SYSTEMS ANALYSIS FOR ROBOTIC MINING

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Dedication

This thesis is dedicated to my parents Antonio and Anna Maria Mottola.

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Abstract

Mining automation has incrementally progressed from line-of-sight remote operation to teleoperation and automatic control of mobile machines, mainly due to significant advances in underground communication systems. The present trend points towards a robotic mining environment where mobile machinery and stationary equipment will be fully integrated with a mine-wide information system overseeing all aspects of mining via a communication network. The successful design and implementation of the software and hardware components necessary to realize this vision depends on the level of seamless integration achieved. The complexity involved in terms of systems functionality and coherence necessitates systems analysis and computer-aided software engineering tools to actively support this integration effort.

Hence, the primary objective of this thesis is to introduce and relate systems analysis concepts and tools to the business of mining. This investigation begins by setting the industrial context of this work with respect to past initiatives and future trends. It discusses different approaches to the design and implementation of mining information systems. It reviews the fundamentals of software and information engineering as well as structured and object-oriented analysis and design. It presents a survey of computerized tools for systems analysis. It then applies systems analysis concepts and tools to a high-level top-down analysis of a Mine Information System and examines a specific mining process in detail. Finally, it compares the applicability of structured versus object-oriented analysis and design methodologies to the complex problem of mining.

Résumé

L'automatisation minière en souterrain a connu une progression depuis l'opération à distance jusqu'au contrôle automatique d'équipements lourds grâce surtout à d'importants développements en matière de communication sous terre. Présentement, on se dirige vers un environnement minier robotique dans lequel l'équipement mobile et fixe à travers la mine serait relié à un système d'information par l'intermédiaire d'un réseau de communication. La conception et réalisation des éléments matériels et logiciels nécessaires au développement de cet environnement dépendent largement du niveau d'intégration atteint lors de la planification de ces systèmes. C'est pourquoi une analyse approfondie avec l'aide d'outils informatisés est primordiale afin d'étudier la complexité des systèmes requis.

L'objectif principal de cette thèse est donc d'introduire les concepts de l'analyse des systèmes et d'établir un rapport entre ceux-ci et le domaine minier. Le contexte industriel de ce document est d'abord situé par rapport aux initiatives passées ainsi qu'aux tendences futures. Différents points de vue sont discutés au sujet de la conception et de la réalisation de systèmes informatisés pour le domaine minier. La théorie fondamentale du génie logiciel et informatique est présentée ainsi qu'un sondage d'outils d'analyse assistée par ordinateur. Ces théories et ces outils sont par la suite appliqