost. Reliability is a problem at all levels of electronics, from materials to operating systems, because materials go to make up parts, parts compose assemblies, and assemblies are combined in systems of ever increasing complexity and sophistication. Therefore, at any level of development and design, it is natural to find the influence of reliability engineering acting as a discipline founded to devote special engineering attention to the unreliability problem. In the design of complex electronic systems, considerable effort is made to obtain reliable system performance. It is recognized that the electronics art, especially complex systems, is often in revolution. It is sometimes referred to as an exploding technology. Without time for orderly evolution of systems, applications of electronics suffer most from unreliability. The ratio of new to tried and true portions of electronic systems is relatively high; therefore, until the new becomes tried and true, its reliability must be suspect. Therefore, any BITE system should be constructed of proven components. The rugged components needed to withstand a mine environment are available in versions meeting stringent military specifications. Unfortunately, the cost is prohibitive. A processor board, selling for $750 as a commercial part, rises to over $2000 for the same component as a military part. Since the specifications for a mine are not as stringent as for a fighter aircraft, the system specification will address components meeting high reliability commercial standards. In this manner, costs will be reduced and reliability will be based on standard, proven components and technologies.

SYSTEM OVERVIEW

Recently, loader manufacturers have been investigating the possibilities of expanding the capabilities of their instrumentation by using electronic equipment. One company has developed a system that utilizes electronic sensors that relay information to a central receiving unit. When a monitored function attains a potentially harmful situation, a warning device is activated to alert the operator. Another loader manufacturer is using electronic sensors to measure stresses in machine structures during operation. This information is then collected and used as design parameters for new equipment.

This use of electronic and computer technology is an expanding trend in the front-end loader field. The BITE system is an extension of this trend. The ultimate BITE system incorporates a full computer into the loader that collects and stores information from the transducers to provide useful interpretable data to operators, maintenance personnel, and management individuals. This ultimate system would require massive amounts of memory capacity resulting in technical and physical constraints. Also, as the size and complexity of the equipment increases, the costs for purchase, installation and operation rise dramatically. These considerations necessitate the design of a BITE system using a phased approach. A basic monitoring system will form the foundation for an expandable total monitoring package. This basic system monitors the most critical functions while maintaining simplicity to keep costs low. Four options will then be available to fulfill the required needs of the individual monitoring package.

Basic System

The basic system is designed to provide the most benefit to the operator. Displays monitoring machine functions include the following:

- Engine oil pressure
- Hydraulic oil pressure
- Hydraulic oil temperature
- Torque converter oil temperature
- Engine coolant temperature
- Steering hydraulic oil pressure
- Steering hydraulic oil temperature
- Fuel level
- Ammeter
- Tachometer
- Speedometer
- Hourmeter
- Stability indicator
- Hydraulic pump casing temperature
- Brake pressure
- Operational mode input
- Center pin strain gauge

Variations in these functions alert the operator of a potential malfunction. Fluid pressures and temperatures reflect the condition of the system in which they are contained. They are, therefore, good indicators of overall machine performance. The hydraulic pump casing temperature display warns the operator if the pump is overheating. This allows time to correct the problem by rebuilding or replacing the pump before failure occurs with the resulting peripheral damage. The stability indicator is used to increase the safety of the loader by alerting the operator to unsafe operating angles by utilizing a tilt sensor to determine when instability occurs. The operational mode input is the only management aid in the basic system. Since the front-end loader is such a versitile machine, this operational mode designation provides the management staff with information concerning the amounts of time spent on various operations.

Maintenance Option

The maintenance option requires the addition of a memory medium to record the various pressures and temperatures collected by the basic system. From this recorded information, the computer can develop histograms for the maintenance men to use in diagnosing equipment conditions. The histograms that can be developed include the following:

- Engine oil pressure
- Hydraulic oil pressure
- Steering hydraulic oil pressure
- Brake system pressure
- Engine coolant temperature
- Hydraulic oil temperature
- Steering hydraulic oil temperature
- Torque converter oil temperature
- Hydraulic pump casing temperature

The histogram data can be obtained by the maintenance personnel through a central connector to the memory as illustrated in Figure 8. Using these histograms, the mechanic can spot deteriorating components and fix or replace them before excessive damage can occur.

Figure 8 - Artist's Conception - Maintenance Display

Performance Option One

This option provides additional information concerning loader performance for use by the operator and maintenance personnel. It includes a start up check to indicate whether the correct fluid levels are present for proper machine operation. The fluid levels examined include engine oil, hydraulic oil, steering hydraulic oil (if separate), engine coolant, torque converter oil, and transmission fluid. If any of these levels are not adequate, it will be indicated upon starting the machine. This start up check will also provide the mechanic with a quick indication of fluid levels during preventive maintenance periods. Another aspect of option one is filter loading indicators. As the air, oil, or hydraulic filters become clogged, a warning light flashes to remind the operator that the filter must be cleaned or replaced. Tire inflation pressure and fuel pressure are also monitored. In addition, a warning light is included to prevent operation of the transmission while the parking brake is engaged.

Performance Option Two

This option concentrates on improving loader production by indicating improper operating techniques to the operator. The operator displays for this option include the following:

- Warning lights for - Bucket overload
Tire overload
Impact force
- Digital readout for - Fuel consumption
Run time remaining on fuel
Hydraulic cycle times

- Stability indicator using weight shift

Warning lights are used for the factors that have a negative influence on productivity or availability. Tire spin produces excessive wear on tread surfaces and drive train units. Since these are among the most expensive maintenance items on a loader, protection is required. A warning light is, therefore, used to alert the operator if the front and rear wheel speeds deviate greater than 10 percent of each other.

Overloading is also detrimental to the loader systems. Warning lights are included to dissuade the operator from overloading the bucket with too much material or too dense of a material, and from overloading the tires with too great of a load on the front end. Since buckets and hydraulics are designed for a specific material density, a bucket filled with too dense of a material will overload them and failures may result. Another warning is also included to alleviate stress cracks in the bucket and boom due to ramming the working face with excessive force.

Greater accuracy in determining stability is possible in this option. Information drawn from the same strain gauges monitoring tire load can be used to calculate weight shift for stability.

Hydraulic cycle times are to be used as a check for hydraulic system efficiency. They will aid both the operator and the mechanic to diagnose hydraulic malfunctions. Cycle times would not be read continuously; rather, periodic checks should be taken throughout the workday.

Fuel consumption information can be used by management for operating cost determinations or as a guide for the operator to improve fuel economy.

Performance Option Three

Option three provides the management personnel with the production information necessary to evaluate the effective usage of the loader. Engine power output requirements can be compared to the quantity of work being performed. Cycle times can be determined using a cycle reference input by the operator and distance travelled. This information can be helpful to both the operator and the management staff. The operator may realize if he is travelling too far to complete a loading maneuver and subsequently correct his error. The management can use the information to calculate loader production per mode of operation and ultimately determine the most effective use for the loader.

Several items remain needing attention. The system presented here as a base unit is based on the lowest cost/benefit ratio. It allows the progression to the next generation of electronic monitoring technology for the lowest incremental cost. Options add flexibility in allowing the manufacturer to customize the unit to suit the needs of the users for each machine type and operational mode.

The key element in its usefulness is operator acceptance. The system depends on operator input in order to function effectively. Specifications can address technical requirements and insure reliability. They cannot address externalities such as operator acceptance. It is imperative, therefore, that the operator not perceive the unit as a "tattle-tale" or enemy. Management must use this tool constructively and encourage the operator to view it as an aide. The operator must have access to everything going to or from the unit!

The need for memory is a key element in any computer design. A critical element of the prototyping of this system will be algorithm optimization to reduce the required memory size. The environment in a FEL precludes the use of moving memory media such as tape drivers or floppy disks. Fixed media such as random access memory (RAM), read-only memory (ROM), and "bubble" memories are made for this application. If algorithms can be standardized, ROM offer the highest storage density for fixed programs. Then RAM or "bubble" memories can be used for temporary storage. Since RAM is the proven technology, it is imperative that systems be kept simple so that memory requirements are minimal. Dividing our system into options allow for incorporating simplicity - as "bubbles" mature, the system and its operation can cost-effectively become more complex. Standardized operating systems also allow ROM to be used for storing the largest amount of information in the smallest packages. Changes to the operating algorithm then only require changes in the ROM (personality module) for various machines or operating modes.

The issue of productivity measurements is complex with front-end loaders. Cycle times for mobile machinery are extremely variable. The variety of jobs which a FEL performs would require numerous cycle definitions. Due to the variegated nature of these jobs, no reliable definition can be determined. What can be determined are the factors which negatively influence production. Ramming a pile of material, overloading the bucket, or using excessive speed when in the carry mode all increase production (shorten cycle time), but cause increased component failure and unscheduled downtime. For this reason, the basic system only monitors negative productivity factors since availability is the key factor in FEL productivity. Options are provided where defined cycles can be established and monitored in a manner similar to that used on the dragline system.

SPECIFICATION OVERVIEW

The conceptual design of a BITE system for front-end loaders is based on applying proven electronic technologies to the monitoring functions of existing machines. This application will require the addition of monitoring, measuring, and communications equipment to the front-end loaders. This may require modification to the loaders to the extent necessary to provide mounting space for the BITE unit and its associated display unit.

Automation of this nature requires the addition of sophisticated electronic equipment. As such, the reliability of this equipment determines the reliability of the entire unit. The environment to which this equipment will be subjected needs to be well defined so that reliable equipment can be designed. Equipment manufacturers have given us a great deal of information in this area. A complete environmental description for FEL in surface mines is unavailable since those manufacturers having completed analyses consider it proprietary. Some key missing elements considered necessary for reliable equipment design are amplitudes and spectral content of FEL vibration, levels and spectral content of FEL electromagnetic susceptibility, mechanical shock levels, and dust concentration. The values cited in this study (see Appendix B) are based on the best available information currently being used by manufacturers.

Three prime questions must be addressed by the design of any electronic system to be used on FEL. Will it stand the environment; will it be durable and reliable; and will it be serviceable by the maintenance personnel available?

The automotive industry provides ample evidence of the harshness of the environment that vehicular electronics must withstand. The coal mine provides a parallel environment in items such as temperature extremes and humidity while surpassing it in harshness for items such as dust and vibration. Consequently the extremes of temperature, electromagnetic interference, voltage transients, adverse atmosphere, minimal maintenance, and fluid immersion all combine to create a need for a specification that approaches and sometimes surpasses "MIL-SPEC." The full specification recommended by this project team can be found in Appendix B. Several points addressed in it require further clarification.

Investigators have reported in SAE conference papers that engine compartment temperatures can reach 140°C. Since the temperature range from MIL-SPEC integrated circuits is -55°C to 125°C, care should be taken not to place BITE systems in this area. To do so would require components with special high temperature characteristics and the cost would be prohibitive. Any design must be based on allowing proper cooling of the BITE unit for the temperature extremes of the mounting location.

The power system for a BITE unit requires special consideration. Starting a FEL in severe cold conditions can cause the supply voltage to the power supply to drop as low as 25 percent of nominal. Jump starts from other vehicles can cause overvoltage levels of several hundred percent. The overvoltage condition can also be applied in reverse polarity. Noise levels generated by electromagnetic interference (EMI) can reach 15 percent of nominal levels. Adequate protective circuitry and filters must be included in any power supply design or component failure will occur.

Transients present a serious design consideration. Load dump transients, inductive load switching transients, alternator field decay transients and coupling transients all combine to place anomalies on signal and power lines. Power lines must be decoupled and filtered. Signal lines should also receive shielding and filtering considerations.

The subject of EMI has increasing relevance daily because of the expanding use of sensitive (i.e., low level analog and digital signals) electronic systems. The source of EMI can be external to the vehicle, such as radio transmitters; or internals, such as alternators, fan motors, and high energy ignition systems. Either source can be introduced into a BITE system by three principal mechanisms: 1) conductive coupling, 2) radiative transfer, and 3) quasistatic electromagnetic coupling (near-field magnetic or capacitive). Designers have an array of EMI susceptibility reducing weapons that must be considered during the design of the BITE system. These include twisted pair signal lines, high mu magnetic shields, selective filtering, and low impedance circuitry. Little information exists on the EMI spectrum for FEL. Subsequently, the specification was written using the automotive spectrum, but field research should be conducted to confirm the accuracy of this assumption.

It is also essential to minimize intermittent failures from thermal expansion and contraction. Encapsulation is a standard technique for accomplishing this on discrete components and printed circuit boards. Automotive experience has shown the use of silicone gel as the encapsulating material to be valid. It withstands the temperature extremes while preventing shock damage and still presents minimum stress to the components. The use of ceramic rather than plastic semiconductors should be used for their protection from thermal fatigue.

The display console will act as the primary interface between the computer and the operator. As such, it should be designed incorporating due consideration of ergonomic principles. Tactile and audible feedback should be used where feasible. The use of readily available computer peripherals would minimize hardware costs while utilizing proven equipment designs. The display console, in conjunction with its data communications link to the maintenance person's hardcopy output device, should be capable of informing the maintenance person of the location of a faulty module.

The design of a BITE system should conform where applicable to the Code of Federal Regulations, Title 30. In particular, the portions of Chapter 1, Part 18 dealing with ground fault interrupters, interlocks, fuses and circuit breakers, intrinsically safe design procedures, and plug polarization should be followed.

The durability and reliability of any vehicular electronic system is of considerable importance. The reliability of the BITE system must equal or exceed the reliability of the mechanical systems it replaces. The system has the objective of reducing equipment downtime so it must not be allowed to increase downtime by unreliability. The specification shows only a representative number for prototype development. Once the system has been finalized, an accurate determination should be made of system reliability.

A corollary issue is that of ease of maintenance. The candidate BITE system must be self-reliant. No assumption can be made of the educational level of maintenance personnel. The system should fail soft (i.e., allow continued machine operation) and provide an indication to the maintenance person of the source of trouble. Subsequent repair or replacement should be simple and quick to perform so as to minimize system downtime.

Dust remains a serious problem to specify. MSHA standards call for dust levels not to exceed 2 mg per cubic meter of air. Equipment currently being developed for the Department of Energy has specifications of 1000 mg per cubic meter. Recent field investigations have shown levels as high as 55 mg per cubic meter. These same investigations have witnessed levels in western mines where dust behaved as a "fluid solid." The specification given here follows a strategy of using an initial figure aimed at a worst case environment. Further field investigations should be conducted to determine the most appropriate figure.

BITE SYSTEM DESCRIPTION

BITE SYSTEM DESCRIPTION

The designer of any mining equipment BITE system is faced with a very difficult problem. Environmental constraints mandate the use of rugged components similar to those currently in use in military avionics systems. The variegated nature of the tasks performed by front-end loaders demands that any BITE system have growth capability and flexibility. This implies an ability to respond to changing task assignments and operational requirements with a minimum of downtime. The above requirements often translate directly into expensive and complex systems. Cost pressures from increased system complexity, the attendant higher maintenance expenses, a shortage of skilled maintenance personnel, and general economic inflation all will force the designer to address, and reduce, the cost of BITE systems.

The BITE unit described herein addresses these problems by defining a Digital Vehicular Information System (DVIS). This system emphasizes several basic design concepts that are listed below:

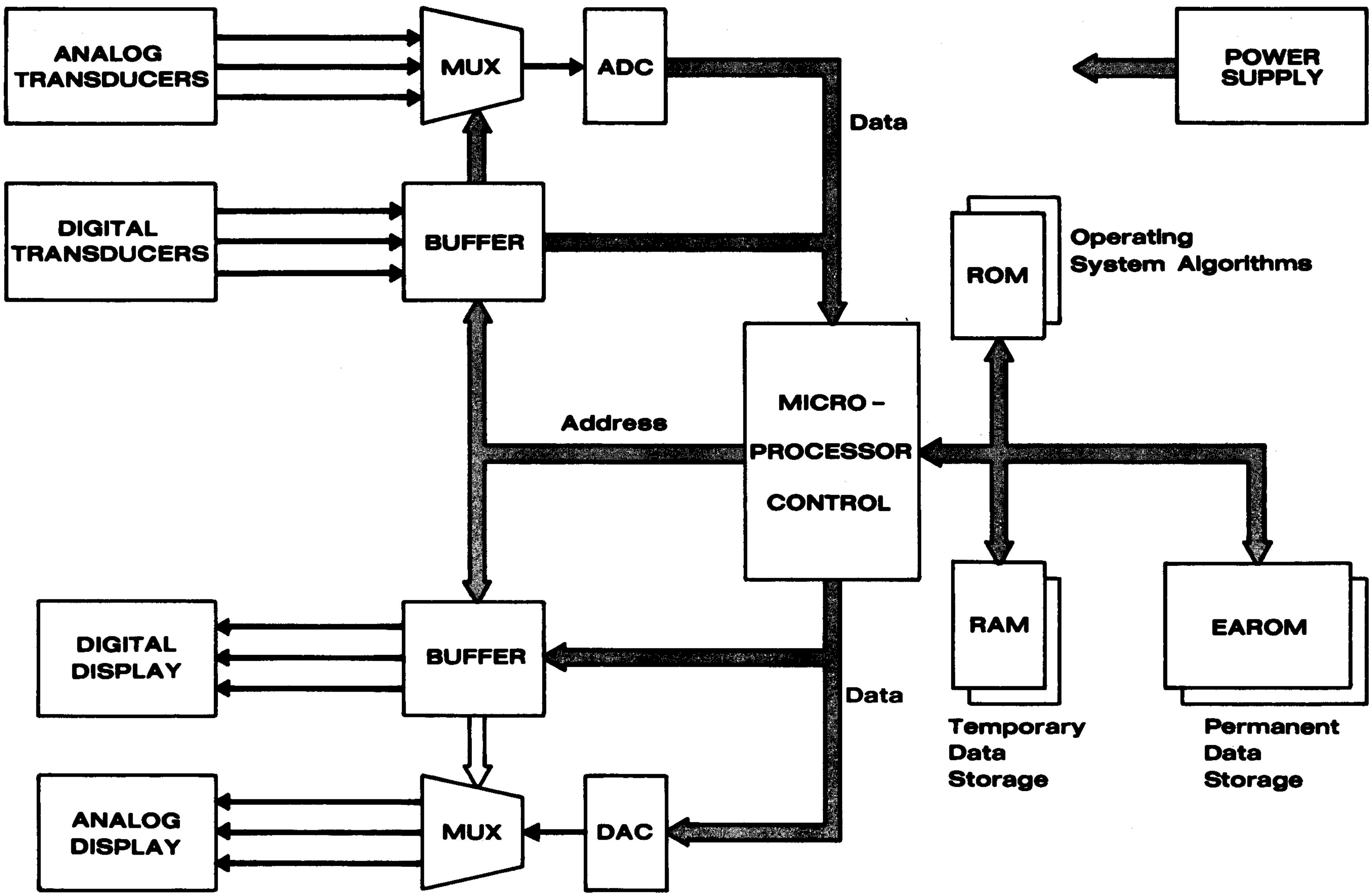
- System intelligence will reside in a "basic module" that can be adapted to machine type by a "personality module" and to operational requirements by a standard set of "function modules."
- Modifications to the system to meet operational requirements shall principally be accomplished through software rather than unique hardware.
- Greater mean-time-between-failures (MTBF) will be accomplished through standardization and redundancy.
- Flexibility will be incorporated through provisions for expansion by way of inserting hardware modules into the basic unit's backplane bus.

BASIC UNIT

The basic unit that will be used on all loaders will consist of a set of sensors for providing input data; an information data bus that distributes information in a common format; an information processing unit for performing data processing and storage; and an information presentation and control system for providing the required display and control systems.

By initiating any design effort with the requirements of the total digital information system and defining a family of standard transducers, data processing modules, memory modules, and display components, it is possible to design a multitude of different BITE systems with a minimum number of standardized electronic building blocks. Modifications can be accomplished by software changes in the operating system algorithms without redesigning the system or creating specialty designs. This reduces the field maintenance problems since the small number of standard units require a small spare parts inventory and reduced training expenditures for maintenance personnel.

Figure 9 shows a typical control system which interacts with the vehicle via the transducers and displays shown. Both digital-output transducers (event-type, pulse-rate encoded, etc.) and analog-output transducers are shown. The analog transducers interface to the processor via an analog multiplexer (MUX) and analog-to-digital converter (ADC) while the digital transducers interface through level-shifting buffers and counters. Similarly, the displays are driven by digital-to-analog converters (DAC) and demultiplexers as shown. The control logic consists of one or more microprocessors whose operation is controlled by a program of instructions stored in read-only



DIGITAL VEHICULAR INFORMATION SYSTEM

FIGURE 9

memory (ROM) and which use random access memory (RAM) for temporary storage of data. The processor samples the transducer outputs periodically or on demand, interpreting the results, and displaying the vehicular operation as needed.

The next step involves specifying the duties to be performed by a BITE unit specifically for front-end loaders. Analysis of the data shown in Appendix A and Source 30 reveals that FELs are used for a variety of tasks. A partial listing of these tasks is shown below.

1. Land clearing and preparation of location
2. Construction and maintenance of access roads and haul roads
3. Dig and load overburden
4. Cleanup tool for shovels and draglines
5. Load coal at face
6. Load coal from pockets left by big loading machines (scramming)
7. Dig and load fire clay
8. Boost trucks from pit
9. Tow disabled vehicles
10. Build dikes
11. Relocate culvert pipe
12. Relocate pumps
13. Maintain spoil piles
14. Move electric cable skids
15. Load from surge piles

Of all of the above uses, only numbers three and five lend themselves to cyclic analysis such as was a principle design concept for the dragline BITE systems. This data also shows that a major portion of the FELs available time is spent on the other numbers (tasks). For this reason, the basic unit will not include comprehensive productivity functional analyses. These types of analyses are limited in application to those users with FELs dedicated to cyclic loading. Since this is not a major market segment, it will be specified as an option.

It has been determined (Source 30) that the major maintenance costs and most common cause of downtime for haulage vehicles stemmed from operator-induced damage to the engines and drive trains of these machines. The most frequently cited were damage to the transmission which is usually attributable to lack of operator training, lack of sufficient experience on the job, inability on the operator's part to develop the necessary skill level, inattention while on the job, or operator overload (too many instruments to monitor, and controls to operate while attempting to safely maneuver the machine)! The training given operators ranged from non-existent to a one shift training session with an experienced operator following a manufacturer's training aid program. The former is more prevalent than the latter. It is apparent that preventative maintenance, pre- and post-start inspections, and proper loader use are the areas most often neglected. A portion of this problem exists because the operator is at least partially responsible for inspections and daily maintenance activities at a number of mining operations. Unless the personnel policies and training procedures ensure highly qualified operators, this practice surely leads to increased machine downtime. The lack of comprehensive periodic (pre- and post-start) inspections reduces the safety of the operator and other personnel in the vicinity of the loader and increases the possibility of catastrophic failure of the loader, systems, or engine. Machine abuse creates the same problems, only in real-time. For these reasons, it is felt that any BITE system must place prime importance on availability constraints and the operator's needs. The base unit can be most cost effective by addressing the needs of the largest user segment (the operator) over the widest spectrum of machine uses (monitoring operating conditions and status of machine without respect to end-use of loader). The automatic monitoring of the machine; the presentation of situation update displays upon operator request (without information overload); and the provision for alert warnings when the machine or operator is malfunctioning have the greatest impact on the safe, efficient, and cost effective operation of loaders.

The BITE basic unit provides these services without requiring expensive training programs (neither in time nor money). The intelligence of modern electronics technology is utilized to construct a system which ensures its own reliability (and reduces maintenance costs) through built-in self-diagnostic features. It also provides real-time monitoring — allowing the operator to concentrate on running his machine and producing coal rather than checking the temperature of his transmission fluid. Options will provide summary data for maintenance personnel and summary reports for management on productivity.

The BITE basic unit is not a panacea for FEL availability constraints. Often times preventative maintenance and on-the-job equipment inspections are not systematically made by the operators. FEL cabs and work stations are covered with dirt, dust and oil. Grease, spilled oil, and debris, which constitute a major hazard, are found in the cabs. The windows and instruments are dirty. Instruments are often inoperative, and the equipment in a state of disrepair. In some mines it appears the operators have adopted a failure philosophy of "drive too destruct." When both owners and operators evidence such philosophy, no technological innovation can reduce downtime or inefficiency. The system requires the operator's acceptance and the maintenance person's care. No system can be made "idiot-proof!"

Figure 10 illustrates the conceptual block diagram for the BITE system. The shaded components comprise the universal basic unit to be installed by the manufacturer in his loaders. It is comprised of a power supply which delivers filtered and conditioned power to all system components; a personality module for customizing the unit's operations to fit a particular machine type; a central processing unit for data processing; a data acquisition and control module for signal routing; and a signal conditioning unit with its associated transducers, activators and displays for data gathering and dissemination.

The components necessary to construct the basic unit are given in Table 8. These components are interconnected by the system bus as shown in Figure 10. The components interact as depicted in the flowchart given in Figure 11.

System Bus

The system bus forms the backbone of the BITE basic unit. For ease of standardization for cost minimization, the unit should be designed around an industry standard backplane bus. Numerous examples of computers have been built cost effectively utilizing mother/daughterboard configurations where the motherboard incorporates a standardized bus. These standard buses include the Multibus, the S-100, and the STD-Bus.

TABLE 8

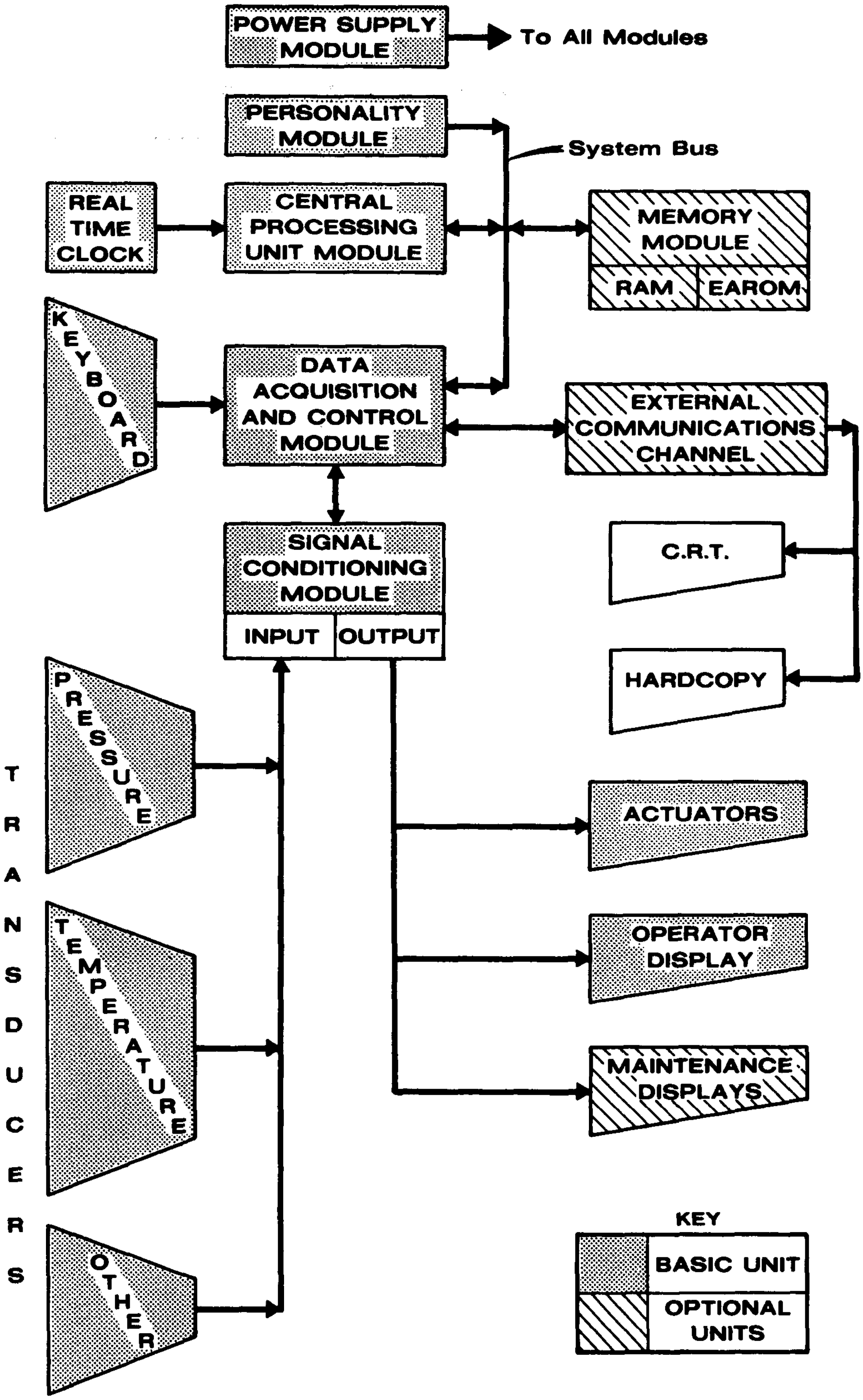
BASIC UNIT COMPONENTS

I. BASIC UNIT

- Power Supply Module
- Personality Module
- CPU Module
- Data Acquisition and Control Module
- Signal Conditioning Modules
- Keyboard
- Operator's Display
- RTC
- Transducers
- System Bus

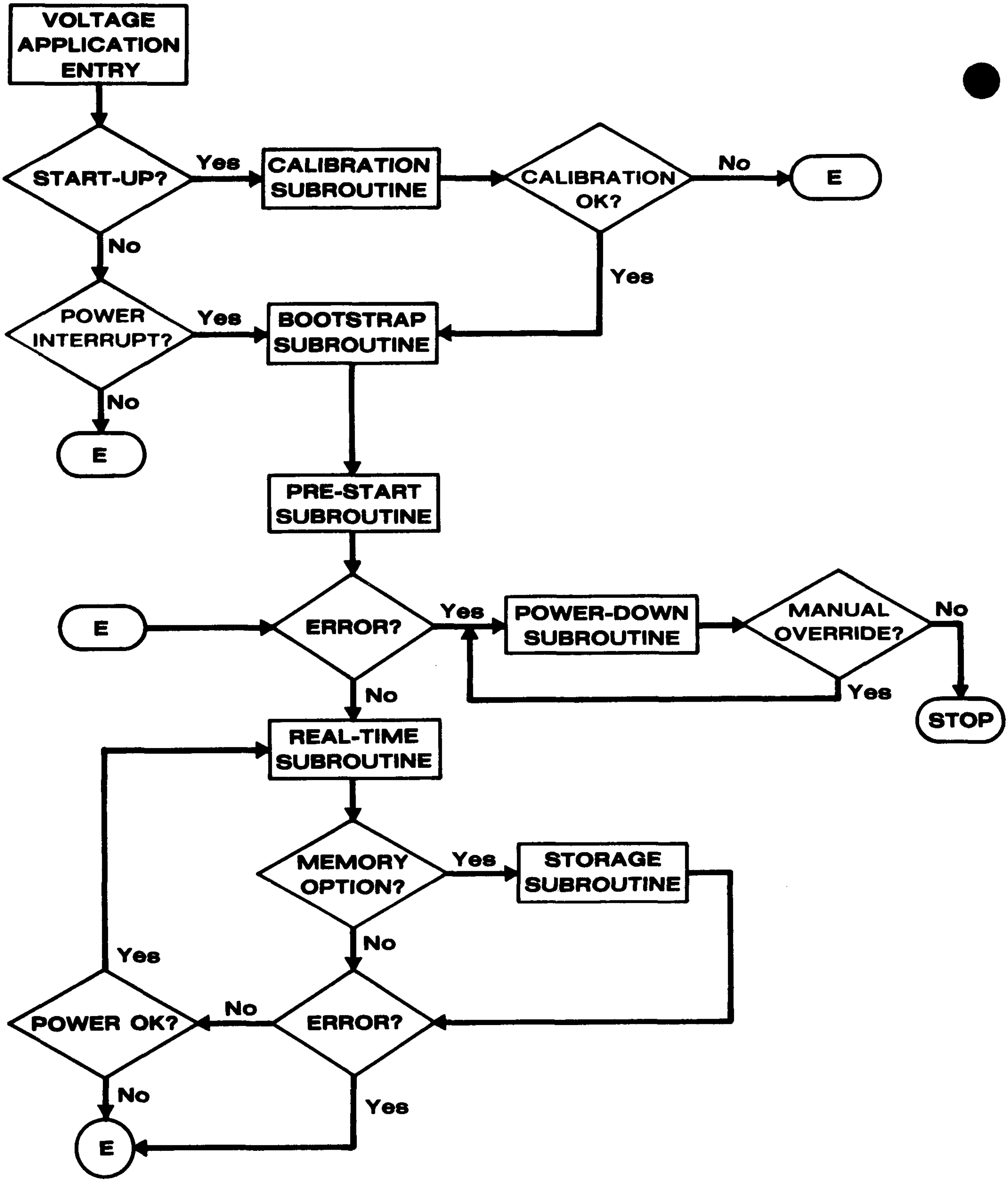
II. OPTIONAL UNITS

- Specialty Channel Cards
- Memory Module
- Maintenance Display
- External Communications Channel
- Personality ROM



BITE BLOCK DIAGRAM

FIGURE 10



BASIC UNIT OPERATIONAL FLOWCHART

FIGURE 11

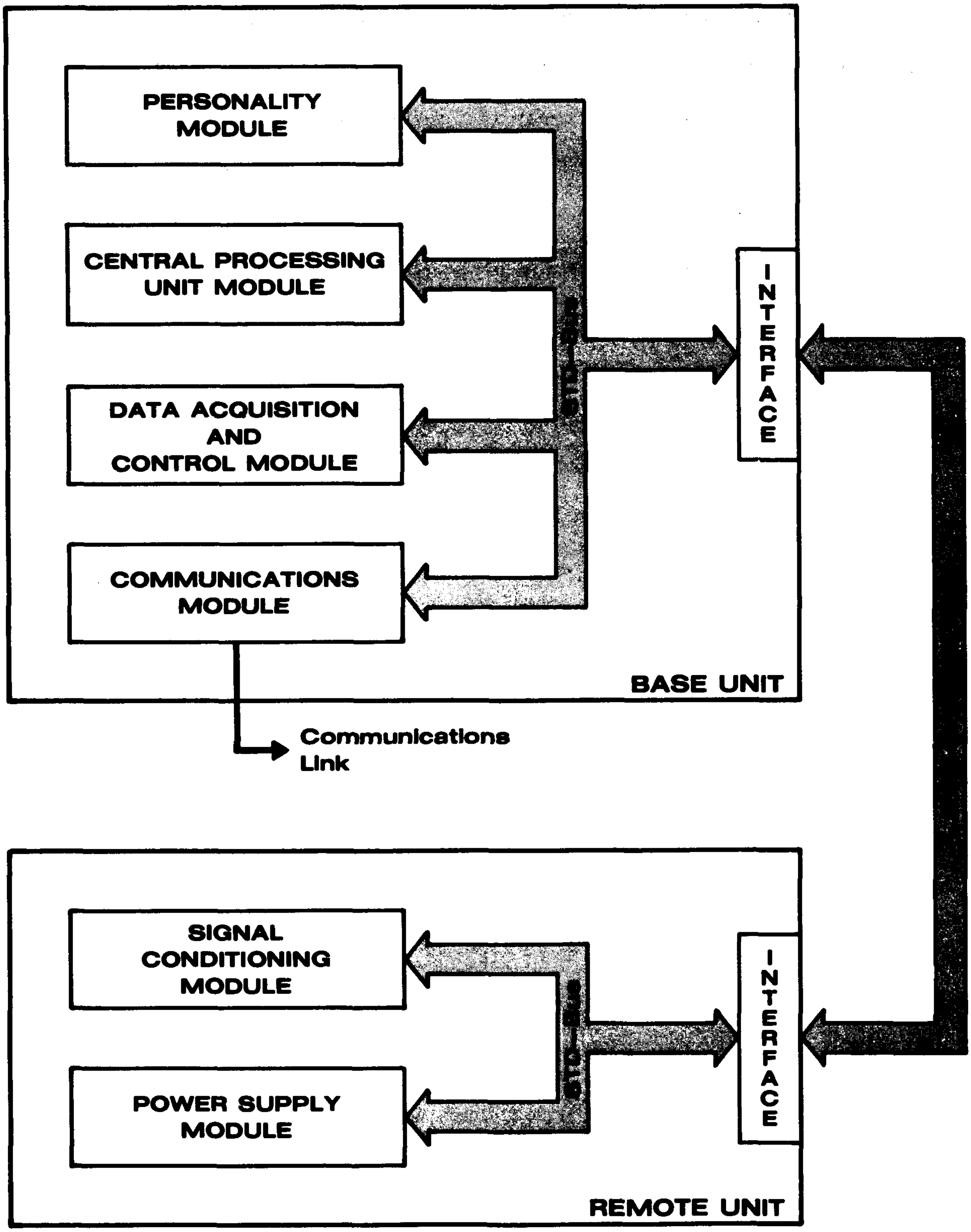
The feasibility of using one of these standard bus configurations should be determined before any system prototyping is initiated. The act of standardization can be carried a step further if the BITE unit is divided into physically separate units due to space limitations or redundancy requirements. In this situation, a data transfer protocol such as the IEEE-488 General Purpose Interface Bus (GPIB) should be used to interface the units over a separate data interchange bus. Whereas the backplane bus is internal to the BITE unit and serves to convey data, address data, and control signals between printed circuit boards, the data interchange bus is external to the BITE unit and conveys data in an ASCII format between functional units or modules. Figure 12 illustrates the relationship of these two buses plus the data communication's bus. A GPIB bus is limited in usefulness for long communication links. When the BITE unit is coupled to a remote computer terminal or hardcopy readout device such as is shown in Figure 8, a serial data link that uses currently available integrated circuits for formatting, coding, and error detection in a Synchronous Data Link Control (SDLC) protocol over a RS-232 link should be utilized.

Power Supply Module

The power supply module performs several critical tasks or functions. These include:

1. Power line noise suppression
2. Transient suppression
3. Regulated voltage output
4. Current limiting
5. Back-up battery

The FEL provides a noisy environment for electrical systems. Consequently, it is imperative to incorporate filtering and transient suppression in the power



BUS CONFIGURATION

FIGURE 12

supply as noted in the specification. Since power supplies also generate large heat loads, thermal management must also be incorporated in any design. Thermal considerations may necessitate the locating of the power supply in its own enclosure at a location remote from the BITE display or basic unit. Should this be necessary, filtering should be provided at each module's input. Otherwise, the power supply should use standard voltage and current regulating techniques.

Logic will also have to be incorporated in the power supply design to initiate power-up and -down sequences. These sequences are contained in the personality module and shown on the flowchart, Figure 11. The control signals necessary to differentiate which sequence is to be used must come from this module. Additionally, a back-up battery will be needed to maintain system power during power outages long enough for the operating system to transfer vital operating data from the volatile temporary RAM storage to the non-volatile EAROM storage (see glossary). Provisions for and maintenance of the state-of-charge of the back-up battery will be a provision of the power supply module.

Personality Module

The personality module is the key element necessary to allow a standardized BITE system to be tailored for use on a variety of loader models and in different operational requirements. The module will be used to define the characteristics of each specific front-end loader that the BITE unit will be used on and contain all of the pertinent data relative to the machines as may be required by any other module. Table 9 describes the control algorithms that will reside in the personality module. The use of these algorithms is again illustrated in Figure 11. Each system module will access the personality module through the system bus to retrieve control sequences and mathematical control data for system operation.

The personality module will be constructed in such a manner as to be expandable. Integrated circuit sockets will be included for the addition of ROMs for each option as it is added to the basic unit. The basic unit will include sufficient ROM to operate the basic system on the desired loader. ROMs will be added when an option is added so as to supply to the basic unit the operating system necessary to utilize the option's features. Details of these control algorithms are given in Table 9.

Central Processing Unit Module

The central processing unit (CPU) module forms the heart of the BITE system. Consideration must be given to the proper packaging of this module since the aforementioned environmental constraints will directly affect the reliability of its operations. Design efforts will have to be coordinated with equipment manufacturers. The optimum location for this module would be in the FEL cab. Space limitations will be of major import in this step. The amount of space available will determine the module's envelope. Once this is established in concert with the manufacturers, package detail design can be initiated. A permissible, mineworthy packaging enclosure will be needed. It will be necessary to shock-mount the unit. The enclosure should contain a modular mounting frame containing the system bus. The power supply may be included in this enclosure. If so, precautions must be

TABLE 9
PERSONALITY MODULE ALGORITHMS

SEQUENCE	MICRO-COMPONENTS	SUBROUTINE USES					
		Calibration	Bootstrap	Pre-Start	Real-Time	Power-Down	Option
INITIALIZATION	Auto-Start (Power-Up Bootstrap)	X	X				
	Calibration	X					
DIAGNOSTIC	Transducer Test		X			X	
	RAM Test		X			X	
	CPU Test		X			X	
STORAGE	Memory Transfer			X	X	X	X
	Power-Down Bootstrap					X	
	EAROM Program					X	
DISPLAY	Auto Poll		X				
	Keyboard Callup	X	X	X			
	Configuration Learn		X				
ERROR	Comparator			X	X		
PRE-START	Static Transducer Poll			X			
REAL-TIME	Dynamic Transducer Poll				X		X
	RTC Access				X		
	Compute				X		
EMERGENCY	Data Delay			X		X	
	Override			X		X	
	Tilt Detect			X		X	
CONDITIONING	Linearization	X					X
	Scaler	X					X
	Filter	X					X

taken to ensure proper thermal management. The module, with or without an internal power supply, must contain wiring capable of handling the fullest complement of module power requirements.

The module's enclosure must be capable of handling any configuration of processing modules, input/output modules, memory modules, and control modules capable of supplying basic unit operational requirements and control algorithms. These algorithms, stored in ROM, will be an inherent component of the central processing unit module. They shall access a real-time clock (RTC) included on the CPU board for time-related calculations.

Depending on microprocessor selection, the RTC can be either hardware or software. There are two basic approaches to keeping track of time with a microprocessor. The first is by external logic through a dedicated clock chip, a hardware approach; the microprocessor only reads the data and uses it. A variant of this approach is the interrupt mode in which a signal generated by external logic interrupts the microprocessor at fixed intervals, for example, every 10 milliseconds, and increments a software register. In the second method, a software approach, timing loops are generated in software.

The disadvantage of the software approach is the more difficult programming. The adjustment of basic timing intervals to the same length requires care, particularly with processors having variable-length instruction times. In addition, the processor cannot perform any other function when it is in a loop. The software method does have a cost advantage in that no external hardware is needed. Additionally, the restrictions that accompany an interrupt driven mode are avoided: the rate must be high enough for good time resolution, but not so high as to burden the processor. All these factors must be analyzed during the design process.

The basic unit's central processing unit addresses three functional areas. These are pre-start diagnostics to verify that the FEL is capable of proper operation; real-time operational checks to ensure continued proper operation; and real-time safety monitoring to alert the operator of undesirable conditions. The basic operatinq function of the microprocessor is to bring in data from the transducers, to process it on the basis of pre-programmed strategies stored in ROM, and to hand out the results in the form of parametric data to the displays and actuators.

The control problem which the module must solve involves four factors. The module must:

1. Convert all transducer inputs into digital numbers and transfer them into the microprocessor.

2. Determine the state of the system from these inputs and compute optimal actuator values for all controlled functions and suitably scaled numbers for the displays.

3. Output all digital values and convert them into suitable physical control parameters for the actuators.

4. Repeat all of the above at a rate sufficient for safe, reliable FEL operation.

The solution to these problems determines several key unit characteristics. These are as follows:

1. The unit must work reliably in a harsh environment.

2. The unit must perform all processing, decision making, and storage of data under microprocessor control on-board the FEL.

3. All functions must be performed automatically without the need for human intervention.

4. The BITE unit must be self-contained, easily installed and maintained, and frugal in its power requirements. It must also diagnose its own condition.

5. The unit must be expandable so as to allow each owner to customize its functions to his needs. This includes the provision for transfer of data to off-board computers for extended analysis.

6. The unit must provide humanly engineered displays for apprising the operator of machine status upon demand.

The central processing unit (CPU) controls all other elements in the computer and performs the arithmetic and logic operations necessary to execute the program in the system memory. Some of the basic arithmetic operations that must be performed by the CPU are: (1) addition; (2) subtraction; (3) multiplication; (4) right and left shift; (5) table look-up and interpolation; (6) logical operations; and (7) branch and jump operations. Most off-the-shelf microprocessors which are currently available at a price which is not prohibitive have an 8-bit architecture. In this type of microprocessor, most variables require double-precision capability. In most cases, this requirement is easily met since double length registers are available or two registers can easily be manipulated together. A detailed analysis should be made of the available microprocessors and their suitability for this application. Additionally, a full development system should be constructed for a BITE unit. This BITE development system should have extended capabilities to test and evaluate many different approaches. Once a suitable approach is determined, the algorithm can be reorganized and incorporated into a production design.

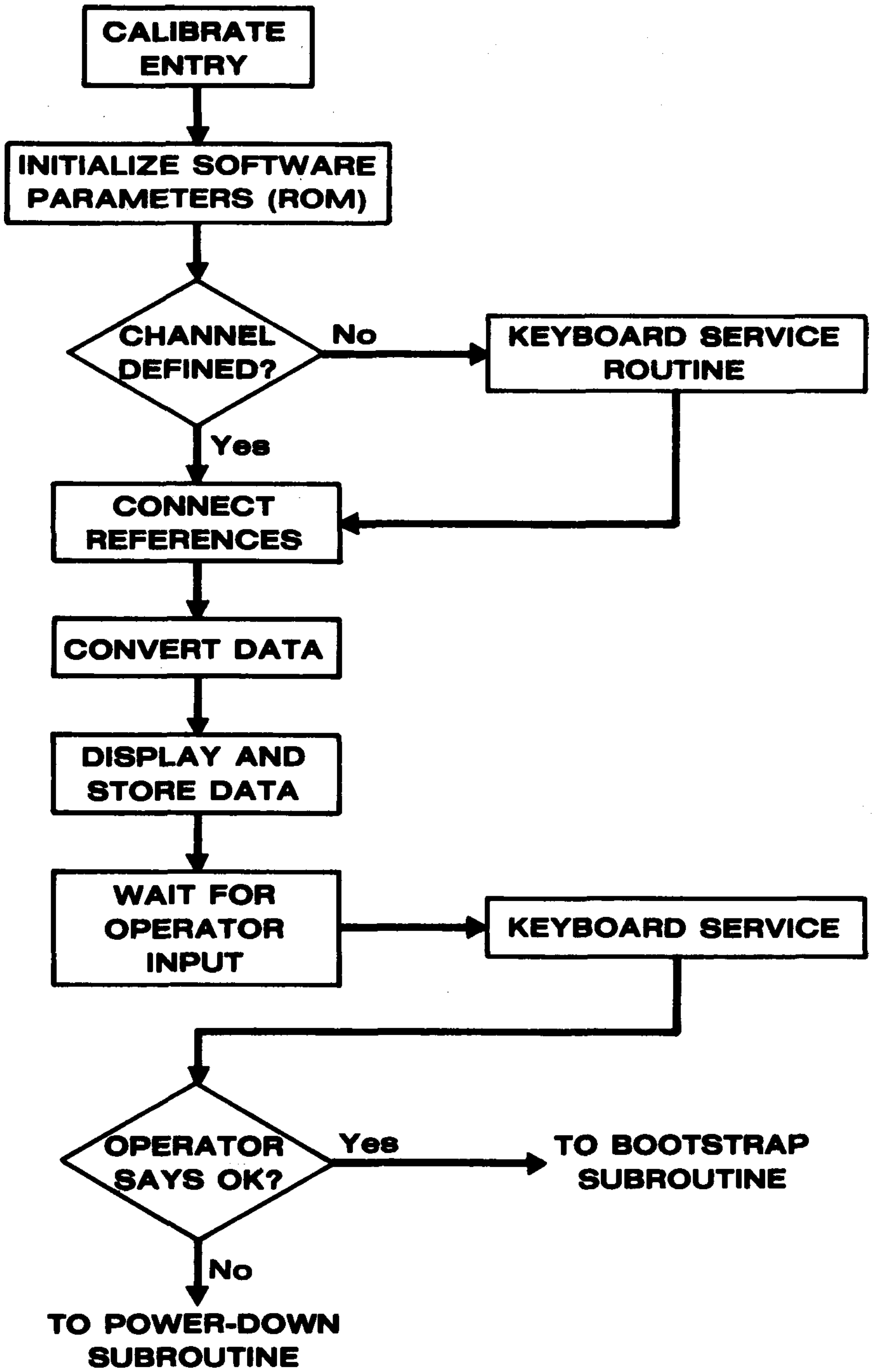
Most applications have minimal RAM requirements. Therefore, the capacity of the RAM in BITE should be limited to 256 bytes of data for the basic unit. This memory can be used as the scratch pad memory for the control program. However, as will be seen in the section describing the system memory, this memory capability can be expanded for options requiring data storage. Options such as the level and frequency histograms in the maintenance option will require 1024 to 2048 bytes for programs and another 2048 bytes per function for data storage.

A factor to be considered in microprocessor selection is instruction execution speeds. These determine the time frame occupied by the implementation of the control algorithms. In general, to compute the output values, several inputs must be read from the sensors and one or more stored control schedules consulted. The values read from the control schedules are then used to compute the actuator output values. Since the schedules cannot contain stored values for all possible combinations of inputs, it is usually necessary to interpolate between the values obtained from the schedules. This interpolation is the most time-consuming part of the control algorithms executed by the microprocessor, and requires several multiplications per interpolation. Thus, when selecting a standard architecture or designing a system architecture, the ability to perform multiplications efficiently must be given major consideration.

The experience of manufacturers of mobile data processing units has shown that several precautions need to be taken to "harden" any BITE unit to its environment. These include isolating and filtering all input lines; optimization of ground structures; separation of noisy circuits; and redundant circuits for control signals and all lines passing through connectors. It is also imperative that manual overrides be provided for any control feature that prevents machine operation. A machine being automatically shutdown for falling oil pressure should not be stranded on a railroad track!

The central processing unit module will operate according to the flowchart given earlier in Figure 11. The operational procedure will be for the operator to make a pre-start check of his machine. This will be initiated with a walk-around of the machine checking for worn or damaged tires, excessive dirt accumulations, and other items not monitored by BITE such as fluid leaks. Then the operator will use the BITE unit to perform a check of machine status. He will enter his operator number and machine function information through the keyboard. Upon starting the machine, the BITE unit will automatically initialize itself, calibrate itself, and poll all transducers. The digital readouts on the display panel will allow the operator to check all temperatures, pressures, and other critical parameters. He will then take action on any warning lights or safety alerts displayed. If systems are all normal, he will select those parameters he desires continuously displayed on the bargraphs and commence operation.

Figure 11 shows several subroutines that are essential components. Figure 13 details the calibration procedure which is automatic except for



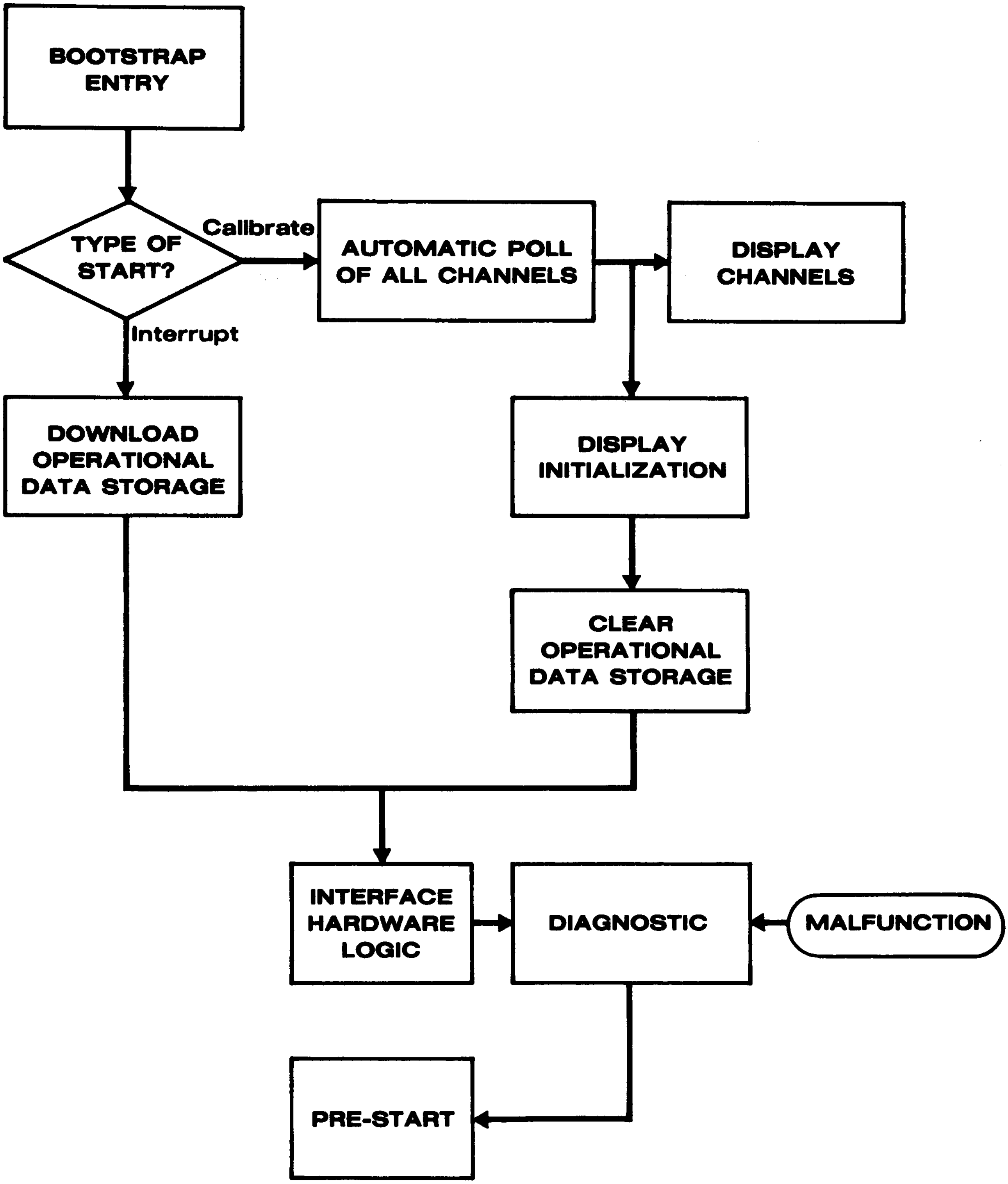
CALIBRATE SUBROUTINE FLOWCHART

FIGURE 13

channel definition. Assignment will be made of standard parameters for each channel. For example, engine oil pressure may always be on Channel 1. For unassigned or special function channels, the maintenance man or operator will be required to input channel assignments. EAROM may be provided for semi-permanent storage of this data to prevent having to repeat its entry on each start-up.

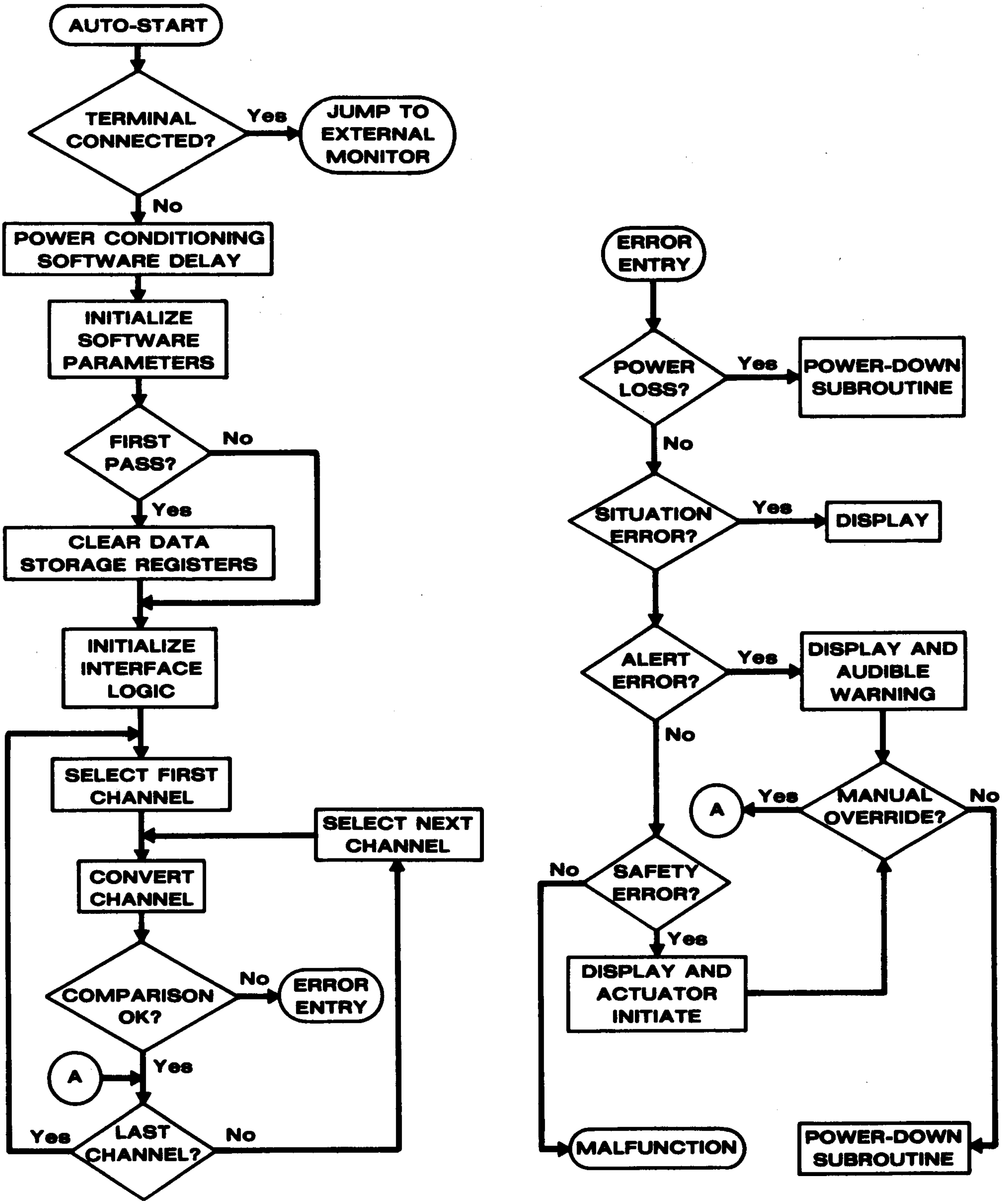
Figure 14 illustrates the BITE bootstrap subroutine. It is necessary for the unit to automatically perform its duties. This routine downloads previous operational data which was stored during temporary power outages. It also clears memory (data storage) and displays the parametric data on all monitored functions sequentially. At this time it also completes diagnositc routines to ensure that all BITE systems (basic and optional) are working. Error codes will be displayed to allow maintenance on defective components. These codes will isolate a problem down to a replaceable module. Assuming proper operation, the machine automatically proceeds to the pre-start subroutine.

Figure 15 examines the pre-start subroutine. The software for this sequence consists primarily of routines to access all channels and convert the signals to digital data. Other routines to ensure that data is within acceptable limits as defined by the control algorithms is in the personality module. These routines also control the displaying of the processed data to the operator as normal operating displays (continuous via bargraph or upon request via digital readout), or as situation and alert indications (via lights and audible indicators). The manual override feature described earlier



BOOTSTRAP SUBROUTINE FLOWCHART

FIGURE 14



PRE-START SUBROUTINE FLOWCHART

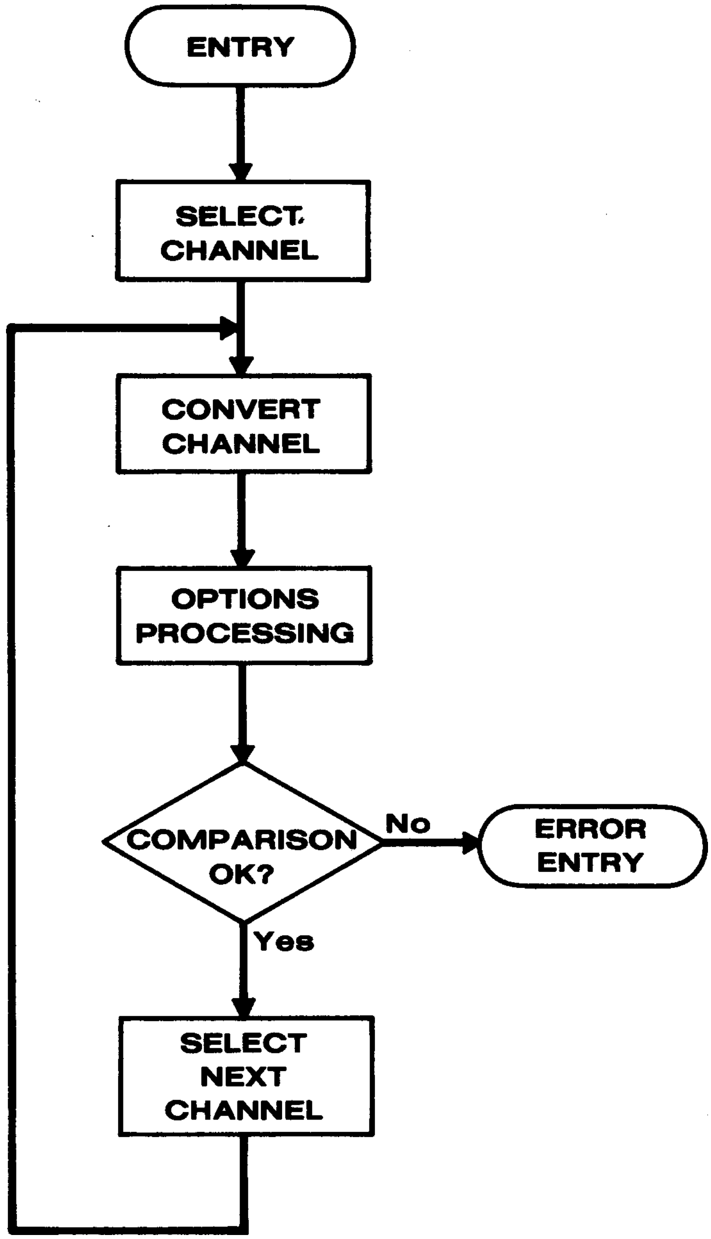
FIGURE 15

also comes into play during this routine. It is of a nature so as to allow operation of the machine for a predetermined amount of time before disabling the machine. This will allow the operator to place the machine in a safe storage configuration until maintenance can be performed.

The real-time subroutine flowchart is shown in Figure 16. This subroutine is basically repetitive of the pre-start subroutine except that it is performed repeatedly as long as the machine is in operation. It also supplies the processing time for the options such as time and frequency histogram preparation in the maintenance option. An auxiliary operation to the effective use of this routine is the Power-Down Subroutine given in Figure 17. Whenever power levels fall, either due to an error condition causing BITE to cease machine operation or to power loss from power supply failure or normal machine shut-down, this routine automatically stores all data gathered on machine performance, and transfers control to an external controller if elected. Although the Basic BITE Unit deals primarily with supplying the operator machine operational data, it incorporates the intelligence to effectively utilize varied options.

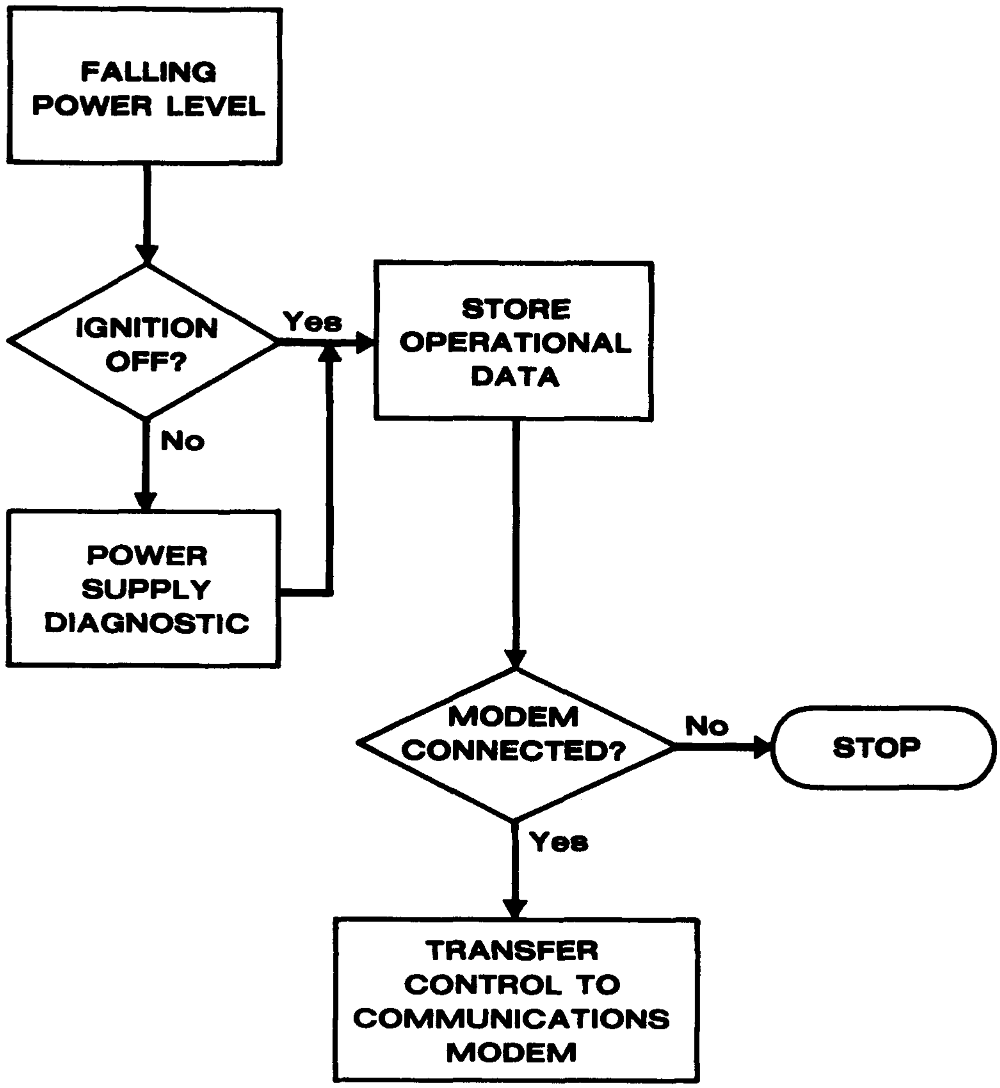
Data Acquisition and Control Module

This module contains the interface logic necessary to couple the signals from the transducers to the display panel and the central processing unit module. Whereas the previously described modules may consist of one only printed circuit board, this module will by its nature consist of several circuit cards. The module is responsible for keyboard interfacing, communication channel operations, and data multiplexing from the signal conditioning



REAL-TIME SUBROUTINE FLOWCHART

FIGURE 16



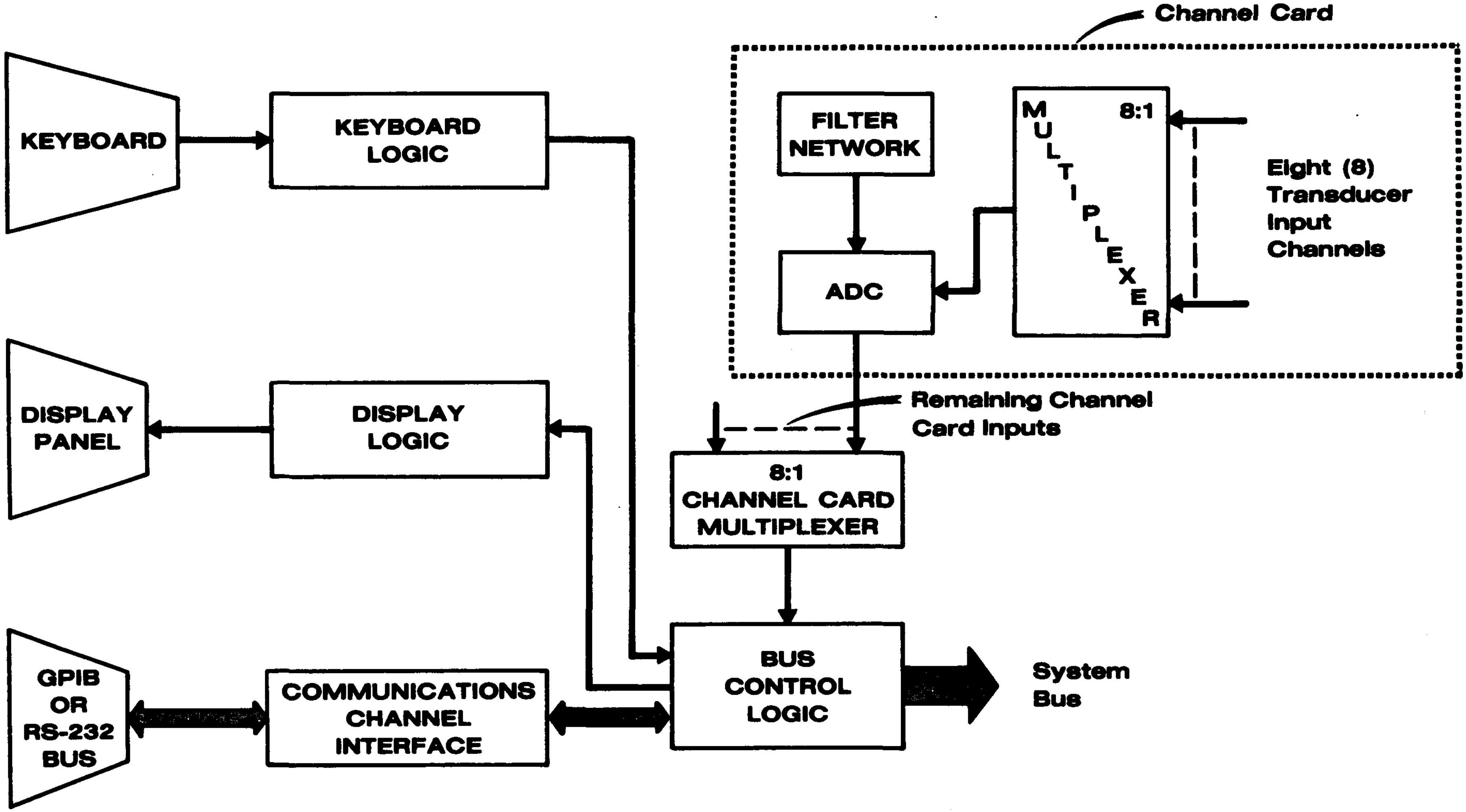
POWER-DOWN SUBROUTINE FLOWCHART

FIGURE 17

circuits to the data conversion circuitry which is part of the module. Figure 18 illustrates a typical block diagram for a data acquisition network. It includes: (1) channel cards which provide multiplexing and conversion circuitry for eight transducer inputs; (2) plug-in printed circuit cards to select the filtering and calibration components necessary for the types of transducers selected; (3) multiplexing circuitry for multiple "channel cards;" and (4) bus control logic for controlling data flow among the keyboard, displays, and communications channel.

The objective of a system design such as this is to provide multichannel inputs with self-contained signal conditioning. This allows freedom in the expansion and interchangeability of channel numbers and functions. Good data acquisition system design practices would dictate the inclusion of low pass filters and calibration relay/resistor networks for each channel. The channel count of eight channels per card is a result of the wide availability of standard ADC modules containing eight dual polarity inputs. Expansion beyond eight channels, such as is required in the BITE basic unit, is accomplished by the addition of additional "channel cards" feeding the channel card multiplexer. The module's motherboard will provide all the connections for power, differential inputs, and common single-ended ground outputs for eight channel cards. Each channel card must then supply the drive for eight signal conditioning modules (one per transducer). For simplicity, all temperature transducers should be grouped on one card, pressure transducers on another, etc.

The module also contains logic for interfacing a keyboard, the communications channel, and the displays. The keyboard service subroutine,



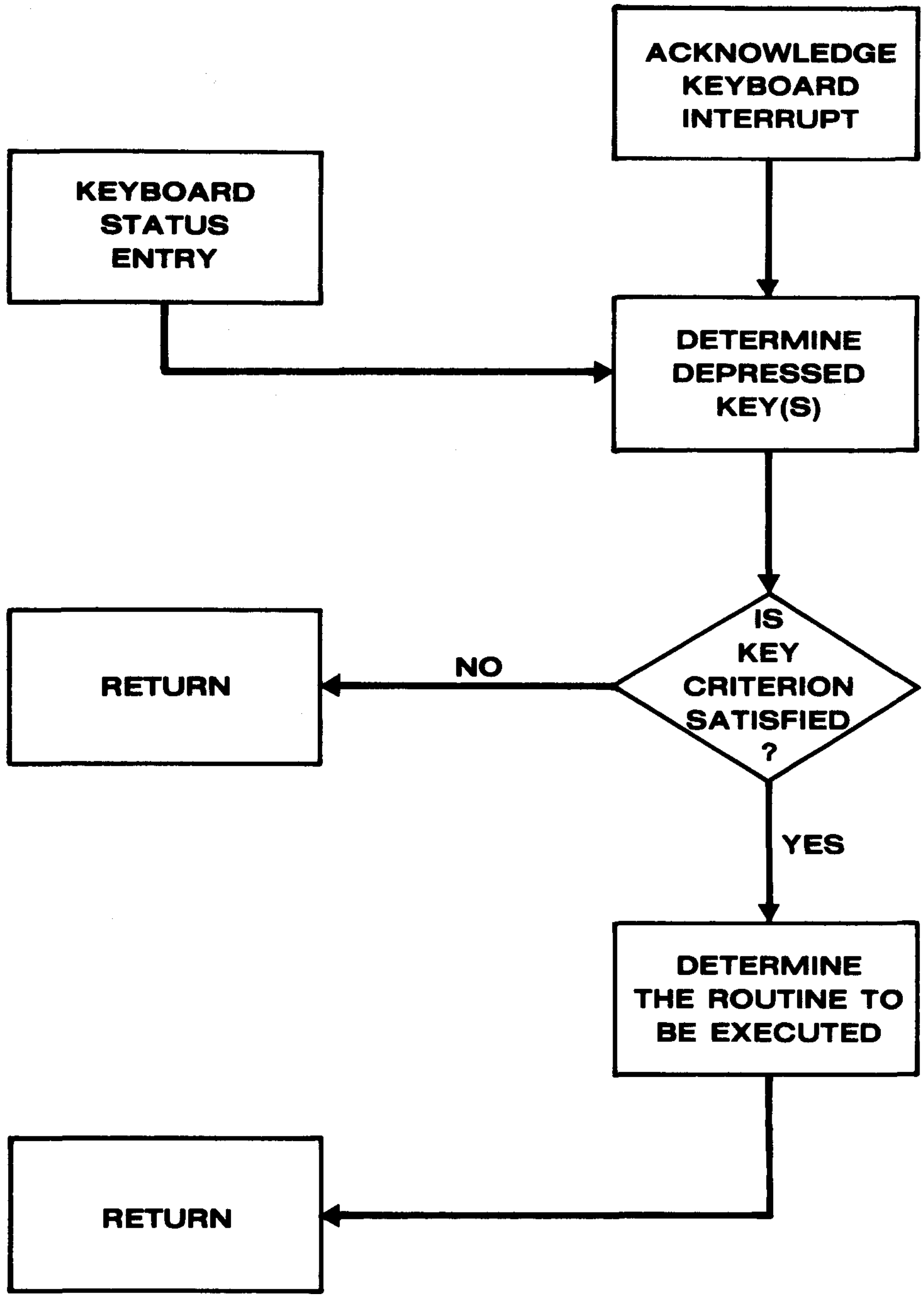
DATA ACQUISITION AND CONTROL MODULE BLOCK DIAGRAM

FIGURE 18

shown in Figure 19, determines when and which key is depressed. It performs a decoding and debouncing function. Once a legitimate key depression is acknowledged, it is communicated to the central processor over the system bus by the bus control logic.

The communications channel should be designed to operate in a high noise environment. It should use optical couplers and differential line drivers for bus interfacing. The bus selection is dependent on the off-board data analysis requirements. Initially, it may be sufficient for the BITE unit to do all data processing and communicate the results to an external hardcopy device over an RS-232 link. Any system requiring "handshaking" and BITE interrogation by an external processor should utilize a GPIB link. The General Purpose Interface Bus (GPIB) is specified by the IEEE Standard Specification 488. This document specifies the mechanical, electrical and functional requirements of the GPIB. The GPIB provides a standard digital interface for instrumentation equipment and therefore recently developed instrumentation can be interfaced to the BITE system and provide expanded capabilities. The BITE computer can handshake with any peripheral device on the GPIB and transfer data either to or from the peripheral device. The signal lines defined by the IEEE Specification include eight data lines, three data transfer handshake lines, and five management bus lines.

The other standard interface is the EIA Standard RS-232-C bus which is used for data interchange between data terminal equipment and data communicating equipment employing a method of serial binary data



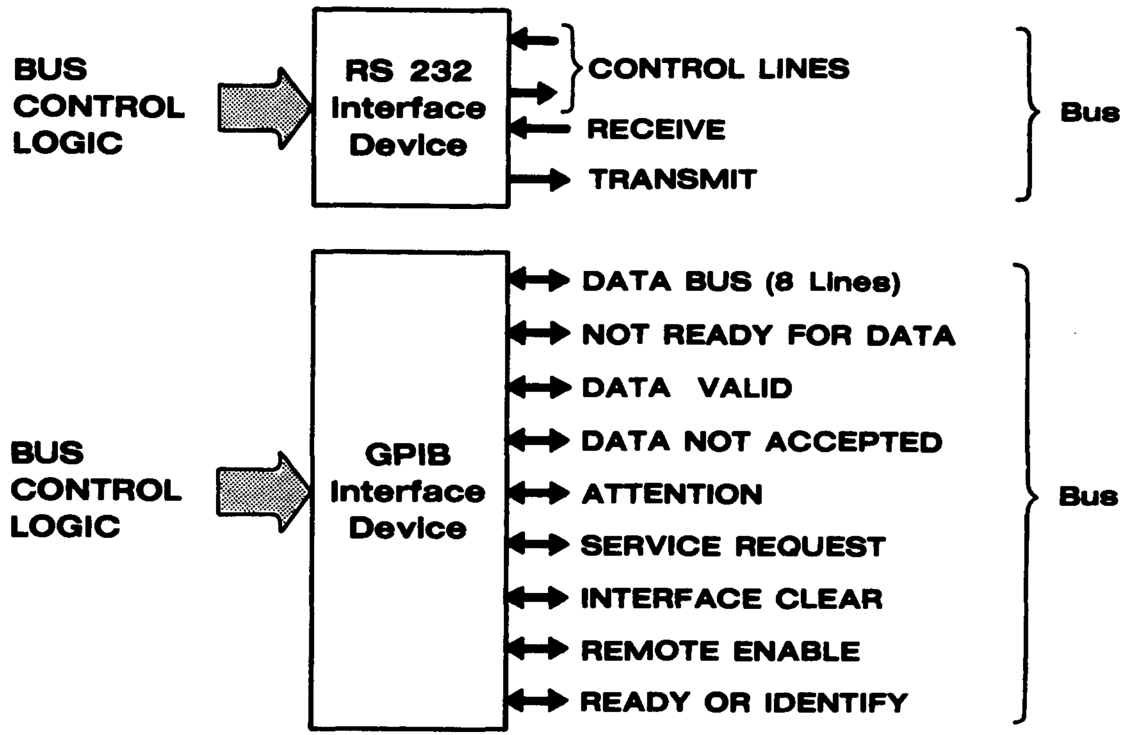
KEYBOARD SERVICE SUBROUTINE FLOWCHART

FIGURE 19

transmission. The transmit and receive lines transfer the serial data between the interface computer and the peripheral unit. The control lines provide a handshake operation between the transmitter and receiver and indicate the status of the system equipment and of the data registers in the equipment. The data is usually transmitted as an eight bit binary word consisting of a seven bit ASCII character with a parity bit. Block diagrams of both of these interfaces are shown in Figure 20.

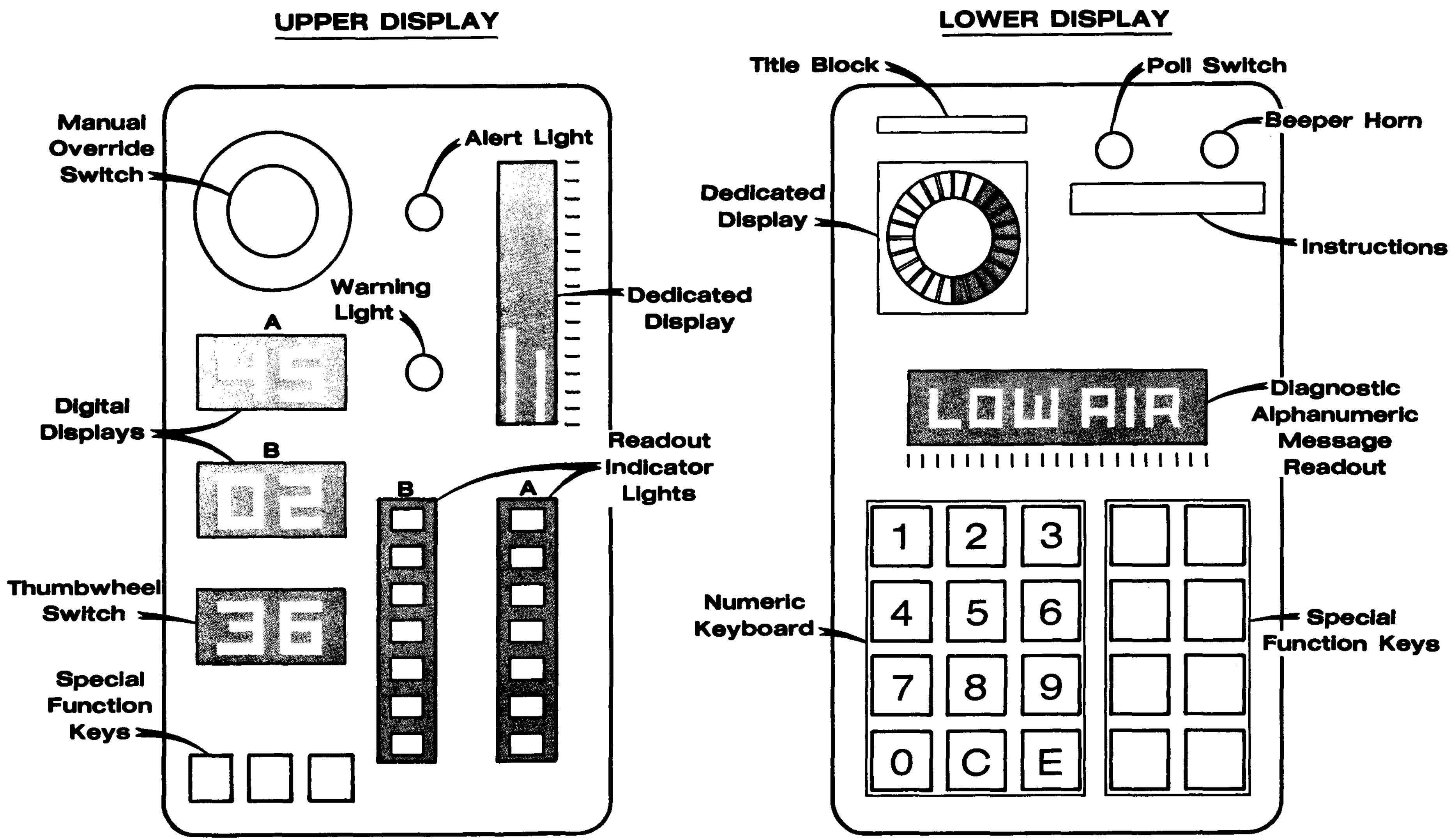
The final element of the data acquisition module is the display and display interface. As mentioned earlier, the display panel includes situation displays to help the operator work effectively within the machine's limits, and alert displays to warn him of negative productivity situations or undesirable situations. It contains a keyboard for data input to allow the operator to configure the channel parameters and supply operational data to BITE. The display interface will also contain a diagnostic panel driver that will locate and identify system faults down to the plug-in module level. All system functions will be "transparent" to the operator until he requests information or a fault/error condition is recognized by the BITE processor. In these instances, an appropriate warning indicator will be activated and coded readouts displayed. Figure 21 illustrates a possible panel configuration.

It is imperative that human engineering analyses be conducted to determine the optimum panel layout. Previous studies have shown that flashing lights are not desirable except for singular warnings. Large numbers of lights are also undesirable as they lend confusion to the perception



COMMUNICATION INTERFACE BLOCK DIAGRAM

FIGURE 20



BITE DISPLAY

FIGURE 21

process. The learning process and perception accuracy is severely impaired when all functions are displayed simultaneously. The best display configuration, and the one illustrated, is to use discrete digital readouts for selective displays, and continuous level bargraphs for constant readouts.

The display panel is divided into two sections - one providing operator information on machine status, and the other providing keyboard and diagnostic capabilities. The operator uses the keyboard to configure the readouts to supply him the continuous information of his choice. For example, one operator may desire engine coolant temperature and hydraulic oil pressure on the bargraphs and air pressure on one digital readout while another may want only hydraulic fluid and torque converter temperatures shown continuously. At any point in time the operator can obtain detailed information on any monitored parameter through one of several methods. Just as initiated automatically during the pre-start check, a button will generate an automatic polling of all channels. The parametric data is displayed sequentially on displays A & B with a readout indicator light identifying the parameter's origin. Another button can be used to select individual parameters for periodic or continuous display. Table 10 defines the types of parameters available on the basic unit.

The displaying of information is transparent to the operator. The BITE processor monitors all parameters continuously without displaying them until the operator requests information or the processor determines that any one of the group is outside of acceptable limits. When an error condition such as this is detected, the intelligence of the processor and

TABLE 10

MONITORED PARAMETERS

I. Temperature "Channel Card"

- Engine Oil
- Hydraulic Oil
- Transmission Fluid
- Engine Coolant
- Hydraulic Pump Case

II. Positive Pressure "Channel Card"

- Engine Oil
- Hydraulic Oil
- Transmission Fluid
- Fuel
- Brake
- Steering

III. Differential Pressure "Channel Card"

- Air Filter Load
- Oil Filter Load
- Hydraulic Oil Filter Load

IV. General "Channel Card"

- Fuel Level
- Ammeter
- Speedometer
- Parking Brake Engagement
- Tirespin
- Impact Accelerometer
- Tilt Sensor

its stored algorithms is used to determine whether it is to be classified as a situational, alert, or safety warning sequence. Manufacturers will be responsible for entering the parameters, their acceptable limits, their classification, and the channel assignments into the personality module in cooperation with the machine users. Once classified, the operator will be notified of the machine's condition in an appropriate manner.

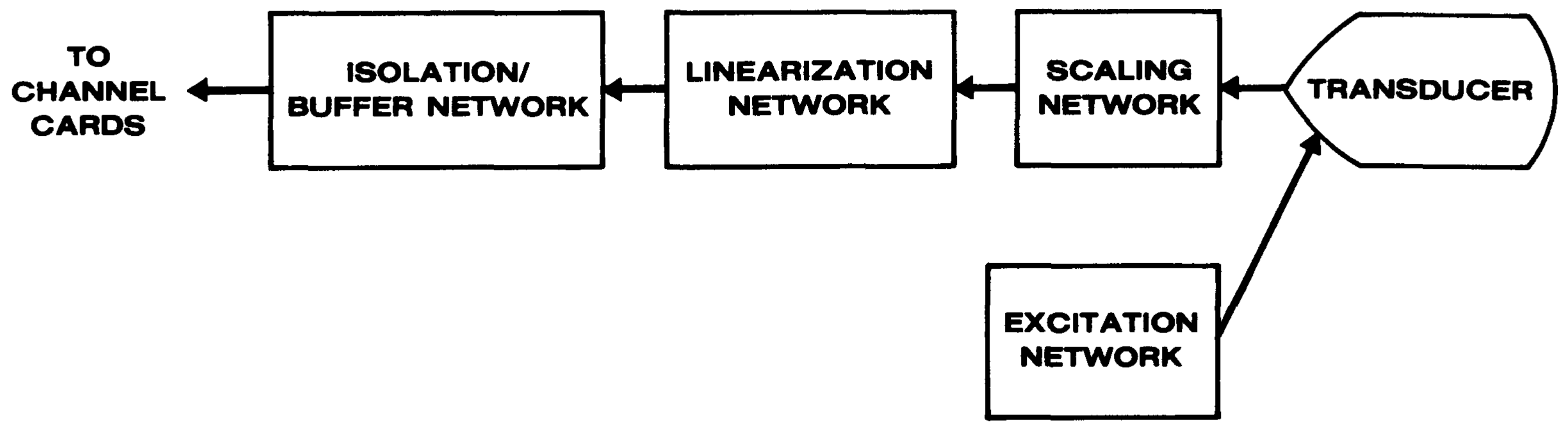
Signal Conditioning Module

The eight inputs supplied to the channel cards emanate from transducers by way of the signal conditioning modules. The block diagram of a conditioning module is shown in Figure 22. The module can best be described as a plug-in printed circuit card that provides isolation, scaling, and linearization for each type of transducer interface required.

It is anticipated that several types of tranducer interfaces will be required. These include (1) semiconductor temperature and pressure/vacuum transducer interfaces; (2) voltage level interfaces; (3) current level interfaces; (4) pulse to analog transducer interfaces; (5) strain gauge transducer with bridge excitation; (6) potentiometric transducer interfaces; and (7) resistance thermometer transducer interfaces.

Transducers

Reports given at recent IEEE conferences state that 71 percent of the system failures of diagnostic systems result from design errors. This percentage is broken into 31 percent of the failures due to EMI influences



SIGNAL CONDITIONING MODULE
BLOCK DIAGRAM
FIGURE 22

on the electronic circuitry, and 40 percent due to transducer failures. Owing to the rugged mine environment, it is of critical importance to the success of BITE that reliable transducers are utilized. The key to their cost-effectiveness is high volume production of quality transducers. The transducers now being constructed for the automotive market meet our needs for accuracy and reliability. It is suggested, therefore, that these components be utilized for system prototyping. The types of transducers may be required are delineated in Table 11.

TABLE 11

TRANSDUCER REQUIREMENTS

I. Temperature

- Resistance Thermometer or Thermocouple (-50°C to +150°C)
- Semiconductor
- Thermistor

II. Pressure

- Strain Gauge with Bridge Excitation
- Semiconductor

III. Rotational Speed

- Tachometer Generator
- Pulse Wheel Pick-up

IV. Electrical

- Voltage
- Current

V. General

- Load Cells
- Tri-axial Accelerometer
- Potentiometric Displacement

Equipment Summary

The BITE basic unit described here can be broken down to consist of the components given in Table 12. Pending prototype development, these components were used to generate the cost estimates used in this feasbility study.

TABLE 12

BASIC UNIT EQUIPMENT SUMMARY

1. Mineworthy Packaging Enclosure
2. System Bus
3. Power Supply
   (+5v, ±12v; 50-100w)
4. Microprocessor
   (8 bit architecture)
5. Scratchpad RAM
   (256 byte)
6. Personality Module
   (8 Kilobyte ROM)
7. Channel Cards
   (3-1 each pressure, temperature, general)
8. Transducers
   (8 each pressure, temperature, general)
9. Operator's Display Panel

OPTIONAL UNITS

The basic unit will function to reinforce or replace existing FEL instrumentation. We anticipate that manufacturers and mine operators will not accept a sudden change from existing electro-mechanical instruments of known reliability (even if poor) to this electronic system of unknown reliability. For this reason, the basic unit can be operated in parallel with existing instrumentation while proving its worth. This allows operators to progress on the learning curve of new technology acceptance while still relying on known elements. The options given in the following paragraphs allow the BITE system to blossom to its full potential and yet still be tailored to the individual needs of the owner/operator.

Maintenance Option

The first available option that may be used to tailor BITE to an individual owner's needs is the maintenance option. As was described in the BITE System Development section of this report, this option provides the maintenance man with statistical data on the machine's operating parameters in the form of histograms.

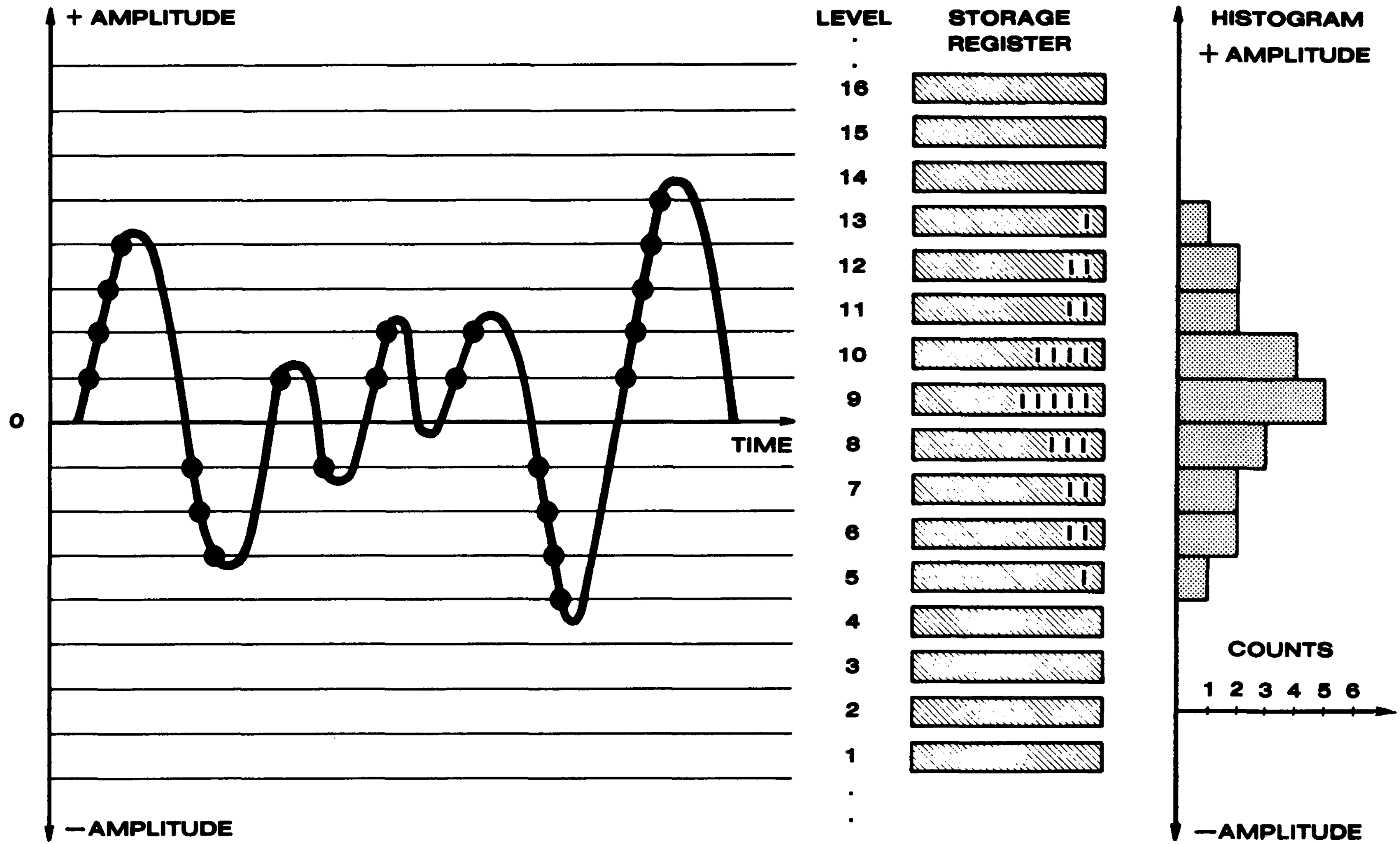
The histogram is a statistical technique for portraying the load history of each monitored parameter. This technique has been used successfully on hydraulic pressures in the STAM unit (see Source 19). The BITE unit allows for a software implementation of the same principles to output to the maintenance man data on the magnitude and duration of pressure and temperature levels. The hardware necessary to accomplish this is detailed in Figure 10, BITE Block Diagram, and Table 8, Basic Unit Components under the appropriate headings.

This option utilizes transducers included in the basic unit that measure various pressures and temperatures. Software added to the personality module implements histogram algorithms that store their computational results in a memory module added for this option. Once computed and stored, several options are available to the owner. Software can be included to display on the Diagnostic Alphanumeric Message Readout (see Figure 21 - Lower Panel) the peak level and its time duration at that level for any selected channel. Alternately, the complete histogram for each channel can be transmitted to an external hardcopy device (see Figure 8) over the external communications channel for analysis. It is envisioned that this data can be viewed on a cathode ray tube (CRT) for real-time analysis; stored on a tape recorder for later transmittal to the company's in-house computer for analysis in combination with other mine equipment data in a total mine management system; or printed on a graphic plotter for permanent storage.

The concept behind the use of the histogram is to determine the history of a parameter statistically. The technique allows us to determine the amount of time a parameter such as hydraulic pressure exceeds specified levels. For example, if the control algorithm specified the levels associated with normal hydraulic pressure operations, maximum rated hydraulic pressure level, and "spike" pressure levels, the readout could inform the maintenance the amount of time the machine maintained normal pressure levels; the number and duration of times the operator overloaded the machine at or above rated capacity; and the number of times the hydraulic system generated spikes. This type of information is invaluable for predicting the fatigue life of components subjected to complicated load histories.

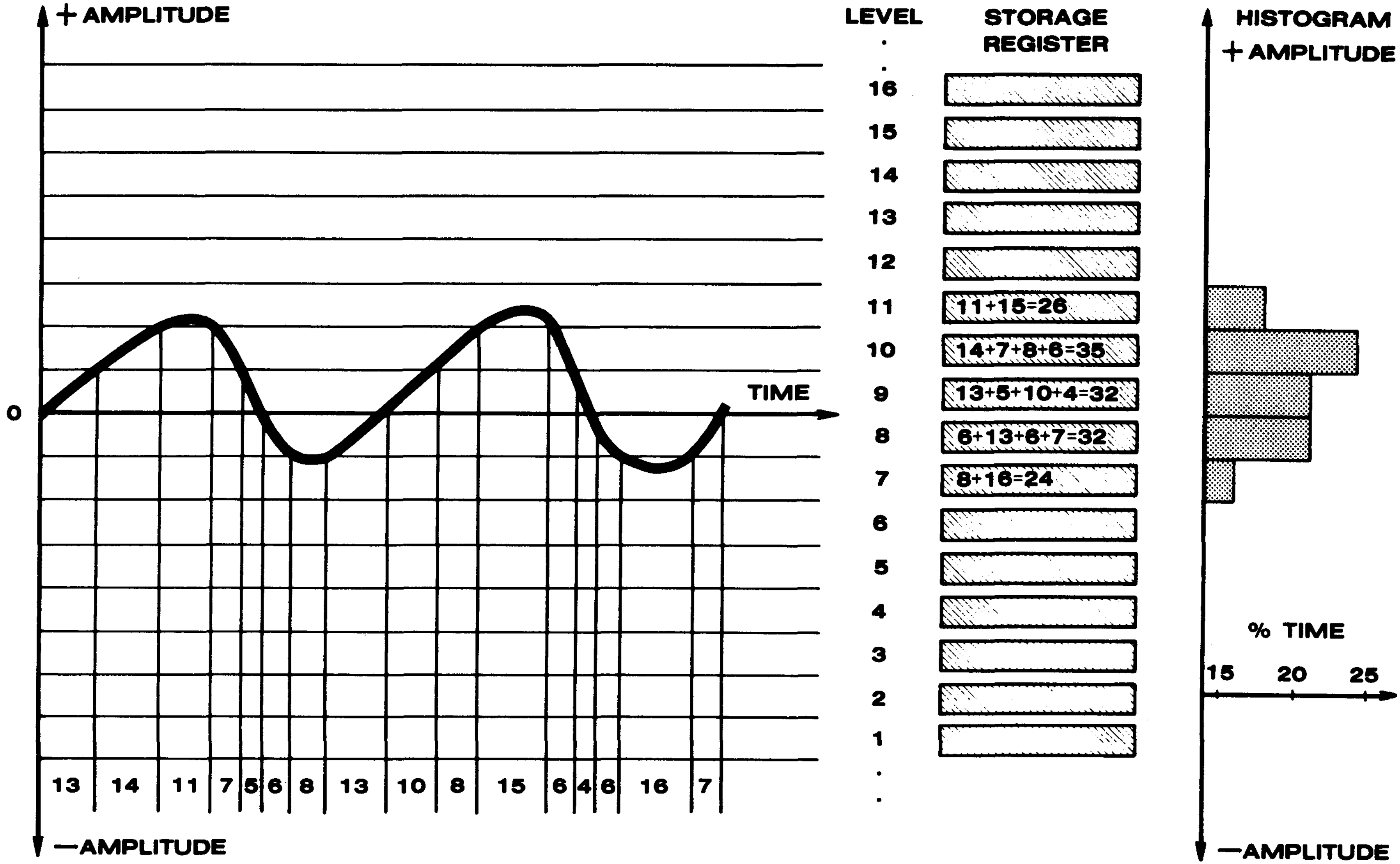
In Figure 16, the real-time subroutine flowchart provides processing time for options. The maintenance option requires two algorithmic implementations in order to generate the required histograms. One is a level counting routine and the other is a duration counting routine. Inherent in the circuitry of the data acquisition and control module are comparison circuits. These require two inputs - a reference level or levels, and the monitored signal level. The reference levels originate in the personality module. Every time the input signal exceeds the reference level, a count is added to the appropriate storage register (one for each level). A histogram can then be constructed from the stored counts. A typical signal is shown in Figure 23 along with the resulting storage register contents and histogram.

The other required histogram is the duration counting routine. The real-time clock is used in conjunction with the level counting circuitry to measure the amount of time that the imput signal remains above the specified levels. Another typical signal is shown in Figure 24 to illustrate the generation of a duration histogram. As can be seen from the figure, it is now possible for the maintenance man to determine the loading on hydraulic components or the thermal extremes fluid systems must endure in terms of time rather than by trying to interpret a time-variant analog load history.



LEVEL HISTOGRAM GENERATION

FIGURE 23



DURATION HISTOGRAM GENERATION

FIGURE 24

Performance Option One

This option is designed to provide for two additional functions. It automatically monitors all fluid levels and thereby serves to reduce down-time due to scheduled preventative maintenance. It also monitors several parameters which are needed for activation of alert or situational warning lights.

The additional hardware needed will be level sensing transducers, special air pressure sensors, and two channels cards. One channel card will be for use with the level transducers that monitor all the vital fluid levels on the machine. Existing resistance probe and float switch type transducers can be used for level monitoring. These transducers can be those used in the automotive market which have proven themselves to be reliable, rugged, and cost-effective. The only software needed for servicing this card is the inclusion of a ROM in the personality module. This ROM will contain an algorithm to perform the necessary comparison checks in the channel conversions of the pre-start and real-time subroutines.

A second channel card will be necessary. It will have several differential input pressure transducer channels. These will serve to measure the pressure drop across the air, oil, and hydraulic fluid filters. Should any filter become restricted and cause a large pressure drop, software contained in this option's ROM would cause an entrance into the error routines of the pre-start and real-time subroutines. Existing software would then cause activation of the alert indicator light to notify the operator and maintenance man of an impending failure. In this manner, severe damage to the engine or drive train due to lack of lubrication can be prevented.

This second channel card will be a special purpose item. In addition to the differential pressure channels, it will contain several special purpose channels. One will be a digital channel which checks parking brake engagement. If engaged, the situational display light will aprise the operator so that he does not operate the machine. An additional special channel will service a tire inflation pressure transducer similar to that currently being used on commercial aircraft. Tire life should be extended and safety improved through the constant maintenance of proper tire pressures.

Performance Option Two

This option provides for operator feedback on "negative productivity." A specialty channel card will be added along with a ROM to implement the necessary control algorithms in the options processing block of the real-time subroutine. In the area of transducers, tachometers will be placed on all wheels, load cells will be placed on the bucket pivot pins and axles, and an accelerometer placed on the articulation joint. In this manner, if the operator overloads the bucket, attempts to generate excessive breakout force, spins the wheels, or rams into consolidated materials, the processor will generate a "negative productivity" alert. Similar circuitry will be used to activate a warning horn signal when the BITE unit senses excessive tilt in the attitude of the machine.

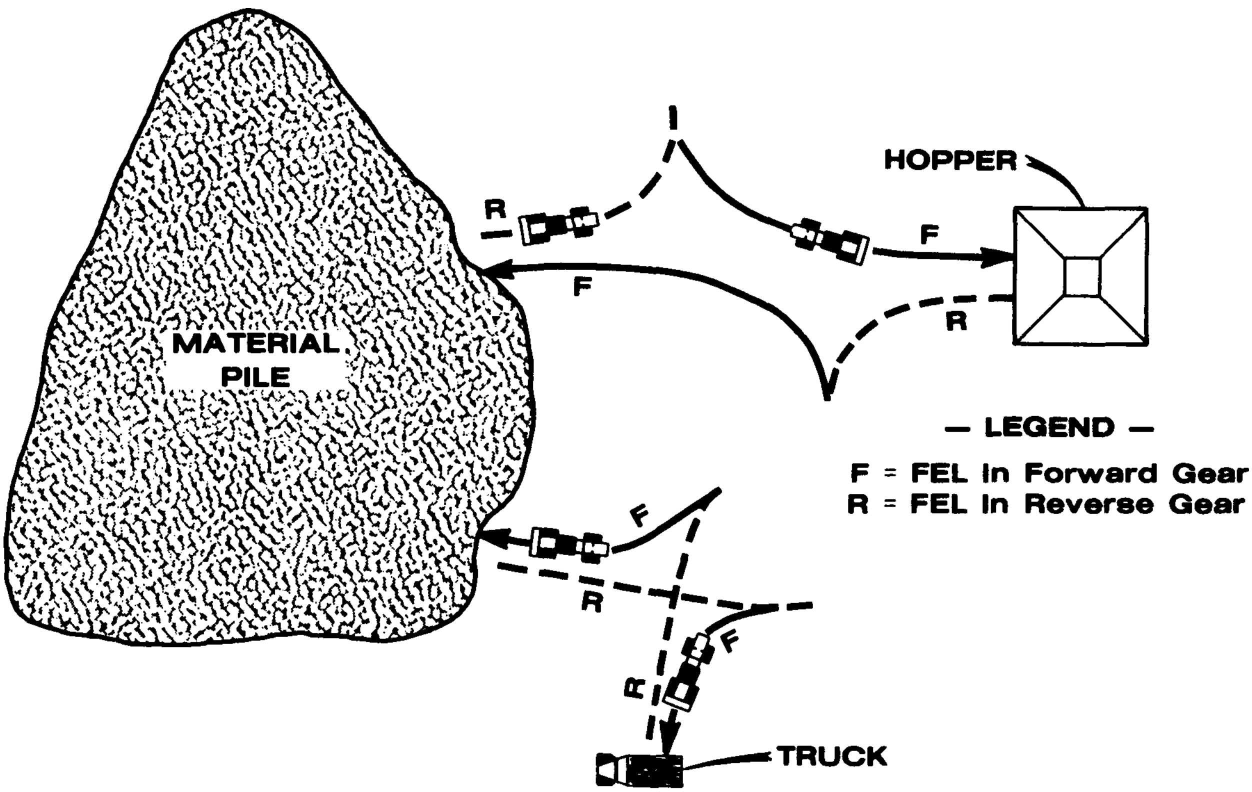
The intelligence of the central processing module will be used for the remaining features of this option. Using existing channel outputs, the fuel consumption and remaining run time can be calculated. Additionally, one special function key can be used to trigger a sequence that causes the machine's hydraulic cycle times to be indicated for a standard operator-activated machine cycle such as raising the bucket to full height and holding it there for one minute. The time, pressures, and pressure decays present in such a cycle can serve to indicate the condition of hydraulic pumps and seals.

Performance Option Three

The final option detailed in this report provides management information. Spare channels on existing channel cards can be utilized for the two condition sensors needed. A ROM will have to be added to the personality module in order to implement a control algorithm in the real-time subroutine options processing block.

FEL productivity is calculated by two methods - work output and cycle times. Work output can be determined as a function of the energy used during any particular shift. A load cell will be installed to measure the torque output of the engine. The processor will use this plus engine speed information to prepare a histogram of the power or energy levels used throughout a shift. This information will be relayed to the owner's office computer. There it will be combined with production information to determine operator/machine efficiency as measured by power consumed per ton of coal produced or overburden moved.

Cycle time information is very difficult to produce on FEL. This option presents one technique which appears feasible. In Figure 25, a typical cycle is depicted for operations that are repetitive such as loading haulage vehicles from a shot face. It is apparent that reverse is engaged twice per repetitive loading cycle. A digital switch will be used to trigger the central processor whenever reverse is engaged. If the special function switch enabling this function has been set, this signal will act as an interrupt to the microprocessor. Software will then access the real-time clock (RTC) and the cycle times for each portion of the cycle will be measured, displayed for the operator, and stored for later transmission to management with the power usage data.



LOADER CYCLES

FIGURE 25

BITE ECONOMIC ANALYSIS

BITE ECONOMIC ANALYSIS

The feasibility of any electronic system depends in large part on the economics of its implementation. Existing instrumentation has proven to be cost effective for its limited applications. The BITE system expands these application capabilities by several orders of magnitude. For it to be acceptable to mine operators, and therefore feasible economically as well as technically, it must maintain its cost effectiveness at all levels of expansion.

Previous sections of this report have dealt with the technical feasibility of BITE. In this section, the economic feasibility of BITE will be addressed. The analysis will be comprised of three types of analyses: 1) system costs; 2) scenario costs; and 3) market research. As will be seen, the system costs are very reasonable. A full $25,000 BITE system on a new Caterpillar 992 represents only 5% incremental cost. Depending on the output of the mine, the payback for the system's addition can be less than one year. The example scenario illustrated later began generating several hundred thousand dollars extra profit the first year! Although we can determine incremental costs for a BITE system based on numerous assumptions, the final feasibility of it depends on FEL owner/operator acceptance. For this reason, a market research study was conducted. The conclusion of this study being that the owners are very amenable to the inclusion of BITE on the machines they buy if the manufacturers give the system their full support capabilities. BITE is economically feasible due to a relatively low initial cost and significant increases in productivity. It is also technically feasible due to recent advances in integrated circuit technology that have lowered costs while increasing performance.

BITE SYSTEM COSTS

Several approaches are feasible for determining the cost of a BITE system. One approach originates from the concept of determining the level of recurring costs that are acceptable to mine owners/operators. Once this level has been established through market research, it could be established as the selling price of a BITE unit after adjustment for amortized nonrecurring costs. The objective of any feasibility study would then be the technical one of determining if an acceptable BITE system could be built for that price. The fallacy in this approach is determining with any degree of confidence what is an appropriate price to the mine owners/operators. Each piece of machinery, and therefore a BITE unit, has a different value to each person contacted. Dissimilarities in type of mine, types of machines used, types of operating procedures and types of preventative maintenance procedures, all contributed to a spectrum of cost/benefit ratios to individuals. BITE will not generate uniform increases in availability or productivity at all mines. A mine with 30 percent FEL availability will pay a higher premium for BITE than one with an 80 percent availability. For these types of reasons, a second approach was judged to be superior.

The second approach uses a polar alternative to the first approach. A BITE unit of specific characteristics was defined initially. This work was based on existing trends in industry and contact with mine owners/operators. Once suitably defined, cost data was generated on producing the unit. Having a unit with defined benefits and costs, each operator could then determine for himself its acceptability.

In order to generate cost data for the BITE unit previously defined in this report, several assumptions were mandatory.

All of the costs referenced in the following paragraphs are "add-on" costs. It is conceived that initial BITE production units will be sold as accessory devices that are installed in parallel with existing FEL instrumentation. No reflection is made of the economies of scale present in future production where the BITE hardware is substituted for existing dash instrumentation at the factory. The present prices represent upper limit price levels due to the double inventories of instrumentation required and double labor costs for installation of both units.

A second assumption addresses the issue of nonrecurring costs and amortization. With rapid advances in technology occurring daily and programming costs for software skyrocketing, estimates in this area are of questionable accuracy. Consequently, we surveyed several manufacturers. The consensus was that 0.5 to 1.0 million dollars would be a reasonable estimate of nonrecurring development costs.

We also consulted industry records and contacted equipment manufacturers to determine production levels. It was determined that in excess of 1,000 new FEL's go into the field yearly. A condition expressed by a majority of mine owners/operators surveyed was that the manufacturers must incorporate BITE into their standard product line and give it full service support. For this reason, it was assumed that 1,000 units would be a reasonable amortization quantity. Obviously, the more units BITE is incorporated into, the lower the charge per unit for nonrecurring costs.

Recurring costs are also heavily influenced by the volume of production. Manufacturers will be able to obtain significantly lower unit costs through higher EAU (Estimated Annual Usage) quotations. The smallest EAU break is at the 10 piece level. Since several units will have to be prototyped, this breakpoint was used for pricing. Larger production quantities on the part of the manufacturers will allow using higher EAU breakpoints and lower unit costs.

Owing to the confidential nature of business cost data, no allowance has been made in the cost estimates for manufacturer's profit, overhead allocations, or warranty costs. These vary among manufacturers and each will have to control his cost of goods sold to the extent necessary for achieving the required selling price after adding allowances for these factors.

The cost of transducers represents another area of significant variability. Many of the transducers needed for BITE are already installed and in use on existing FEL. Other transducers are available in the form of technology transfer from the automotive market. The remainder not covered above are available from the industrial controls marketplace. No new transducers need development. Several designers contacted suggested that the unit costs for transducers in a system such as this might comprise as much as 20 percent of the hardware costs. This figure was subsequently used as a "rule of thumb" in cost estimates.

A final area of variability concerns the grade of components utilized. The costs associated with computers and components built to military grade specifications are exorbitant for this application. Two grades appear to be suitable — commercial and industrial. The differences between those grades applicable to this study lie in their environmental specifications and reliability levels. Commercial grade components represent the lowest cost estimates. They achieve lower cost/performance ratios due to restricted temperature limits (0 to +50°), and lower permissible tolerable vibration and shock levels. Regardless of these facts, they have been included in the cost estimation procedure for two reasons. The operating environment of automotive electronic systems closely parallels that of FELs in these areas. Since commercial grade components are used in the automotive market, it is conceivable that these same components are technically suited to BITE usage. This would result in significant cost savings due to economies of scale. The reason for inclusion is due to a consideration of the BITE unit's location. The preferred location of the unit is in the operator's cab. Located here, BITE will be exposed to a less severe environment than that presented in the technical specification. This modified environment is quite well suited to commercial grade components.

Industrial grade components represent the higher cost portion of the estimates. These components represent the level of technical complexity necessary to survive the environment on a FEL outside of the operator's cab. It must be stressed that both of these cost extremes are based on using existing developed computer printed circuit boards. The cost to develop new boards, which in reality perform the same functions, is deemed undesirable and unnecessary.

Table 13 develops the cost estimates for commercial and industrial grade BITE units. The totals derived show that a commercial grade computer may cost in the vicinity of $5,000 while a corresponding system built to industrial grade standards may cost as much as $25,000. It should be noted that it was felt that the extremely high costs for the industrial grade system would limit its market to the extent that its nonrecurring developmental costs were only amortized over 500 units. Otherwise, the computations are identical except for grade considerations and the level of workmanship required.

These estimates were used in the sections to follow on scenario analysis and market research.

TABLE 13

DUAL GRADE COST ESTIMATES

	Industrial[1]	Commercial[2]
Central Processor	$ 2,600	$ 250
Data Acquisition	2,800	800
Personality	3,700	700
Case and Bus	2,025	380
Power Supply	2,125	300
Miscellaneous[3]	1,200	#
Transducers	2,900	440
Displays	2,200	600
Assembly	2,700	1,100
Development	2,000	500
	$24,250	$5,070

NOTES:
1. Based on Standard Intel Bus, 8080A.
2. Based on Mostek STD-Z80 Bus, Z80.
3. Special cabling, connectors, quality control, and assembly techniques for industrial system.

SCENARIO GENERATION

Equipment utilization and methods of operation are essential aspects of determining the benefits of a new product's implementation. Front-end loaders, being one of the most versatile types of equipment in surface mining, can be involved in most any phase of the mining process. Their mobility offers advantages for use as primary overburden stripping units as well as for support and construction. A front-end loader working in a production capacity offers two methods or modes of operation. When haulage trucks are available, the loader will operate in a strictly loading mode. Many times, when the haul distance is not great, the loader will transport and deposit the material in a load and carry mode, thus eliminating the need for haulage vehicles. Each of these methods of operation produces different effects on cycle times, failure rates and types of failing components.

In a strictly loading mode, the front-end loader operates in a cyclic manner. A typical cycle includes loading material at the face, maneuvering to dump, dumping, and maneuvering to dig. This process requires four complete stops and starts with four travelling direction reversals. The continuity of this cyclic operation depends on the effectiveness of the loader-truck scheduling. Often times the loader must wait for the truck or vice versa. This method of cyclic operation results in frequent downtimes in mines. The most common sources of this downtime are the engine and drive-train failures. The constantly fluctuating loads on these components promote fatigue, failure and stress. Continuous operation also creates overheating problems with the engine and hydraulics.

The load and carry mode of operation eliminates the need for haulage trucks by using the loader to transport the material to the deposition site. A typical cycle requires loading at the face, maneuvering and travelling to dump, dumping, and maneuvering and travelling to dig. Unlike the cyclic loading operation where cycle times are relatively consistent, the load and carry cycle can vary from less than one minute to several minutes. Travel distance is extremely influential, not only on determining cycle times but in the amount of wear and tear the loader will experience. In a load and carry operation, the loader must travel on temporary roads constructed by a dozer. The loader may also be required to assist in the construction and maintenance of the road. Additional responsibilities, including dressing the face and smoothing the spoil area, increase cycle times and result in the previously mentioned inconsistency. Failures from this type of operation occur mainly in the drivetrain and hydraulics. Tires suffer the most due to splits, chipping, and impact damage from rocks and holes. Heavy stress loads are delivered to hydraulic components from carrying a fully loaded bucket over rough terrain. Transmissions, torque converters, differentials, and planetary drives also incur large stresses from travelling at near maximum capacity.

Front-end loader utilization usually depends on the size of the loader and the method of mining. Smaller loaders are generally used for clean up and equipment support. Large units can be used for overburden stripping, coal removal, topsoil handling, or general construction. Mining method and available equipment generally dictate the application.

Overburden Removal

Front-end loaders gain the most usage as primary overburden stripping units in the Eastern coal regions. The relative smallness of the mines and the ruggedness of the terrain make the loader the ideal excavator for these hilly and mountainous areas. Both load and carry, and truck loading methods are employed. In a load and carry operation, the loader works in combination with a dozer to remove the overburden material. The dozer pushes approximately half of the material leaving the remainder for the loader to excavate and place. The material being moved by the loader must usually be broken out of a consolidated state. This exerts great stresses on the loading and drivetrain systems. Tires also suffer terribly since the working surface is strewn with rocks and holes.

During truck loading operations, a dozer pushes the overburden into an unconsolidated pile. The loader then digs from this pile and loads haulage trucks. This type of operation places fewer stresses on hydraulics since large breakout forces are not required. Tire wear is also less prominent than in a load and carry mode due to a smoother running surface; however, tire failure rates are still significant.

In several Midwestern and some Western mines, front-end loaders are used to construct dragline benches which sometimes require the removal of several feet of top material. This operation requires a load and carry methodology to excavate the material and dump it into the previous pit. Although the loader in this situation is not the prime mover, the effects of overburden removal are still destructive to loader components.

Coal Loading

Front-end loaders are utilized extensively for coal loading operations throughout all surface mining regions. Their accuracy for selective coal loading eliminates the collection of undesirable bottom material and makes them one of the most economical machines for coal removal. Coal removal involves the cyclic loading of coal haulage trucks. This process is basically the same throughout all regions; although, the equipment size increases as coal seams thicken. Component wear and failure occur with less frequency on loaders used strictly for coal loading. Smooth working surfaces and low material density are the reason. Engines usually cause the most problems due to coal dust infiltration and fatigue from fluctuating power requirements.

Topsoil Handling and Auxiliary Support

Extreme mobility and versatility are the major advantages of front-end loader use. This encourages their use for general construction and auxiliary support purposes. Most times these are light duty application such as cleaning coal and do not provoke excessive downtimes.

Topsoil handling usually involves truck loading for segregation and stockpiling. Considering the unconsolidated nature and nonabrasiveness of topsoil, the type of operation is not hard on the machine. Clearing and grubbing operations such as stump removal do involve more power exertion and can damage buckets, hydraulics, and tires.

REPRESENTATIVE SCENARIO ANALYSES

For the purpose of evaluating the economic advantages of implementing the BITE system, as shown in Figure 26, a mine from the Eastern coal region was selected. This mine employs a mountaintop removal technique to extract approximately 490,000 tons of coal. A Caterpillar 992-B front-end loader and a Hough H400-C front-end loader perform the major overburden stripping functions. A Caterpillar 988-B front-end loader is also utilized and divides its time equally between overburden stripping and coal removal. The general site information and equipment capacities are shown in Appendix C(1). As is evident, the only difference between the two analyses is the availability factors for the front-end loaders.

The production output of the existing operation is totally dependent on the combined productive capacities of the three front-end loaders. An increase in their production rate will significantly raise the output of the mine. As explained in earlier sections, installation and cooperative use of a BITE system would result in increased availabilities. Realizing that the loaders at this mine receive fairly good preventive maintenance and obtain good availability ratings of 80 percent, an increase of 10 percent was accepted as a reasonable estimation of the effects of a BITE system. This increased availability allows the removal of approximately 35,700 additional tons of coal per year. No additional equipment purchases were required to accomplish this feat since the reserve capacities of the presently operated equipment were more than adequate to handle the increased production. In fact, this new production rate would serve to reduce the delay time now experienced for truck loading.

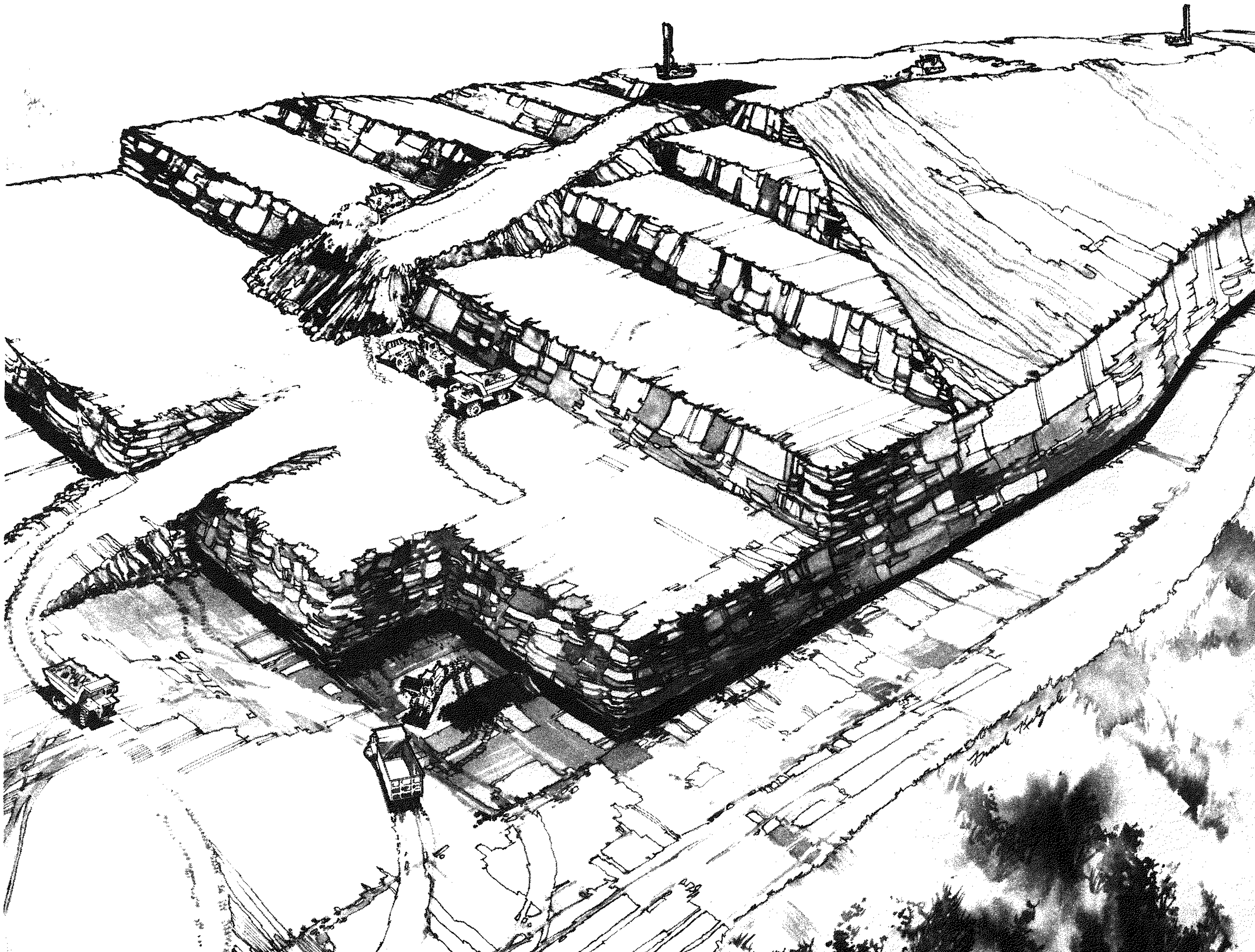


Figure 26 - Artist's Conception of Scenario Mine

The BITE system effectively increases the time the front-end loader is available for productive use by significantly reducing the occurrence of unscheduled downtimes. The effects of this increased availability on loader production rates are compared in Appendix C(1). Since this extra production is obtained without additional equipment or manpower requirements, the necessary capital increases by only the price of implementing the BITE system on the FELs. This price is far less than the additional revenue generated by the increased production. A fact that is evidenced by examination of the economic analyses contained in Appendices C(3) and C(4). An explanation of the analysis process is presented in Appendix C(2).

The results of this comparative economic analysis indicate that the BITE system can save $2.29 per ton of extracted coal. This yields a savings of $0.21 per BCY of overburden moved. These values are for this particular mine only; however, they do depict an example of the economic benefits of implementing the BITE system to increase loader availabilities.

The lower extraction cost provides dramatic savings on a yearly basis. Mining 288,900 tons of coal at the rate of $23.80 per ton requires a capital of $6,875,800. Mining 324,600 tons at $21.51 requires $6,982,100. Figuring total sales as the total tonnage times the sales price of $27.57 per ton yields values of $7,965,000 and $8,949,200 for the mine without the BITE and the mine with the BITE respectively. Subtracting the cost of mining from the total sales leaves a gross profit of $1,089,200 without BITE and $1,967,100 with BITE. This is a savings of $877,900 per year. Since the life of the mine at 324,600 tons per year would be 1.5 years, the total savings over the life of the mine would equal $1,316,900. This is free and clear gross profit, since the cost of the three BITE units (totaling approximately $75,000) was already accounted for when determining the cost to extract the coal.

The benefits of the BITE system extend beyond an increase in production. The safety of mine personnel is also better protected with BITE utilization. Monitoring brake pressures, vehicle stability, and vital components provides a quick indication of unsafe conditions. In addition, deteriorating equipment presents hazards for continued equipment utilization as well as for operator safety. Through routine maintenance, intensified by the use of BITE, equipment components are kept in good working condition. This results in a more productive and much safer machine.

MARKET RESEARCH

An important factor influencing the development of a new product such as BITE is marketability. The determination of expected product acceptance dictates whether further efforts to evolve the new device will provide economic benefits upon completion of the production model. For this reason, a market study was conducted of mine operators to discern their attitudes toward the BITE system.

The initial step of this study was to establish a high confidence level sample of mines utilizing front-end loaders. This was accomplished by compiling a list from the Keystone Coal Industry Manual of all mines using front-end loaders. This list appears in Appendix D. Each mine was then assigned a number, and a statistically significant sample of mines was selected using a random number generator. Telephone contact was then made with these mines to establish BITE marketability.

The results of this study indicate that the market interest is presently available to warrant further development of the BITE system. A majority of the mine operators contacted expressed enthusiasm for the BITE concept and its advantages. However, they considered it impossible to realistically determine BITE's economic value to their respective operations without additional information. This would require the identification of any economic constraints and the determination of all production advantages that would be gained through BITE utilization in each operation. Since this information was not available, the results of this marketing study are only preliminary and not definitive. However, the following conclusions can be drawn from the collected responses:

1. The mining industry is receptive to the concept of BITE.

2. Marketing evaluations cannot be performed on new devices without firm examples of demonstrated advantages.

3. The BITE system must be developed to a prototype stage and its benefits demonstrated.

4. Exact components and circuit boards must be selected for suitability evaluation.

5. Exact pricing must be established for the basic system and all options.

6. Systems engineering must define the best configurations for the various loader models.

7. Extensive testing must be conducted to establish in-field data on reliability and to develop actual examples of production and availability increases for mining applications.

The major emphasis of BITE's marketing program must be concentrated on establishing its credibility with loader manufacturers. This is essential since it is through the manufacturers that BITE will be implemented. In addition, their support and cooperation will provide many advantages. The mine operators will feel more confident buying a product that has gained the trust of loader manufacturers. Required capital expenditures would be decreased since the developmental costs would be amortized over a greater number of units. Support and maintenance services would automatically be available then through existing manufacturer service representatives. These actions hinge upon a well written specification and subsequent successful demonstration of BITE.

The mining industry has been very reluctant in the past to accept new ideas in equipment design without knowing their cost/benefit relationship. These relationships would be governed by equipment utilization and mining conditions. They would also depend on the existing levels of operator expertise and the extensiveness of the current preventative maintenance programs at the mine. Most operators contacted during this survey felt that the advantages offered by BITE usage would outweigh the cost factors for a loader used in a production capacity. Their assumptions, however, could not be verified with the information available at this stage of BITE development. This requires the construction of a prototype device and extensive testing. The results of these tests could then form a data base against which prospective buyers could evaluate the potential benefits of the BITE system for their mining application.

With the costs of mining spiraling due to inflation and government regulations, the BITE system offers a viable solution to the economic penalties of front-end loader downtimes. Its continued development would help to propagate further advancement in equipment design through more effective means of accounting for failure causatives. Its use would also provide for more effective equipment utilization and increased mine safety. It is therefore indicated from the results of this study that the BITE system should be pursued for future use in front-end loaders.

CONCLUSIONS

CONCLUSIONS

Electronic monitoring and instrumentation systems have been proven on many types of equipment from spacecraft to automobiles. Recently, mining equipment has joined this rapidly expanding field. Draglines have been equipped with computer monitoring systems that analyze machine usage and optimize production. The objective of this study was to determine the feasibility of implementing front-end loaders with a similar computer-based monitoring system to increase mechanical availability and decrease operating costs. Augmented productivity was also anticipated from the utilization of this device. In order to achieve these objectives, a baseline system was developed to satisfy the needs of the loader operator while subduing the effects of the harsh mine environment. This system addresses the functions most critical to efficient and economical machine operations. It also provides protection for essential machine components by removing the necessity for human interpretation of relayed data.

It is the conclusion of this study team that the BITE monitoring system described within this report offers a viable approach to the development of more useful and effective instrumentation for front-end loaders. Its most substantial contribution would involve the addition of the ability to predict component failures and subsequently reduce the amount of unscheduled downtimes dramatically. The significant increase in the rate of mechanical availability attained from this reduction in unscheduled downtimes will supply the mine operator with many economical advantages. Some of these are exemplified in the economic evaluation performed in this study.

The aim of this study was not to increase the penetration of electronics into another application area, but rather to increase the value of the front-end loader to the owner. The motivation for electronic monitoring and control is based on: (1) the ability to replace mechanical components with electronic systems capable of higher performance; (2) the improvement of vehicle availability and safety through on-board diagnostics; and (3) the addition of features for the convenience of the operator, maintenance man, and owner. The major obstacles to providing these benefits are the low cost and high reliability required under extremely adverse operating conditions. Recent advances in integrated electronics have addressed both of these issues.

The overall objective of this study was to investigate the feasibility of using BITE systems on front-end loaders. The investigation also required the generation of a preliminary specification (see Appendix B) in order to determine the types of equipment required by the operating environment. Based on this data, a baseline hardware system was specified and estimated costs developed. The design is based on incremental improvements in functional design. BITE units can be initially added in parallel to existing instrumentation to allow time for operator acceptance. Manufacturers can then substitute BITE for existing mechanical instrumentation. Eventually, fully optioned BITE equipped FEL can be used in a Total Mine Management System (TMMS) where other mine vehicles also contain suitably configured BITE units. This allows for an evolutionary rather than revolutionary process of development, with each step being cost effective.

A BITE system for front-end loaders is a real feasibility. Our cost estimates reveal that its add-on price varies over a range of five to twenty-five thousand dollars. The exact price depends on the development costs and the number of units that it may be amortized over. These factors will be determined by the acceptance of the concept by manufacturers. The price also depends on the type of circuitry required to withstand the environment. The lower figure is based on using commercial components similar to those used in the automotive market and the higher based on using military components. Although we feel that the lower figure is the most realistic, we conducted our scenario analysis using the higher figure in a "worst-case" type analysis. This analysis justified the feasibility of the BITE concept by revealing that increased availability on the part of BITE equipped FEL allowed higher production which translated into a savings of over two dollars per ton of coal in operating costs. The savings will be even more dramatic when system costs are finalized and approach the lower figure. What remains is for systems analysis to determine the optimum configuration of hardware for implementation by manufacturers.

Initial contact with members of the mining industry, including mine operators and equipment manufacturers, has relayed a favorable attitude toward the use of innovative equipment such as this. With federal regulations stiffening and inflation in double digit figures, it is essential that mining companies utilize any innovations that will help to produce coal more efficiently. Equipment manufacturers must also strive to continually improve their product to insure its worth to the present and future markets.

The major emphasis of this study has been to improve the output ability of loaders used in a productive capacity. This, however, is not the only application where the BITE will be effective. Loaders used in a supportive role will also benefit from the implementation of BITE. Primary overburden stripping and coal loading units usually receive adequate attention from mine maintenance personnel due to the costly effects that the downtimes of these essential units present. Support equipment are also important to the mine; however, they are often neglected in favor of the primary production equipment. The BITE system will call attention to these support units when repairs are needed, and before neglect can lead to failure.

The initial intent and major emphasis of the BITE system is to protect the components of the loader and assist the maintenance personnel in the establishment of effective preventive maintenance. These objectives can be realized with the proper introduction of this computer technology to the mine environment. Mine management personnel are basically interested in a productive and profitable method of mining. The BITE system, if it is to be marketed successfully, must provide definitive advantages over the existing monitoring devices, and it must be cost effective. Component reliability is probably the most important factor affecting the marketability of this device. Several of the mine operators contacted felt that the reliability of a totally electronic system would be suspect. This skepticism is due to the limited existence of electronic devices in the mining industry. However, there is merit to their hesitation. Any alternative electronic device must exhibit equivalent reliability characteristics when compared to the electromechanical instrumentation it will replace. This reliability is essential to its worth as an alternative instrumentation system and the overall worth of a loader equipped with this device. For this reason, the BITE was designed using a modular approach.

A basic monitoring system featuring selectable digital displays and audio-visual warning devices was selected to replace the present instrumentation. It is felt that the introduction of a limited scope and low cost system to the field will result in better acceptance by mine personnel. Fewer parts requirements coupled with the use of off-the-shelf hardware will provide a rugged and durable system that is sufficiently cost effective to gain operator confidence. Once this simple system has developed favorable levels of reliability and has become generally accepted in the field, more complex electronic systems will find a more willing market.

Utilizing the modular approach also allows the mine operator the freedom to select the options most suitable for his mining situation. A small operator may be satisfied with the basic system whereas a large mining firm may prefer the advantages of the total package. This flexibility of system design makes the BITE a cost effective addition for any size mining operation.

Operator attitude ultimately has a profound effect on the effectiveness and life of the BITE system, and so it was considered in the initial design. Most of the responsibility for responding to signaled malfunctions and effecting their repair lies with the operator. An effective BITE system must, therefore, relay the required information in such a manner that the operator feels helped rather than encumbered by it. If an operator spends more time trying to defeat the device rather than using it to his advantage, then BITE will never accomplish its intended objectives.

Indications from this and previous studies (Source 42) show that operator attitude greatly determines the life of the loader and its components. If, for any reason, an operator wants to render any component inoperable, his knowledge of the loader makes it possible to do so. This is exemplified in a case study from "Constraints to the Availability of Front-End Loaders" (Source 42). The operators at the mine did not like to operate a Hough H400C loader as it was usually down for repairs. At a mine where loader availabilities ranged from 81 to 90 percent, this Hough H400C averaged a devastating 67 percent availability. For this reason, the BITE must not be viewed as a "tattletale" device. Any recorded information must be accessible to the operator to insure acceptance and a favorable attitude.

An important aspect in the concept design involves the operating environment. The BITE unit will be subjected to extremely harsh environmental conditions. The magnitude of these conditions dictates the component specifications and ultimately the cost. The initial design described within this report was specified utilizing the best available information on the operating environment any loader will experience. Studies have been conducted on the exact loader environments; however, the sponsoring companies will not release this information due to proprietary rights.

Several of the mine operators contacted felt that troubleshooting and maintaining the BITE system would present problems. Since this type of equipment is generally not found in mining situations, available maintenance personnel will have not knowledge of how to repair it. To alleviate this difficulty, the BITE unit has been equipped with a self-diagnosing program. This program locates a malfunction in a specific module or card. All the maintenance personnel have to do is replace the card with a spare and ship the defective card to the nearest service representative for repair. A substantial network of service representatives must be available if the BITE is to gain total acceptance.

The modular design of the BITE system makes it possible to adapt this unit to other types of machinery with similar functions of operation. Minor changes in programming and adjustments in sensor requirements are all that is required to add this monitoring capability to other types of mobile equipment. This potential ability for interchangeability opens new markets for the system which may lower its cost.

In addition to increasing the loader's availability, the BITE system will augment the safety aspects of the machine by helping to maintain operation within the limits of the loader. This will prevent the overloading of hydraulics, tires, engines and drivetrains. Also, through the diagnosis of disintegrating components, catastrophic failures that may leave the operator in a hazardous situation can be avoided.

The development and utilization of a BITE monitoring system is a logical step in the continuing efforts to improve the efficiency of coal production. By creating equipment that is more dependable and by improving the quality of preventive maintenance, the BITE unit will help to bring down the costs of coal extraction. What remains is for a subsequent study to amplify the preliminary findings of this study into a specification capable of guaranteeing a successful demonstration. As shown in the recommendations, a great deal of background analysis has yet to be done to insure the success of a government sponsored BITE demonstration. What is shown here is that the BITE concept is feasible and should be pursued.

RECOMMENDATIONS

RECOMMENDATIONS

In the mining industry, it is essential to utilize all available equipment to its fullest capabilities to achieve the maximum productive output from a mine. Since productivity determines the incoming revenue and the success of the mining venture, the untimely breakdown of an essential piece of equipment can be very costly. Long delays for replacing parts and the compounded production losses caused by the unavailability of the machine can cripple a mining operation and destroy profits. The BITE system can effectively help to reduce these unscheduled downtimes and should, therefore, be pursued as a worthwhile improvement to mining equipment.

The actual implementation of the BITE system into a front-end loader presents many technological challenges. Although the electronics technology is presently available to construct an operable BITE unit, its adaptation to the harsh environment provided by an operating front-end loader creates several problems with reliability and economics. In order to resolve these problems, additional research is necessary to refine the equipment specifications required by the environment, and to identify the available components that will supply the needed reliability cost effectively. The following recommendations describe the research efforts that must be completed before a reliable, cost effective BITE system can be specified and subsequently demonstrated with a high probability of success.

(1) DEFINE THE BITE ENVIRONMENT

The type of operations performed by front-end loaders in a mining situation create a very hostile environment for electronic devices. High concentrations of dust, temperature extremes, moisture and vibration are some of the elements that BITE will have to withstand. These elements, although identified, have never been isolated with sufficient accuracy to permit precise system specification. Since the costs of electronic components are totally dependant on the required strength and durability, a range of environmental parameters must be established to allow proper system design at a reasonable cost. Two areas must be examined for their impact on BITE design. These include the elements originating from the mine environment and those created by machine operation.

Mine Environment

The operating conditions created by the mining process present a critical problem for the use of electronic devices on mining equipment. Adverse environmental conditions deteriorate the integrity of electronic components with continued exposure and inadequate protection. This raises the question of how much protection is adequate. The mining environment has never been accurately monitored to determine the severity of the conditions that affect electronic equipment. A study must be conducted of various mines throughout the county to establish minimum, maximum and mean values for temperature, humidity, electromagnetic interference (EMI), and dust concentrations. Prototype BITE units should include instrumentation capable of gathering environmental data under actual operating conditions that will complement existing data and supply values for any missing data.

The diverse locations of mining operations throughout the country create a wide range of environmental conditions. Some locations may be plagued with extreme amounts of dust whereas others may suffer more from high humidity. For this reason, the study of the mining environment must also consider these variations and qualify the resultant values by region and type of mining into an "environmental envelope."

Loader Environment

The front-end loader is an extremely mobile and versatile machine. This creates a unique environment for any electronic equipment mounted on it. Machine generated heat, vibration, EMI, and impact shocks can destroy the effectiveness of an underprotected component. In order to provide adequate protection, the effects and severity of these conditions must be known. Since this information is not available, testing must be conducted to establish maximum, minimum and mean values for these conditions. These tests must provide representative numbers for a variety of FELs. Instrumented BITE units could also be used for this function.

With the establishment of specific values defining the environmental conditions that BITE system must withstand, the individual components can then be accurately designed and specified to provide the maximum amount of reliability at the minimal cost. The question of whether existing hardware can withstand the environment as assumed is yet to be demonstrated. This background information is critical to the reliability of any system design.

(2) RESEARCH ALL AVAILABLE INTEGRATED CIRCUIT TECHNOLOGY

Printed circuit boards (PCB) are one of the most important elements in the BITE system. Their quality must be sufficiently high to provide reliable and cost-effective service under the severe conditions of the loader environment. The selection of a particular PCB family for use in this system should only be made after a comprehensive background study is completed on existing standard products. In order to facilitate the decision, a comprehensive search must be conducted to identify the major manufacturers of applicable printed circuit boards. In addition, this search should examine the major types of applicable integrated circuit (I.C.) families made by the various manufacturers to determine their capabilities, limitations, and costs. From this information, a cost efficient and reliable system can be selected. A conclusion of this activity would be the determination of the actual cost of hardware for BITE.

(3) VISIT FRONT-END LOADER MANUFACTURERS

An additional issue must be analyzed to insure a successful demonstration of BITE on commercially available loaders. The successful demonstration will ultimately determine the rate of incorporation of BITE as standard equipment by loader manufacturers. The issue relates to the installation configuration called for in the specification used as the basis for the demonstration. Additional contact must be made with the major manufacturers of front-end loaders to discuss the benefits of the system and discern their unique requirements. During these contacts, the design and objectives of the system should be thoroughly explained to fully acquaint the manufacturers with the BITE concept.

Several other factors should also be determined through the course of these contacts. Component size and available space constraints should be identified and possible solutions outlined for the various models of loaders. Operating parameters should be investigated to establish the monitoring ranges necessary to accommodate the different models. Any production constraints that would increase the cost or prohibit the use of BITE must be examined and possible solutions identified. Besides providing data critical to the development of the specification capable of insuring a successful demonstration, information will be gained that can be utilized to more accurately estimate the cost of a BITE unit.

(4) DETERMINE FEASIBILITY OF APPLYING BITE TO OTHER EQUIPMENT

One of the initial intentions of the BITE concept was to develop a unit that would be adaptable to other types of mining equipment. The versatility would open larger markets for the BITE which would result in lower unit costs. The adaptation of the BITE system to other equipment may necessitate several design alterations to accommodate individual specific requirements for component protection. These alterations may vary with each type of machine chosen for instrumentation.

Feasibility analyses should be conducted to determine the design changes that may be required to implement BITE on haul trucks, scrapers, hydraulic excavators, and dozers. These studies should provide an assessment of the benefits in relation to costs and establish the parameters to be monitored for each type of equipment. A background study such as this could define a common BITE unit applicable to numerous machine types. Visits to mines and manufacturers should be included to accurately define the applicable machines and uses.

(5) EXAMINE THE ROLE OF BITE IN A TOTAL MINE MANAGEMENT PROGRAM

The BITE system possesses the ability to provide management personnel with much performance information concerning the machine on which it is installed. This information can be used to develop accurate equipment management plans based on realistic values for costs and production. The development of a program to utilize this management aid by implementing all production equipment with BITE should be evaluated. This program should define the roles of the various equipment in the total mining scheme and relate this to the information supplied by BITE. Using this relationship, equipment management plans can be drafted to schedule maintenance, inventory repair parts, economize equipment utilization, and optimize production. This would facilitate a more accurate and cost efficient method for equipment management in a mining operation.

(6) EVALUATE TRANSDUCER REQUIREMENTS

Sensing devices account for the majority of failures in existing monitoring systems and continually compromise the systems. Several designers of this type of equipment cite transducers as their most unreliable component. This problem of reliability originates due to the function of the sensing unit. These units must be located on the remote areas of the machine where environmental conditions are severe. Several types of these devices are constructed using complex circuitry and intricate detail. Constant exposure to high vibration levels, EMI, extreme temperatures and heavy shock loads can easily destroy these transducer's integrity. The use of transducers of this class will compromise the effectiveness of BITE and must be avoided.

Therefore, a background study should be initiated to determine the reliability and cost effectiveness of existing transducers used in the automotive, industrial and military market places. Research efforts must be concentrated on examining methods of constructing and manufacturing sensing devices which yield high levels of reliability. Emphasis will be placed on selecting transducers that will not compromise the system. Ultimately, these research efforts should provide durable and dependable sensing devices that will form a solid foundation for a reliable and cost effective monitoring system.

(7) CONDUCT HUMAN ENGINEERING STUDIES

Positive operator response is essential for an effective monitoring system. Displays must be designed to assist the operator with the operation of the machine rather than distract from it. Warning lights must grab the operator's attention without requiring special efforts by the operator to constantly check LED panels. To accomplish these goals, previous research results should be incorporated in the design of effective displays. These studies should consider the proper configurations to utilize the limited space most efficiently and to offer the most convenience to the operator.

Additional attention should be given to types of displays that should be used to relay the various information. Previous studies (sources 6 and 31) indicate that certain displays relay information more effectively than others. It is recommended that a study should analyze the information to be relayed and determine the best display for the application. Since operator acceptance is critical to BITE success, this background study is a key element in BITE development.

(8) OPERATIONAL ASSESSMENT

In order to integrate the previously discussed analyses into a specification capable of a successful demonstration, an operational assessment must be undertaken. This assessment would require the breadboarding and testing, both laboratory and field, of BITE system components.

Breadboard development is an important part of establishing the practical feasibility of a new product prior to fullscale demonstration. Testing under simulated conditions can reveal areas of design that require improvement or intrinsic weak points which may limit demonstration feasibility.

During this assessment, consideration must be given to identify the best system configuration for maximum flexibility. This is necessary to provide a degree of adaptability among the various loader models. This assessment should also finalize the system specification using the parameters established from previously recommended studies.

(9) SUMMARY

The most important recommendation of this study is one calling for additional studies. Modern control technology exemplifies a process of creating complex control systems through an evolutionary and developmental process. Key to the eventual success of the BITE concept is the need for a a methodical and thorough systems engineering effort. A plan should be developed from the preceding recommendations that logically evolves a BITE unit capable of working on FEL and other mine equipment in a cohesive mine management system. This will allow the implementation of BITE at a reasonable cost and provide the mining industry with the considerable benefit. This plan should address the problems of system demonstration and subsequent market penetration.

Before a specification for a BITE system demonstration can be de-developed, comprehensive background studies must be undertaken to analyze available components, operating environmental conditions, transducer reliabilities and integrated systems operability. The current study proves that BITE is an economically and conceptually feasible study. In addition, it establishes that operators are interested in the benefits that might be afforded them by BITE.

APPENDICES

APPENDIX A

FEL USAGE BY STATE AND FUNCTION

APPENDIX A
FEL USAGE BY STATE AND FUNCTION

MINE NO.	MINE CODE		MINE METHOD	UNIT OPERATION CODE*																	
				SITE PREPARATION							MINING				RECLAMATION			
				1	2	3	4	5	6	7	1	2	3	4	1	2	3	4
1	Ari.	1	Area											1				
2	Ark.	2	Area											1				
3	Ind.	7	Area											1				
4	Ken.	9	Area											1				
5	Miss	11	Area											2				
6	Mon.	12	Area											1				
7	Okl.	14	Area											5				
8	W. Va.	22	Underground	1	1	1	1	1							1			3
9	W. Va.	46	Underground	1	1	1	1	1	1	1					1	1	1	1
10	W. Va.	47	Underground	1	1	1	1	1	1	1					1	1	1	1
11	W. Va.	48	Haul Back									2		1				2
12	Ill.	51	Open Pit									1						
13	Ill.	54	Area									1						
14	Ind.	58	Area											2				
15	Ill.	59	Area											2				
16	Wy.	60	Open Pit									1		2				
17	Ken.	61	Area									3		1				
18	Ind.	94	Area											2				
19	Ind.	95	Area											9				
20	Ken.	132	Haul Back	1	1			1		1		2		2				
21	W. Va.	212	Haul Back	1	1			1		1					1	1		
22	W. Va.	213	Mtn Top Removal	1	1			1		1					1	1		
23	W. Va.	214	Area	1	1			1		1					1	1		
24	W. Va.	215	Mtn Top Removal	1	1	1		1				8						
25	W. Va.	217	Other	1	1		1	1				4		2				
Total FEL Usage				9	9	4	4	9	2	6	0	22	0	35	6	5	2	7

*** Site Prep.**

1. Haul Rd. Constr.
2. Haul Rd. Drainage Constr.
3. Surface Wtr. Div. Constr.
4. Stream Div. Constr.
5. Sed. Pond Constr.
6. Clearing & Grubbing
7. Topsoil Handling

*** Mining**

1. Blasting
2. OB Removal
3. OB Haulage
4. Coal Removal Haulage

*** Reclamation**

1. Backfill & Grading
2. Topsoil Redistrib.
3. Reveg.
4. Road and Structure Reclamation

APPENDIX B

BITE TECHNICAL SPECIFICATION

APPENDIX B
BITE TECHNICAL SPECIFICATIONS

The following physical environmental conditions must be met by BITE systems:

- TEMPERATURE

Operating	− 40°C to + 125°C
Non-operating	− 55°C to + 125°C

- DUST

Concentration	1000 mg/m^3
Mean Size	0.5 to 3 microns

• HUMIDITY	90 to 100 percent
• MOISTURE	Condensation present
• VIBRATION	Continuous to 500 Hertz at-
Machine Frame	3 g (rms)
Bucket and Boom	5 g (rms)
• MECHANICAL SHOCK	Unknown*
• THERMAL CYCLING	30 cycles, −40°C to + 80°C
• THERMAL SHOCK	5 cycles, −40°C to + 80°C
• TRANSIENT PROTECTION	
Voltage	Up to five times nominal
Duration	1 to 500 microseconds
• EMI SPECTRUM	20 kilohertz to 100 megahertz

- GENERAL

1. The unit must be of an expandable, modular design so that it is capable of operating with a variety of FEL machines with the aid of a personality module.

2. The unit shall be housed in mineworthy packaging enclosures suitable for MSHA permissibility approval.

3. Circuit design procedures should emphasize MSHA approved intrinsically safe guidelines as detailed in Code of Federal Regulations, Title 30, Chapter 1, Part 18.68.

4. The control system and power supplies should be designed to have controlled power-up and power-down sequences so that no transients are generated. If back-up battery power (uninterruptable power supply) is not featured, the power-down sequence must insure storage of program cycle information.

5. All algorithmic operating system programming must be stored in non-volatile memory so that operation can begin immediately upon power-up or after restoration of interrupted power. Program data may be stored in non-volatile magnetic media or volatile random-access memories (RAM). Program data relating cycle operation or report generation must be transferred to non-volatile, solid state, electrically alterable read-only random-access memory (EAROM) for "permanent" storage until erased by the operator.

6. Critical applications requiring long-run analog signal transmission should use twisted shielded-pain wiring with balanced, wide amplitude level ranges and low impedance sources. Optical isolators should be used for critical digital signals. Single point grounding is essential for all circuits.

7. Power supply design procedures should allow for variable input voltage (as much as -75 percent under cold weather conditions) levels of ± 25 percent. Transient levels approaching +125 volts should be considered. Power conditioning circuitry should include shielded transformers and filters to prevent feed-through and protective circuitry for overvoltage, reverse polarity voltage, and overcurrent conditions. A standard battery ground strap connects the power ground (battery negative terminal) to the instrument ground (engine block). This strap carries ignition primary current and may have a high RF impedance. Thus, a significant ignition noise voltage level may exist on the power ground with respect to the instrument ground. The use of ground isolated DC to DC converters to power the electronics will permit the converter outputs to be referenced to the quiet extended instrument ground. All electronics should be isolated from the vehicle sheet metal to prevent ground fault currents. Where raw battery power is used, as in the case of actuators, display monitors, and ignition; ground isolation is used in the interface circuits. Ground Fault Interrupters (GFI) should be inherent in the design.

8. Reliability shall be enhanced through the use of magnetic transducers where feasible. Units developed for the current generation of automotive diagnostic systems shall also receive consideration. All case materials should be corrosion resistant. All sensors and circuit elements should be hermetically sealed. Encapsulation with a silicone gel and usage of ceramic integrated circuits is also recommended.

9. The operator's cab is a prime candidate for the location of the BITE unit. Space limitations and/or thermal management considerations may make it necessary to locate the power supply and signal conditioning circuitry remotely. Any active cooling measures shall provide a positive pressure inside the packaging enclosure so as to aid dust exclusion.

10. Control circuitry shall initiate automatic bootstrapping upon power-up (initial or after an outage). Bootstrap routines shall perform a diagnostic check of all BITE systems. They shall also calibrate the system to parameters stored in the personality module for that particular type of machine.

11. Testing shall be completed on FEL in typical mine environments to determine the EMI levels and spectral contents. Adequate shielding shall be provided to reduce the EMI levels within the BITE unit to non-disruptive levels.

12. Reliability shall be defined by the mean-time-between-failures (MTBF) of the entire unit and shall exceed 100 hours. A failure is defined as any malfunction not correctable by the operator within one minute through controls accessible during routine maintenance. For increasing the reliability of electrically controlled devices, de-rating designing of the device, use of highly reliable component parts and construction of devices with the least number of parts is quite important. In addition, "burn-in" operation for parts and assembled devices before shipment should prove very effective in improving reliability.

The major elements of a reliability program are: Parts quality control, reliability prediction, part stress derating, stress analyses, failure reporting, failure analyses, failure mode and effects analysis (FMEA), reliability demonstration testing and production sample testing. The real goal of the reliability program is to achieve the stated MTBF in actual service use.

13. Maintainability shall be achieved through the use of plug-in modules such that replacement of faulty modules will reduce downtime to a minimum. The mean-time-to-repair (MTTR) shall

not exceed one hour. The repair and maintenance procedure for the BITE system should be based on field replacement of subassemblies and circuit modules. Only high reliability commerical or military grade components should be utilized in its construction.

14. The BITE control system must be designed to fail "soft." System failure must not prevent or impede operation of the machine. Redundancy in critical circuitry and/or multiple microprocessor arrangements should be considered.

15. Reliability predictions shall be based on MIL-HDBK-217C for a ground, mobile environment.

* Measurements are needed to determine the peak shocks equipment will be subjected to in normal operation (see page B-3).

APPENDIX C

DETAILED SCENARIO ANALYSIS

APPENDIX C(1)
SITE INFORMATION
AND EQUIPMENT CAPACITIES

GENERAL SITE INFORMATION

A. Area to be Mined = 30.7 Ac

B. Minimum Cover = 60'

C. Maximum Cover = 190'

D. Coal Thickness ≈ 9 Feet

E. Volume of Overburden to be Removed = 5,300,000 B.C.Y.

F. Volume of Coal to be Mined = 490,000 Tons (In Place)

G. Strip Ratio = 11.1

H. Overburden Swell Factor = 35% (Based on Material Type)

I. Additional Spoil Storage Area Resulting From Previous Contour Cut = 19.7 Ac

J. For the Purpose of Evaluation, Computations for all Concepts were Based on Total Area Permitted Per Mining (30.7 Ac)

EQUIPMENT PRODUCTION PARAMETERS

A. Not Utilizing FEL BITE System

1. Drills

   a. Drill pattern = 10' x 10' (average)
   b. Drilling rate = 2.0' per minute (average)
   c. Depth of holes = 30' (maximum)
   d. Job efficiency = 50 minutes per hour
   e. Mechnical availability = 85%

2. Front-end loaders

   a. Basic cycle time = 0.65 min.
   b. Material size = 0.08 min.
   c. Material pile = 0.02 min.
   d. Bucket fill factor = 90%
   e. Mechanical availability = 80%
   f. Total cycle time = 0.75 min. or 1.33 cycles/min.

3. Rear dump trucks

   a. Haul distance = 1600' (round trip) average
   b. Average speed = 880' per minute (10 mph)
   c. Load times
      - 40 ton trucks = 3 loader cycles or 2.25 min.
      - 50 ton trucks = 4 loader cycles or 3.0 min.
   d. Haul time = 1.8 mins. (total)
   e. Spotting time = 1.0 min.
   f. Dumping time = 0.5 min.
   g. Total truck cycle times =
      - 40 ton trucks = 5.5 min.
      - 50 ton trucks = 6.3 min.
   h. Job efficiency = 50 min. per hour
   i. Mechanical availability = 70%

4. Bulldozers

   a. Average dozing distance = 150'
   b. Average operator = 0.75
   c. Blasted material = 0.80
   d. Slot dozing = 1.20
   e. Grade correction = 1.20
   f. Job efficiency = 50 minutes per hour
   g. Mechanical availability = 85%

B. Utilizing FEL BITE System

1. Drill - same as without BITE

2. Front-end loaders

   a. Basic cycle time = 0.65 min.
   b. Material size = 0.08 min.
   c. Material pile = 0.02 min.
   d. Bucket fill factor = 90%
   e. Mechanical availability = 90%
   f. Total cycle time = 0.75 min. or 1.33 cycles/min.

3. Rear dump trucks - same as without BITE

4. Bulldozers - same as without BITE

FRONT-END LOADER PRODUCTION CAPACITIES

A. Not Utilizing BITE System

1. 988-B loader (utilized 50% O.B. stripping, 50% coal removal)

a. Production per hour =
1.33 cycles/hr. x 7 lcy x .80 x .90 x 50 min./hr. =
335 lcy/hr.

b. Production per day =
335 lcy/hr. x 8.75 hr./shift x 1 shift/day =
2931 lcy/day

2. 992-B loader

a. Production per hour =
1.33 cycles/hr. x 10 lcy x .80 x .90 x 50 min./hr.=
479 lcy/hr.

b. Production per day =
479 lcy/hr. x 8.75 hr./shift x 2 shift/day =
8400 lcy/day

3. 400-C loader

a. Production per hour =
1.33 cycles/hr. x 10 lcy x .80 x .90 x 50 min./hr.=
479 lcy/hr.

b. Production per day =
479 lcy/hr. x 8.75 hr./shift x 1 shift/day =
4200 lcy/day

B. Utilizing BITE System

1. 988-B loader (utilized 50% OB stripping, 50% coal removal)

a. Production per hour =
1.33 cycles/hr. x 7 lcy x .90 x .90 x 50 min./hr. =
377 lcy/hr.

b. Production per day =
377 lcy/hr. x 8.75 hrs./shift x 1 shift/day =
<u>3299 lcy/day</u>

2. 992-B loader

a. Production per hour
1.33 cycles/hr. x 10 lcy x .90 x .90 x 50 min./hr. =
<u>539 lcy/hr.</u>

b. Production per day
539 lcy/hr. x 8.75 hrs./shift x 2 shifts/day =
<u>9432 lcy/day</u>

3. 400-C loader

a. Production per hour
1.33 cycles/hr. x 10 lcy x .90 x .90 x 50 min./hr. =
<u>539 lcy/hr.</u>

b. Production per day
539 lcy/hr. x 8.75 hrs./shift x 1 shift/day =
<u>4716 lcy/day</u>

TIME REQUIRED TO MINE AREA

A. Not Utilizing FEL BITE System

1. Drilling time =
6,797,250 lcy (overburden to be drilled) ÷ 14,878 lcy/day =
456 days or 18 mos. (25 days/mo.)

2. Front-end loaders time =
7,155,000 lcy (total overburden) ÷ (8400 lcy/day + 4200 lcy/day + 1465 lcy/day) =
509 days or 20 mos. (includes 50% Cat 988-B production rate)

3. Truck time =
7,155,000 lcy - 501,500 lcy (dozed) ÷ (4463 lcy/day + 10,588 lcy,
= 442 days
But must be 509 days to accommodate loaders

4. Dozer time =
7,155,000 lcy ÷ 27,530 lcy/hr. = 260 days or 10 mos.

B. Utilizing FEL BITE System

1. Drilling time = 456 days or 18 mos.

2. Front-end loaders time =
   7,155,000 lcy ÷ (9432 lcy/day + 4716 lcy/day + 1650 lcy/day)=
   453 days or 18 mos.

3. Truck time = 442 days
   But must be 453 days to accommodate loaders

4. Dozer time = 260 days or 10 mos.

ESTIMATED YEARLY PRODUCTION BASED ON FEL's

A. Not Utilizing BITE System

1. Yearly production - overburden
   (8400 lcy/day + 4200 lcy/day + 1465 lcy/day) x 300 days =
   4,219,000 lcy

2. Yearly production - coal

   a. Production per day -
      490,000 tons ÷ 509 days = 963 tons/day

   b. Production per year -
      963 tons/day x 300 days =
      288,900 tons/yr.

B. Utilizing BITE System

1. Yearly production - overburden
   (9432 lcy/day + 4716 lcy/day + 1650 lcy/day) x 300 days =
   4,739,400 lcy

2. Yearly production - coal

   a. Production per day -
      490,000 tons ÷ 453 days = 1082 tons/day

   b. Production per hour -
      1082 tons/day x 300 days/year =
      324,600 tons/yr.

APPENDIX C(2)
UTILIZATION ECONOMICS

ECONOMIC ENGINEERING ANALYSIS DESCRIPTION

A. Equipment Cost Summary -

The information in this section was taken from in-house files, which contain capital equipment costs for numerous equipment items. This information was obtained from many different manufacturers of equipment, and is updated on a regular basis.

B. Manpower Summary -

Most of the data in this section was supplied by the mine. The number of people, the hourly rates for both straight time and overtime for most of the people, and the hours paid per shift, were also supplied to Skelly and Loy by the mine. The hours required per year were computed and the rates were applied to arrive at yearly wages. The salaries of the administrative people were estimated.

C. Total Estimated Capital Requirements -

1. Exploration, Site Preparation, Building and Roads - this value was estimated at $100,000, based on the size of the mine.
2. Engineering - this value was also based on the size of the mine. It was estimated at $20,000.
3. Overhead and Administration - this value is estimated to be 50% of the labor and supervision cost.
4. All other items listed in this table are self-explanatory.

D. Estimated Working Capital -

All items listed in this table are three month values of items listed in the estimated annual operating cost table.

E. Estimated Annual Operating Cost -

1. Direct Cost - was obtained from the Manpower Summary Table.
2. Operating Supplies -
   a. Fuel, Lubricant, and Parts, Materials and Miscellaneous - these values are summarized the attached table. The hourly rates used to arrive at the yearly costs were extracted from the 1979 Construction Equipment Cost Reference Guide (National Research and Appraisal Company).
   b. Explosives - the present loading rates were used in calculating the explosive costs for each concept. The formula used to compute explosive cost was:
      1. $125 \text{ lbs./hole} \div \frac{10' \times 10' \times 30'}{27} \text{ bcy/hole} = 1.126 \text{ lbs./bcy.}$

         1.126 lbs./bcy x bcy/year x $0.14/lb = Cost/Year.
3. Auxiliary Cost -
   a. Royalty cost = $1.00/ton
   b. Power - was estimated at $3000/year.
   c. Communications - was estimated at $3000/year.
   d. Payroll Overhead - this value was estimated to be 35% of the labor and supervision cost.
   e. Health and Safety - this value was estimated for each concept, based on the number of employees.
   f. Contract Coal Haulage - was based on a rate of $2.00 per ton.
   g. Strip License and Reclamation Fee - was estimated at $1000 per year.
   h. Indirect Costs and Fixed Costs - are self explanatory items.
   i. Depreciation - this value was taken from the Depreciation Table.

F. Depreciation Schedule -

Yearly charges for equipment were obtained by dividing the total equipment cost by the years of expected life for each of the pieces of equipment. The expected life for most of the equipment was assumed to be 10,000 hours, with the exceptions of the drills, which were estimated at 15,000 hours, and some of the maintenance trucks and the hydroseeder, which were assumed to be 5,000 hours.

Other non-equipment items were depreciated over the life of mining in the area, which is expected to be 15 years. The interim equipment cost is an estimated value that is inserted as a yearly charge for small equipment items which can not easily be predicted.

EQUIPMENT OPERATING COSTS

EQUIPMENT ITEMS	NO.	WORKING HOURS/YEAR	HOURLY COSTS (Dollars)			YEARLY COSTS (Dollars)		
			FUEL	LUBE	M.&S.	FUEL	LUBE	M.&S.
Drills - 5⅛"	2	4,500	$ 2.34	$1.10	$ 7.26	$ 28,100	$ 13,200	$ 87,100
Dozer - D-9	1	3,000	$ 7.95	$1.88	$ 9.88	$ 23,900	$ 5,600	$ 29,600
Dozers - D-9	2	3,000	$ 7.95	$1.88	$ 9.88	$ 47,700	$ 11,300	$ 59,300
Dozer - D-9	1	6,000	$ 7.95	$1.88	$ 9.88	$ 47,700	$ 11,300	$ 59,300
F.E.L. - Cat. 992-B	1	6,000	$10.67	$2.65	$25.12	$ 64,000	$ 15,900	$ 150,700
F.E.L. - Hough 400	1	3,000	$10.86	$2.04	$24.07	$ 32,600	$ 6,100	$ 72,200
50 Ton Trucks - Cat. 773	3	6,000	$ 8.76	$2.06	$18.06	$157,700	$ 37,000	$ 325,100
40 Ton Trucks - Terex 33-07	3	3,000	$ 7.20	$1.66	$15.67	$ 64,800	$ 14,800	$ 141,100
40 Ton Coal Haulers - Cline	3	1,500	$ 5.75	$1.45	$15.24	$ 25,900	$ 6,500	$ 68,600
Coal Loader - Cat. 988-B	1	3,000	$ 7.28	$1.86	$19.01	$ 21,900	$ 5,600	$ 57,100
Grader - Cat. 14-E	1	3,000	$ 3.82	$0.94	$ 6.63	$ 11,400	$ 2,800	$ 19,900
Mechanic Trucks	2	1,000	$ 3.38	$0.37	$ 0.37	$ 6,700	$ 700	$ 700
Water Trucks	2	1,000	$ 3.38	$0.37	$ 0.37	$ 6,700	$ 700	$ 700
Hydroseeder	1	1,000	$ 3.38	$0.37	$ 0.37	$ 3,400	$ 400	$ 11,400
TOTAL YEARLY COST						$542,700	$132,300	$1,082,700

APPENDIX C(3)
ECONOMIC ANALYSIS OF MINE NOT UTILIZING FEL BITE SYSTEM

EQUIPMENT COST SUMMARY

Topsoil Removal and Reclamation	Capacity	Quantity	Total Cost
Cat. (D-9) Bulldozer	410 H.P.	1	$ 233,000
Hydroseeder	--	1	40,000
			$ 273,000
Overburden Stripping			
Gardner-Denver (RD-16B) Drills	5 1/8"	2	$ 300,000
Cat. (D-9) Bulldozer	410 H.P.	1	233,000
Cat. (D-9) Bulldozers	410 H.P.	2	466,000
Cat. (992-B) FEL	10 C.Y.	1	340,000
Hough (H-400) FEL	10 C.Y.	1	348,000
Cat. (773) Trucks	50 Ton	3	765,000
Terex (33-07) Trucks	40 Ton	3	606,000
			$3,058,000
Coal Removal and Loading			
Cat. (988-B) FEL*	7 C.Y.	1	$ 212,000
			$ 212,000
Coal Haulage			
Cline Coal Trucks	40 Ton	3	$ 519,000
			$ 519,000
Maintenance			
Mechanics' Trucks	--	2	$ 40,000
Water Trucks	--	2	44,000
Cat. (14-E) Grader	--	1	121,000
			$ 205,000

Total Equipment Cost = $4,267,000

*When not loading coal, loader assists with overburden removal, assume 50% on each operation.

MANPOWER SUMMARY

Topsoil Removal and Reclamation	Total	Cost Per Year
Dozer Operator	1	$ 31,500
		$ 31,500
Overburden Stripping		
Drillers	4	$ 119,000
Shooters	2	59,500
Dozer Operators	4	126,000
Loader Operators	3	94,500
Truck Drivers	9	267,750
		$ 666,750
Coal Removal and Loading		
Loader Operator	1	$ 31,500
		$ 31,500
Coal Haulage		
Truck Drivers*	3	$ 89,250
		$ 89,250
Maintenance		
Maintenance Crew**	8	$ 259,750
		$ 259,750
	Total Labor Cost =	$1,078,750
Administrative		
Vice-President of Operations	1	$ 42,000
Foremen	3	116,000
Office Personnel	2	42,000
	Total Supervision =	$ 200,000
	Total Labor & Supervision =	$1,278,750

*When not hauling coal, men are used for other mine operations.

**Includes operator for hydroseeder.

TOTAL ESTIMATED CAPITAL REQUIREMENTS

Exploration, Power Facilities, Site Preparation, Buildings and Roads		$ 100,000
Mining Equipment		4,267,000
	Total Direct =	$4,367,000
Field Indirect (2% of Total Direct)		$ 87,000
Engineering		20,000
Overhead and Administration		639,000
	Subtotal =	$5,113,000
Contingency (10% of $5,113,000)		$ 511,000
	Subtotal =	$5,624,000
Fee (2% of $5,624,000)		$ 112,500
	Subtotal =	$5,736,500
Interest During Construction (5% of $5,736,000)		$ 287,000
Working Capital		1,148,700
	Total =	$7,172,200

Estimated Working Capital

Direct Labor, 3 months		$ 320,000
Payroll Overhead, 3 months		111,900
Operating Supplies, 3 months		556,400
Indirect Costs, 3 months		131,400
Fixed Costs, 0.5% of Insurance Base		29,000
	Total =	$1,148,700

ESTIMATED ANNUAL OPERATING COSTS

Direct Cost		
Labor		$1,078,750
Supervision		200,000
	Subtotal =	$1,278,750
Operating Supplies		
Fuel		$ 542,700
Lubricants		132,300
Explosives		467,800
Parts, Materials and Miscellaneous		1,082,700
	Subtotal =	$2,225,500
Auxiliary Cost		
Royalty		$ 288,900
Power		5,000
Communications		3,000
Payroll Overhead		447,600
Health and Safety		4,000
Contract Coal Haulage		288,900
Strip License and Reclamation Fee		1,000
	Subtotal =	$1,038,400
	Total Direct Cost =	$4,542,650
Indirect Cost: 15% of Labor, Supervision, and Operating Supplies		525,600
Fixed Cost: Taxes and Insurance, 2% of Mine Cost		114,700
Depreciation		1,616,500
	Total Operating Cost =	$6,799,350

Oper. Cost/Ton = [$6,799,350+($1,148,700÷15)]÷288,900 Tons = $23.80/Ton

Oper. Cost/B.C.Y. = [$6,799,350+($1,148,700÷15)]÷3,126,000 B.C.Y. = $2.20/B.C.Y.

DEPRECIATION SCHEDULE

Item	Quantity	Deprec./Yrs.	Yearly Charge
Hydroseeder	1	5	$ 8,000
Gardner-Denver (RD-16B) Drills	2	3	100,000
Cat. (D-9) Bulldozer	1	3	78,000
Cat. (D-9) Bulldozer	3	3	233,000
Cat. (992-B) FEL	1	2	170,000
Hough (H-400) FEL	1	3	116,000
Cat. (773) Trucks	3	2	383,000
Terex (33-07) Trucks	3	3	202,000
Cat. (988-B) FEL	1	3	71,000
Cline Coal Trucks	3	10	52,000
Mechanics' Trucks	2	5	8,000
Water Trucks	2	5	9,000
Cat. (14-E) Grader	1	3	40,000
Exploration, Power Facilities, Site Preparation, Buildings and Roads	--	15	$ 7,000
Depreciation: Field Indirect, Engineering Overhead and Administration, Contingency, Fee, and Interest During Construction	--	15	$ 110,400
Interim Equipment Cost	--	--	$ 29,000
		Total =	$1,616,400

CASH FLOW ANALYSIS

Year	Capital Investment	Cash Flow	Present Worth Factor at 15 Percent	Present Worth Capital Investment at 15 Percent	Present Worth Cash Flow Value at 15 Percent
0	$7,172,200	-$7,172,200	1.0000	$ 7,172,200	-$7,172,200
1	29,000	2,405,300	.8696	25,200	2,091,600
2	1,134,000	1,300,300	.7561	857,400	983,100
3	2,548,000	- 113,700	.6575	1,675,300	- 74,800
4	1,134,000	1,300,300	.5718	648,400	743,600
5	153,000	2,281,300	.4972	76,100	1,134,300
6	3,653,000	- 1,218,700	.4323	1,579,200	- 526,800
7	29,000	2,405,300	.3759	10,900	904,200
8	1,134,000	1,300,300	.3269	370,700	425,000
9	2,548,000	- 113,700	.2843	724,400	- 32,300
10	1,777,000	657,300	.2472	439,300	162,500
11	29,000	2,405,300	.2149	6,200	516,900
12	3,653,000	- 1,218,700	.1869	682,700	- 227,800
13	29,000	2,405,300	.1625	4,700	390,900
14	1,134,000	1,300,300	.1414	160,300	183,900
15	-1,616,400	4,050,700	.1229	- 198,700	497,900
			Total	$14,234,300	0

R = $14,234,400 ÷ 5.8474	=	$2,434,300
Less depreciation	=	1,616,400
Depletion + net profit		$ 817,900
Gross profit = 1/0.75 x $817,900	=	1,090,500
Sales = $6,875,900 + $1,090,500	=	7,966,400
Gross Profit.	=	1,090,500
Depletion	=	545,250
Taxable Income	=	545,250
Federal Income Tax	=	272,625
Net Profit.	=	$ 272,625
Annual cash flow = $272,625 + $545,250 + $1,616,400	=	$2,434,275
Selling price per ton = $7,966,400 ÷ 288,900 tons	=	$27.57

UNIT OPERATION COSTS

Topsoil Removal and Reclamation

	Cost/Year
Equipment and Materials	
1 - Cat. (D-9) Bulldozer	$ 78,000
1 - Hydroseeder	8,000
Fuel and Lubricants	
1 - Cat. (D-9) Bulldozer	29,500
1 - Hydroseeder	3,800
Parts, Materials, and Miscellaneous	
1 - Cat. (D-9) Bulldozer	29,600
1 - Hydroseeder	400
Seed and Fertilizer	
22 Ac. at $500/Ac.	11,000
Labor and Operator Costs	
1 - Bulldozer Operator	31,500
1 - Hydroseeder Operator	9,900
Subtotal =	$201,700
Auxiliary Operations	
Strip License and Reclamation Fee	1,000
Miscellaneous Equipment, Overhead and Supervision ($1,997,250 x .0459)	91,700
Total =	$294,400

UNIT OPERATION COSTS (Cont'd.)

Overburden Stripping

Equipment and Materials	Cost/Year
2 - Gardner-Denver (RD-16B) Drills	$ 100,000
1 - Cat. (D-9) Bulldozer	78,000
2 - Cat. (D-9) Bulldozers	155,000
1 - Cat. (992-B) FEL	170,000
1 - Hough (H-400) FEL	116,000
3 - Cat. (773) Trucks	383,000
3 - Terex (33-07) Trucks	202,000
1 - Cat. (988-B) FEL (50%)	35,500
Fuel and Lubricants	
2 - Gardner-Denver (RD-16B) Drills	41,300
1 - Cat. (D-9) Bulldozer	59,000
2 - Cat. (D-9) Bulldozers	59,000
1 - Cat. (992-B) FEL	79,900
1 - Hough (H-400) FEL	38,700
3 - Cat. (773) Trucks	194,700
3 - Terex (33-07) Trucks	79,600
1 - Cat. (988-B) FEL (50%)	13,750
Parts, Materials, and Miscellaneous	
2 - Gardner-Denver (RD-16B) Drills	87,100
1 - Cat. (D-9) Bulldozer	59,300
2 - Cat. (D-9) Bulldozers	59,300
1 - Cat. (992-B) FEL	150,700
1 - Hough (H-400) FEL	72,200
3 - Cat. (773) Trucks	325,100
3 - Terex (33-07) Trucks	141,100
1 - Cat. (988-B) FEL (50%)	28,550
Explosives	467,800

UNIT OPERATION COSTS (Cont'd.)

Overburden Stripping (Cont'd)

		Cost/Year
Labor and Operator Costs		
4 - Drillers		$ 119,000
2 - Shooters		59,500
4 - Bulldozer Operators		126,000
3 - Loader Operators		94,500
9 - Truck Drivers		267,750
1 - Loader Operator (50%)		15,750
	Subtotal =	$3,879,100
Auxiliary Operations		
Miscellaneous Equipment, Overhead and Supervision ($1,997,250 x .8829)		1,763,400
	Total =	$5,642,500

Coal Removal and Loading

		Cost/Year
Equipment and Materials		
1 - Cat. (988-B) FEL (50%)		$ 35,500
Fuel and Lubricants		
1 - Cat. (988-B) FEL (50%)		13,750
Parts, Materials, and Miscellaneous		
1 - Cat. (988-B) FEL (50%)		28,550
Labor and Operator Costs		
1 - Loader Operator (50%)		15,750
	Subtotal =	$ 93,550

UNIT OPERATION COSTS (Cont'd.)

Coal Removal and Loading (Cont'd)

Auxiliary Operations		Cost/Year
Miscellaneous Equipment, Overhead and Supervision ($1,997,250 x .0214)		$ 42,730
	Total =	$ 136,280

Coal Haulage

Equipment and Materials		Cost/Year
3 - Cline Coal Trucks		$ 52,000
Fuel and Lubricants		
3 - Cline Coal Trucks		32,400
Parts, Materials, and Miscellaneous		
3 - Cline Coal Trucks		68,600
Labor and Operator Costs		
3 - Truck Drivers		66,950
	Subtotal =	$ 219,950
Auxiliary Operations		
Contract Coal Haulage - 144,450 Tons at $2.00/Ton		288,900
Miscellaneous Equipment, Overhead and Supervision ($1,997,250 x .0501)		100,100
	Total =	$ 608,950

UNIT OPERATION COSTS (Cont'd.)

Maintenance and Supervisory Operations

	Cost/Year
Equipment and Materials	
2 - Mechanics' Trucks	$ 8,000
2 - Water Trucks	9,000
1 - Cat. (14-E) Grader	40,000
Fuel and Lubricants	
2 - Mechanics' Trucks	7,400
2 - Water Trucks	7,400
1 - Cat. (14-E) Grader	14,200
Parts, Materials, and Miscellaneous	
2 - Mechanics' Trucks	700
2 - Water Trucks	700
1 - Cat. (14-E) Grader	19,900
Labor and Supervisory Personnel	
Maintenance Crew and Truck Drivers	272,150
Supervisory Personnel	200,000
Royalty	288,900
Power	5,000
Communications	3,000
Payroll Overhead	447,600
Health and Safety	4,000
Indirect Costs	525,600
Fixed Costs	114,700
Interim Equipment Cost	29,000
Total =	$1,997,250

UNIT OPERATION COSTS (Cont'd.)

Planning and Development

	Cost/Year
Exploration, Power Facilities, Site Preparation, Buildings and Roads	$ 7,000
Field Indirect	5,800
Engineering	1,300
Overhead and Administration	42,600
Contingency	34,000
Fee	7,500
Interest During Construction	19,000
Working Capital	76,600
Total =	$ 193,800

Summary

	Cost/Year	Cost/Ton
Topsoil Removal and Reclamation	$ 294,400	$ 1.02
Overburden Stripping	5,642,500	19.53
Coal Removal and Loading	136,280	0.47
Coal Haulage	608,950	2.11
Planning and Development	193,800	0.67
Total =	$6,875,930	$23.80

APPENDIX C(4)
ECONOMIC ANALYSIS OF MINE UTILIZING FEL BITE SYSTEM

EQUIPMENT COST SUMMARY

Topsoil Removal and Reclamation	Capacity	Quantity	Total Cost
Cat. (D-9) Bulldozer	410 H.P.	1	$ 233,000
Hydroseeder	--	1	40,000
			$ 273,000
Overburden Stripping			
Gardner-Denver (RD-16B) Drills	5 1/8"	2	$ 300,000
Cat. (D-9) Bulldozer	410 H.P.	1	233,000
Cat. (D-9) Bulldozers	410 H.P.	2	466,000
Cat. (992-B) FEL	10 C.Y.	1	365,000
Hough (H-400) FEL	10 C.Y.	1	373,000
Cat. (773) Trucks	50 Ton	3	765,000
Terex (33-07) Trucks	40 Ton	3	606,000
			$3,108,000
Coal Removal and Loading			
Cat. (988-B) FEL*	7 C.Y.	1	$ 237,000
			$ 237,000
Coal Haulage			
Cline Coal Trucks	40 Ton	3	$ 519,000
			$ 519,000
Maintenance			
Mechanics' Trucks	--	2	$ 40,000
Water Trucks	--	2	44,000
Cat. (14-E) Grader	--	1	121,000
			$ 205,000

Total Equipment Cost= $4,342,000

*When not loading coal, loader assists with overburden removal, assume 50% on each operation.

MANPOWER SUMMARY

	Total	Cost Per Year
Topsoil Removal and Reclamation		
Dozer Operator	1	$ 31,500
		$ 31,500
Overburden Stripping		
Drillers	4	$ 119,000
Shooters	2	59,500
Dozer Operators	4	126,000
Loader Operators	3	94,500
Truck Drivers	9	267,750
		$ 666,750
Coal Removal and Loading		
Loader Operator	1	$ 31,500
		$ 31,500
Coal Haulage		
Truck Drivers*	3	$ 89,250
		$ 89,250
Maintenance		
Maintenance Crew**	8	$ 259,750
		$ 259,750
	Total Labor Cost =	$1,078,750
Administrative		
Vice-President of Operations	1	$ 42,000
Foremen	3	116,000
Office Personnel	2	42,000
	Total Supervision =	$ 200,000
	Total Labor & Supervision =	$1,278,750

*When not hauling coal, men are used for other mine operations.

**Includes operator for hydroseeder.

TOTAL ESTIMATED CAPITAL REQUIREMENTS

Exploration, Power Facilities, Site Preparation, Buildings and Roads		$ 100,000
Mining Equipment		4,342,000
	Total Direct =	$4,442,000
Field Indirect (2% of Total Direct)		$ 88,800
Engineering		20,000
Overhead and Administration		639,000
	Subtotal =	$5,189,800
Contingency (10% of $5,189,800)		519,000
	Subtotal =	$5,708,800
Fee (2% of $5,708,800)		114,000
	Total Mine Cost(Base Insurance Tax) =	$5,822,800
Interest During Construction (5% of $5,822,800)		291,000
Working Capital		1,148,700
	Total =	$7,262,500

Estimated Working Capital

Direct Labor, 3 months	$ 320,000
Payroll Overhead, 3 months	111,900
Operating Supplies, 3 months	556,400
Indirect Costs, 3 months	131,400
Fixed Costs, 0.5% of Insurance Base	29,000
	$1,148,700

ESTIMATED ANNUAL OPERATING COSTS

Direct Cost		
Labor		$1,078,750
Supervision		200,000
	Subtotal =	$1,278,750
Operating Supplies		
Fuel		$ 542,700
Lubricants		132,300
Explosives		467,800
Parts, Materials and Miscellaneous		1,082,700
	Subtotal =	$2,225,500
Auxiliary Cost		
Royalty		$ 324,600
Power		5,000
Communications		3,000
Payroll Overhead		447,600
Health and Safety		4,000
Contract Coal Haulage		324,600
Strip License and Reclamation Fee		1,000
	Subtotal =	$1,109,800
	Total Direct Cost =	$4,614,050
Indirect Cost: 15% of Labor, Supervision, and Operating Supplies		525,600
Fixed Cost: Taxes and Insurance, 2% of Mine Cost		116,500
Depreciation		1,649,700
	Total Operating Cost =	$6,905,850

Oper. Cost/Ton = [$6,905,850+($1,148,700÷15)]÷324,600 Tons = $21.51/Ton
Oper. Cost/B.C.Y. = [$6,905,850+($1,148,700÷15)]÷3,512,200 B.C.Y. = $1.99/B.C.Y.

DEPRECIATION SCHEDULE

Item	Quantity	St. Line Deprec./Yrs.	Yearly Charge
Hydroseeder	1	5	$ 8,000
Gardner-Denver			100,000
(RD-16B) Drills	2	3	78,000
Cat. (D-9) Bulldozer	1	3	233,000
Cat. (D-9) Bulldozers	3	3	182,500
Cat. (992-B) FEL	1	2	124,300
Hough (H-400) FEL	1	3	383,000
Cat. (773) Trucks	3	2	202,000
Terex (33-07) Trucks	3	3	79,000
Cat. (988-B) FEL	1	3	52,000
Cline Coal Trucks	3	10	8,000
Mechanics Trucks	2	5	9,000
Water Trucks	2	5	40,000
Cat. (14-E) Grader	1	3	
Exploration, Power Facilities, Site Preparation, Buildings and Roads	--	15	$ 7,000
Depreciation: Field Indirect, Engineering Overhead and Administration, Contingency, Fee, and Interest During Construction	--	15	$ 111,400
Interim Equipment Cost	--	--	$ 32,500
		Total =	$1,649,700

CASH FLOW ANALYSIS

Year	Capital Investment	Cash Flow	Present Worth Factor at 15 Percent	Present Worth Capital Investment at 15 Percent	Present Worth Cash Flow Value at 15 Percent
0	$7,262,500	-$7,262,500	1.0000	$ 7,262,500	-$7,262,500
1	32,500	2,444,500	.8696	28,300	2,125,800
2	1,162,500	1,314,500	.7561	879,000	994,000
3	2,601,500	- 124,500	.6575	1,710,000	- 81,800
4	1,162,500	1,314,500	.5718	664,700	751,700
5	156,500	2,320,500	.4972	77,800	1,153,800
6	3,731,500	- 1,254,500	.4323	1,613,000	- 542,200
7	32,500	2,444,500	.3759	12,000	919,000
8	1,162,500	1,314,500	.3269	380,000	429,800
9	2,601,500	- 124,500	.2843	739,600	- 35,300
10	1,805,500	671,500	.2472	446,300	166,100
11	32,500	2,444,500	.2149	7,000	525,400
12	3,731,500	- 1,254,500	.1869	697,400	- 234,400
13	32,500	2,444,500	.1625	5,000	397,300
14	1,162,500	1,314,500	.1414	164,400	186,000
15	-1,649,700	4,126,700	.1229	- 202,700	507,300
			Total	$14,484,300	0

R = $14,484,300 ÷ 5.8474	=	$2,477,000
Less depreciation	=	1,649,700
Depletion + net profit	=	$ 827,300
Gross profit = 1/0.75 x $827,300	=	1,103,100
Sales = $6,982,400 + $1,103,100	=	8,085,500
Gross Profit.	=	1,103,100
Depletion	=	551,550
Taxable Income	=	$ 551,550
Federal Income Tax	=	275,775
Net Profit.	=	$ 275,775
Annual cash flow = $275,775 + $551,550 + $1,649,700	=	$2,477,025
Selling price per ton = $8,085,500 ÷ 324,600 tons	=	$24.91

UNIT OPERATIONS COSTS

Topsoil Removal and Reclamation

Equipment and Materials	Cost/Year
1 - Cat. (D-9) Bulldozer	$ 78,000
1 - Hydroseeder	8,000
Fuel and Lubricants	
1 - Cat. (D-9) Bulldozer	29,500
1 - Hydroseeder	3,800
Parts, Materials, and Miscellaneous	
1 - Cat. (D-9) Bulldozer	29,600
1 - Hydroseeder	400
Seed and Fertilizer	
22 Ac. at $500/Ac.	11,000
Labor and Operator Costs	
1 - Bulldozer Operator	31,500
1 - Hydroseeder Operator	9,900
Subtotal =	$ 201,700
Auxiliary Operations	
Strip License and Reclamation Fee	1,000
Miscellaneous Equipment, overhead and Supervision ($2,038,250 x .0456)	92,900
Total =	$ 295,600

Overburden Stripping

Equipment and Materials	Cost/Year
2 - Gardner-Denver (RD-16B) Drills	$ 100,000
1 - Cat. (D-9) Bulldozer	78,000
2 - Cat. (D-9) Bulldozers	155,000
1 - Cat. (992-B) FEL	182,500
1 - Hough (H-400) FEL	124,300
3 - Cat. (773) Trucks	383,000
3 - Terex (33-97) Trucks	202,000
1 - Cat. (988-B) FEL (50%)	39,500

Overburden Stripping (Cont'd.)

	Cost/Year
Fuel and Lubricants	
2 - Gardner-Denver (RD-16B) Drills	$ 41,300
1 - Cat. (D-9) Bulldozer	59,000
2 - Cat. (D-9) Bulldozers	59,000
1 - Cat. (992-B) FEL	79,900
1 - Hough (H-400) FEL	38,700
3 - Cat. (773) Trucks	194,700
3 - Terex (33-07) Trucks	79,600
1 - Cat. (988-B) FEL (50%)	13,750
Parts, Materials, and Miscellaneous	
2 - Gardner-Denver (RD-16B) Drills	87,100
1 - Cat. (D-9) Bulldozer	59,300
2 - Cat. (D-9) Bulldozers	59,300
1 - Cat. (992-B) FEL	150,700
1 - Hough (H-400) FEL	72,200
3 - Cat. (773) Trucks	325,100
3 - Terex (33-07) Trucks	141,100
1 - Cat. (988-B) FEL (50%)	28,550
Explosives	467,800
Labor and Operator Costs	
4 - Drillers	119,000
2 - Shooters	59,500
4 - Bulldozer Operators	126,000
3 - Loader Operators	94,500
9 - Truck Drivers	267,750
1 - Loader Operator (50%)	15,750
Subtotal =	$3,903,900
Auxiliary Operations	
Miscellaneous Equipment, Overhead and Supervision ($2,038,250 x .8827)	1,799,130
Total =	$5,703,030

Coal Removal and Loading

Equipment and Materials		Cost/Year
1 - Cat. (988-B) FEL (50%)		$ 39,500
Fuel and Lubricants		
1 - Cat. (988-B) FEL (50%)		13,750
Parts, Materials, and Miscellaneous		
1 - Cat. (988-B) FEL (50%)		28,550
Labor and Operator Costs		
1 - Loader Operator (50%)		15,750
	Subtotal =	$ 97,550
Auxiliary Operations		
Miscellaneous Equipment, Overhead and Supervision ($2,038,250 x .0222)		45,200
	Total =	$ 142,750

Coal Haulage

Equipment and Materials		Cost/Year
3 - Cline Coal Trucks		$ 52,000
Fuel and Lubricants		
3 - Cline Coal Trucks		32,400
Parts, Materials, and Miscellaneous		
3 - Cline Coal Trucks		68,600
Labor and Operator Costs		
3 - Truck Drivers		66,950
	Subtotal =	$ 219,950

Coal Haulage (Cont'd.)

Auxiliary Operations	Cost/Year
Contract Coal Haulage - 162,300 Tons at $2.00/Ton	$ 324,600
Miscellaneous Equipment, Overhead and Supervision ($2,038,250 x .0498)	101,500
Total =	$ 646,050

Maintenance and Supervisory Operations

Equipment and Materials	Cost/Year
2 - Mechanics' Trucks	$ 8,000
2 - Water Trucks	9,000
1 - Cat. (14-E) Grader	40,000
Fuel and Lubricants	
2 - Mechanics' Trucks	7,400
2 - Water Trucks	7,400
1 - Cat. (14-E) Grader	14,200
Parts, Materials, and Miscellaneous	
2 - Mechanics' Trucks	700
2 - Water Trucks	700
1 - Cat. (14-E) Grader	19,900
Labor and Supervisory Personnel	
Maintenance Crew and Truck Drivers	275,150
Supervisory Personnel	200,000
Royalty	324,600
Power	5,000
Communications	3,000
Payroll Overhead	447,600
Health and Safety	4,000
Indirect Costs	525,600
Fixed Costs	116,500
Interim Equipment Cost	32,500
Total =	$2,038,250

UNIT OPERATION COSTS (Cont'd.)

Planning and Development

	Cost/Year
Exploration, Power Facilities, Site Preparation, Buildings and Roads	$ 7,000
Field Indirect	5,900
Engineering	1,300
Overhead and Administration	42,600
Contingency	34,600
Fee	7,600
Interest During Construction	19,400
Working Capital	76,600
Total =	$ 195,000

Summary

	Cost/Year	Cost/Ton
Topsoil Removal and Reclamation	$ 295,600	$ 0.91
Overburden Stripping	5,703,030	17.57
Coal Removal and Loading	142,750	0.44
Coal Haulage	646,050	1.99
Planning and Development	195,000	0.60
Total =	$6,982,430	$21.51

APPENDIX D

LIST OF MINES USING FEL

APPENDIX D
LIST OF MINES USING FELs

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
	ALABAMA		
1.	Bankhead Mining Co.	1	4
2.	Black Diamond Coal Mining Co.	2	4
3.	Brilliant Coal Co.	1	7
4.	Burgess Mining & Construction Corp.	3	14
5.	Calvert & Marsh Coal Co., Inc.	1	16
6.	Calvert & Youngblood Coal Co., Inc.	2	3
7.	Canamex Coal Corp.	1	3
8.	Cliff Mining Co.	1	6
9.	Cobb Coal Co.	1	8
10.	Drummond Coal Co.	17	65
11.	T. Duckett Construction, Inc.	1	3
12.	Empire Coke Co., Div. of McWane Cast Iron Pipe Co.	1	Unknown
13.	Floyd Mining Co., Inc.	1	4
14.	Jefferson Coal Co.	1	2
15.	Mobile Fuel Shipping, Inc.	3	10
16.	Walker-Fayette Coal Co.	1	Unknown
17.	Westala Coal Co.	1	3
18.	Yancey & Yancey Constr. Co.	1	5
	ALASKA		
19.	Usibelli Coal Mines, Inc.	1	Unknown
	ARKANSAS		
20.	National Mines Corp.	1	5
21.	Titan Mining Co.	3	Unknown
	COLORADO		
22.	Energy Fuels Corp.	3	Unknown
23.	The Pittsburg and Midway Coal Mining Co.	1	1
24.	Sun Coal Co., Inc.	1	Unknown
25.	Utah International Inc.	1	2

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
	GEORGIA		
26.	Canamex Coal Corp.	3	9
27.	Lookout Mountain Coal Co.	1	5
	ILLINOIS		
28.	Amax Coal Co.	3	6
29.	Consolidation Coal Co.	5	5
30.	Freeman United Coal Mining Co., Div. Material Service Corp.	2	Unknown
31.	Jader Fuel Co.	1	Unknown
32.	Midland Coal Co., A Div. of ASARCO Inc.	2	4
33.	Sahara Coal Co., Inc.	1	2
34.	Southwestern Illinois Coal Corp.	2	Unknown
	INDIANA		
35.	Amax Coal Co.	5	13
36.	English Coal Company, Inc.	1	1
37.	Mulzer Crushed Stone Co.	1	Unknown
38.	Solar Sources, Inc.	1	2
39.	L.G. Wasson Coal Mining Corp.	1	3
	IOWA		
40.	ICO Corporation	1	2
	KANSAS		
41.	Cherokee Coal Co.	1	Unknown
42.	Fuel Dynamics, Inc.	1	3
	KENTUCKY		
43.	Amax Coal Co.	1	6
44.	Apache Coal Co.	1	Unknown
45.	Arbor Coal Co.	1	Unknown
46.	B&H Elkhorn Coal Co., Inc.	1	4
47.	B&T Coal Co.	1	1
48.	Bedcor Inc.	1	2
49.	Bell County Coal Corp.	1	3

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
50.	Benle Coal Corp.	1	Unknown
51.	Blue Diamond Mining	2	Unknown
52.	Boorhem Clark Coal Co.	1	2
53.	C&A Coal Co., Inc.	1	3
54.	C&E Coal Co., Inc.	1	5
55.	D.H. Campbell, Inc.	1	3
56.	Caney Branch Coal Co., Inc.	1	Unknown
57.	Capito Coal Sales & Leasing	1	3
58.	Carr Creek Fuel Co.	1	Unknown
59.	Case Coal Co.	1	4
60.	Central Elkhorn Mining Co.	1	7
61.	Coal Valley Corp.	1	2
62.	Cole & White, Inc.	2	8
63.	Congleton Bros., Inc.	1	3
64.	D&S Coal Co., Inc.	1	1
65.	Diamond Coal Co., Inc.	1	7
66.	Diamond Fork Coal Co., Inc.	1	3
67.	Dixie Mining Co.	1	5
68.	Elm Coal Corp.	1	5
69.	Falcon Coal Co., Inc.	2	47
70.	General Refractories Co. Kentucky Mines Div.	1	Unknown
71.	Golden R. Coal Co., Inc.	1	7
72.	Hawkeye Coal Co.	1	4
73.	Helco Minerals Corp.	1	3
74.	Howard Enterprises	1	2
75.	Ikerd & Bandy Co., Inc.	1	4
76.	JMT Company	1	Unknown
77.	M. Johnson Construction Co., Inc.	1	Unknown
78.	K-W Mining Co.	1	3
79.	Kentucky Carbon Co.	1	2
80.	Kentucky Central Coal Corp.	1	3
81.	Kentucky Gem Coal Co., Inc.	1	3
82.	Kentucky Prince Coal Corp.	1	4
83.	Leslie B. Coal Co.	1	Unknown
84.	Majestic Collieries Co.	1	Unknown
85.	Martiki Coal Corp.	1	5
86.	Martin County Coal Corp.	4	15
87.	Marty Corp.	1	8
88.	Middle States Coal Co., Inc.	1	8
89.	Monarch Coal Co.	1	Unknown
90.	Pennsylvania-Kentucky Mining Co.	1	3

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
91.	The Pittsburg and Midway Coal Mining Co.	2	3
92.	Plastic Universal Corp.	1	4
93.	R.J.F. Coal Co.	1	Unknown
94.	Race Fork Coal Corp.	1	Unknown
95.	Rough River Coal Co.	3	Unknown
96.	Royal Gem Coal Co.	1	3
97.	South Central Coal Co.	1	Unknown
98.	South Wind Coal Mining Co., Inc.	1	2
99.	Stansbury & Co., Inc.	2	5
100.	Tarheels Coals, Inc.	2	Unknown
101.	Tesoro Coal Co.	1	15
102.	Texas Pioneer Coal Co.	1	4
103.	Triple Elkhorn Mining Co.	1	6
104.	United Coal Companies	1	3
105.	West Virginia Rebel Co.	1	4
	MARYLAND		
106.	Bridgeview Coal Co., Inc.	1	2
107.	Buffalo Coal Co., Inc.	3	13
108.	Delta Mining, Inc.	3	7
109.	Grafton Coal Co.	1	4
110.	Western America Coal Co.	1	Unknown
	MISSOURI		
111.	Missouri Mining, Inc.	1	3
112.	The Pittsburg and Midway Coal Mining Co.	1	2
	MONTANA		
113.	Decker Coal Co.	1	2
114.	Knife River Coal Mining Co.	1	2
115.	Western Energy Co.	1	4
116.	Westmoreland Resources	1	7
	NEW MEXICO		
117.	Kaiser Steel Corp.	1	2
118.	The Pittsburg and Midway Coal Mining Co.	1	3

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
119.	Utah International, Inc.	1	6
120.	Western Coal Co.	1	2
	NORTH DAKOTA		
121.	Baukol Noonan, Inc.	2	4
122.	Consolidation Coal Co., Western Region	2	6
123.	The Falkirk Mining Co.	1	1
124.	Husky Industries	1	1
125.	Knife River Coal Mining Co.	2	7
126.	North American Coal Corp.	1	2
	OHIO		
127.	Anthony Mining Co., Inc.	1	5
128.	Beasley Energy Inc., Beasley Mineral Surveys	1	2
129.	Bedway Coal Co.	1	5
130.	Bennoc, Inc.	2	6
131.	Boich Mining Co.	1	2
132.	Boyle Coal Co., Inc.	1	2
133.	Buckeye Coal Mining Co.	2	4
134.	Central Ohio Coal Co.	1	5
135.	Consolidation Coal Co., Midwestern Region	3	7
136.	Crown City Mining Co.	1	2
137.	Dean Coal Co.	1	3
138.	East Fairfield Coal Co.	2	3
139.	Hardy Coal Co.	1	Unknown
140.	Industrial Mining Co.	4	11
141.	Keffler & Rose Enterprises	1	Unknown
142.	Keller Mines, Inc.	1	1
143.	McKim Coal Co.	1	1
144.	Muskingham Mines Joint Venture	1	5
145.	Ohio Coal and Construction Corp.	5	12
146.	Ohio River Collieries	2	11
147.	R&F Coal Company	8	58
148.	Reclamation & Air Survey, Inc. Mine Div.	2	5
149.	S&D Construction Corp.	1	3
150.	Schiappa Coal Co., Inc.	1	3

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
151.	Sidwell Bros., Inc.	1	6
152.	Star Mining Co., Inc.	1	3
153.	Stewart & Zinn Coal Co.	1	Unknown
154.	Wilmot Mining Co.	1	3
	OKLAHOMA		
155.	Carbonex Coal Co.	1	4
156.	Cherokee Coal Co.	2	Unknown
157.	Durango Coal and Leasing Co., Inc.	1	2
158.	Fuel Dynamics, Inc.	1	4
159.	Great National Corp.	1	Unknown
160.	Lone Star Steel Co.	1	Unknown
161.	520 South Post Oak Road	1	Unknown
	PENNSYLVANIA		
162.	Alleghany Coal Services, Inc.	1	Unknown
163.	Aloe Coal Co.	1	5
164.	Alumbaugh Coal Corp.	1	4
165.	Arcadia Co., Inc.	1	6
166.	B&G Construction Co., Inc.	1	1
167.	R.D. Baughman Coal Co., Inc.	3	9
168.	Bentley Coal Co., Inc.	3	Unknown
169.	Blackfox Mining & Development Corp.	1	Unknown
170.	Bradford Coal Co., Inc.	1	Unknown
171.	Earl M. Brown Co.	1	7
172.	Bull Run Coal Co.	1	7
173.	The Cardinal Mining Co.	2	6
174.	Carpentertown Coal & Coke Co.	1	1
175.	Chernicky Coal Co., Inc.	1	17
176.	Clarion Fossil Fuels Corp.	1	3
177.	Clearfield Limestone Corp.	1	2
178.	Clifton Mining Co.	2	5
179.	Coal Junction Coal Co.	1	3
180.	Coal Utilities Corp.	1	2
181.	Daset Mining Corp. & Affiliated Companies	2	7
182.	Diamond T Coal Co.	1	1
183.	Doan Coal Co.	3	3
184.	Doverspike Bros. Coal Co.	1	13

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
185.	Dunkard Creek Coal, Inc.	1	1
186.	East Ridge Mining, Inc.	1	1
187.	Adam Eidemiller, Inc.	2	13
188.	Emerald Energy Enterprises	1	2
189.	Empire Coal Co., Inc.	1	Unknown
190.	M.F. Fetterof Coal Co., Inc.	1	17
191.	Fran-Ru Enterprises, Inc.	1	6
192.	Glacial Minerals, Inc.	1	8
193.	Hamlin Coal Co., Inc.	1	3
194.	Heshbon Coal Co., Inc.	1	1
195.	Johnstown Coal & Coke Co.	1	2
196.	Kerry Coal Co.	1	4
197.	L&E Construction and Equipment Co.	1	3
198.	Lechene Coal Co., Inc.	1	3
199.	Markle Bullers Coal Co.	4	Unknown
200.	Mears Coal Co.	1	2
201.	Metro Mining & Minerals, Inc.	1	3
202.	Metropolitan International Inc., Mining Operations	1	7
203.	Midway Coal Co., Div. of Aloe Coal Co.	1	6
204.	Clyde Miles Coal Co.	1	4
205.	Moshannon Falls Mining Co., Inc.	1	Unknown
206.	Old Home Manor	1	Unknown
207.	Penn Pocahontas Coal Co.	1	5
208.	Pennsylvania Energy Corp.	1	3
209.	Pennweir Construction Co.	1	Unknown
210.	Perry Bros. Coal Co.	2	2
211.	R.E.M. Coal Co., Inc.	2	Unknown
212.	Reddinger Coal Co., Inc.	1	5
213.	River Hill Coal Co., Inc.	1	1
214.	S.B.P. Coal Co.	1	2
215.	S&D Trucking Co.	1	10
216.	Sanner Bros. Coal Co.	1	7
217.	C.H. Snyder Co.	1	2
218.	James Stott Coal Co., Inc.	1	10
219.	Svonavec, Inc.	1	1
220.	Swistock & George	1	1
221.	Swistock, Inc.	1	2
222.	Tamburlin Bros. Coal Co., Inc.	1	3
223.	John Teeter Coal Co.	1	2
224.	Tremont Mining Co.	1	1
225.	Twilight Industries, Inc., a Div. of U.S. Natural Resources, Inc.	2	11

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
226.	Valley Coal Co., Inc.	1	2
227.	Vargo Coal Co., Inc.	1	2
228.	W.W. Coal Co.	1	1
229.	West Freedom Mining Corp.	3	4
230.	Western Hickory Coal Co., Inc.	1	2
231.	West Lebanon Coal, Inc.	1	1
232.	Willowbrook Mining Co.	1	1
	TENNESSEE		
233.	Big Ridge Coal Co., Inc.	1	2
234.	McCall Enterprises, Inc.	1	3
235.	S.A.M. Coal Co.	1	6
236.	Sequatchie Valley Coal Corp.	1	6
237.	Southern Energy Resources Co.	1	2
238.	James Spur Coal Co., Inc.	1	7
239.	Standard Marlow Coal Co.	1	4
240.	Walden Ridge Coal Co.	1	2
	VIRGINIA		
241.	Advanced Fuel Co.	1	2
242.	B&C Elkhorn Coal Co., Inc.	1	2
243.	Big M Corp.	1	3
244.	Black Watch Coal Co.	1	2
245.	Blackwood Fuel Co., Inc.	1	Unknown
246.	Clintwood Mining Co.	1	Unknown
247.	General Energy Corp.	1	3
248.	General Minerals Corp.	1	3
249.	Norton Coal Co.	1	Unknown
250.	Westmoreland Coal Co.	1	Unknown
	WASHINGTON		
251.	Washington Irrigation and Development Co.	1	3
	WEST VIRGINIA		
252.	Amherst Coal Co.	1	5
253.	Beasley Energy, Inc., Beasley Mineral Surveys	1	4

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
254.	Bedcor, Inc.	1	3
255.	Belva Coal Co., Inc.	1	2
256.	Buffalo Mining Co.	1	Unknown
257.	SS "Joe" Burford, Inc.	1	5
258.	Carbon Fuel Co.	1	5
259.	Cedar Coal Co.	6	8
260.	Cheyenne Sales Co.	4	6
261.	Consolidation Coal Co., Southern Appalachian Region	4	Unknown
262.	D&C Mining Co., Inc.	2	4
263.	DLM Coal Corp.	1	5
264.	Davis Trucking Co.	1	4
265.	E&J Coal Corp.	1	2
266.	Eagle Coal Dock Co.	1	3
267.	Energy Development Corp.	1	3
268.	Energy Producers, Inc.	1	6
269.	Fresa Construction Co.	1	2
270.	The Galloway Co., Inc.	1	4
271.	Garbart Construction Co.	1	Unknown
272.	Gilbert Imported Hardwoods, Inc.	1	4
273.	Grafton Coal Co.	7	21
274.	Hawley Coal Mining Corp.	2	Unknown
275.	Hobet Mining and Construction	1	3
276.	Imperial Colliery Co.	1	2
277.	Island Creek Coal Co.	3	Unknown
278.	King Knob Coal Co.	3	22
279.	Kitchekan Fuel Corp.	1	Unknown
280.	Larosa Fuel Co., Inc.	1	7
281.	Lechie Smokeless Coal Co.	1	Unknown
282.	Maidsville Coal Co.	1	6
283.	Masteller Coal Co.	2	2
284.	Mining Development Enterprises	1	3
285.	New Era Resources, Inc.	1	2
286.	Peter White Coal Mining Corp.	2	Unknown
287.	Petitto Brothers, Inc.	3	4
288.	Pine Tree Corp.	1	2
289.	Princess Susan Coal Co.	2	10
290.	Raleigh Commercial Development Corp.	1	6
291.	Red Jacket Coal Co., Inc.	1	2
292.	Sharples Coal Corporation	1	Unknown
293.	Stallion Mining Corp.	1	1
294.	Stininger Mining Co., Inc.	1	3
295.	Thompson Coal and Construction, Inc.	1	2

LIST OF MINES USING FELs (Cont'd.)

Mine No.	Mining Company	No. of Strip Pits w/Fels	No. of Fels
296.	Valley Camp Coal Co.	1	Unknown
297.	W-P Coal Co.	1	Unknown
298.	Wes-Pac Energy	1	Unknown
299.	Westmoreland Coal Co.	3	5
300.	R.N. White Contracting Co.	1	1
	WYOMING		
301.	Amax Coal Co.	2	12
302.	Arch Minerals Corp.	3	Unknown
303.	Bridge Coal Company	1	2
304.	The Carter Mining Co.	1	2
305.	Energy Development Co.	1	3
306.	FMC Corp.	1	1
307.	Glenrock Coal Co.	1	2
308.	Kemmerer Coal Co.	1	5
309.	Kerr-McGee Coal Corp.	2	2
310.	Resource Exploration & Mining Inc.	1	4
311.	Thunderbasin Coal Co.	1	1
312.	Wyodak Resources Development Corp.	1	2

APPENDIX E

GLOSSARY

GLOSSARY*

1. Algorithm - A set of well defined rules for the solution of a problem in a finite number of steps.

2. ASCII - American Standard Code for Information Interchange.

3. Backplane - A type of motherboard utilizing shielding to protect against EMI.

4. Bargraph - A diagram of frequency: table data in which a rectangle with height proportional to the frequency is located at each value of a variable that takes on only certain discrete values.

5. BITE - Built-In Test Equipment: electronic device to monitor equipment functions using permanent sensing devices and powered by host equipment's power supplies.

6. Bubble Memory - Type of random access memory using circulating magnetic domains for bit storage.

7. Bus - One or more conductors in a computer along which information is transmitted from any of several sources to any of several destinations.

8. EAROM - Electrically alterable read-only memory: data storage can be made non-volatile by programming with in-circuit electrical signals. Reprogramming is also accomplished in-circuit electrically.

9. EMI - Electromagnetic interference: interference, generally at radio frequencies, that is generated inside systems as contrasted to radio-frequency interference coming from sources outside a system.

GLOSSARY* (Cont'd.)

10. EPROM - Electrically programmable read-only memory: data storage can be made non-volatile by electrically programming the I.C. while in the BITE unit. For reprogramming, card must be removed and erased using ultraviolet light.

11. FEL - Front-end loader.

12. GPIB - General Purpose Interface Bus; also known as IEEE 488.

13. Hardwired Logic - Digital circuits performing logical operations.

14. Histogram - A graphical representation of a distribution function by means of rectangles whose widths represent intervals into which the range of observed values is divided and whose heights represent the number of observations occurring in each interval.

15. I.C. - Integrated circuit: an interconnected array of active and passive elements integrated with or deposited on a single semiconductor substrate by a continuous series of compatible processes and capable of performing at least one complete electronic circuit function.

16. IEEE - Institute of Electrical and Electronic Engineers.

17. LED - Light Emitting Diode: A semiconductor diode, generally made from gallium arsenide, that can serve as a light source when voltage is applied continuously or in pulses.

18. Load and Carry Mode - Method of front-end loader operation where the loader fills its bucket with material and transports the material to some deposition site.

GLOSSARY* (Cont'd.)

19.	Loading Mode	- Method of front-end loader operation where loader fills its bucket with material and dumps it directly into some type of conveyance device.
20.	LSI	- Large Scale Integrated circuit: a very complex integrated circuit, which may contain a thousand or more individual devices, such as basic logic gates or transistors, placed on a single semiconductor chip.
21.	Microprocessor	- Integrated circuit combining the functions normally associated with a full computer in a single package approximately 1" by 2".
22.	Motherboard	- Printed circuit board containing a bus and several connectors to which all other modules are attached.
23.	MTBF	- Mean Time Between Failure: a measure of reliability of a piece of equipment, giving the average time interval between failures.
24.	RAM	- Random Access Memory: a data storage device having the property that the time required to access (read or write) a randomly selected datum does not depend on the time of the last access or the location of the most recently addressed datum.
25.	ROM	- Read-Only Memory: a medium for storing data in permanent, or nonerasable, form; usually a high speed, static and nonvolatile storage mechanism.
26.	RTC	- Real-Time Clock: a pulse generator which operates at precise time intervals to determine time between events and initiate specific elements of processing.

GLOSSARY* (Cont'd.)

27. **Semiconductor** - A solid crystalline material whose electrical conductivity is intermediate between that of a metal and an insulator and is usually strongly temperature dependant.

28. **STAM** - Statistical Analog Monitor: a device to unobtrusively measure operating parameters of hydraulic systems in the field by reducing analog information to a set of statistics describing reference level crossings in relation to time duration.

29. **Thermistor** - A resistive circuit component, having a high negative temperature coefficient of resistance, so that its resistance decreases as the temperature increases.

30. **Transducer** - Any device or element which converts an input signal into an output signal of a different form.

*Adapted from McGraw-Hill Dictionary of Scientific and Technical Terms, New York, N.Y.: McGraw-Hill, 1974.

APPENDIX F

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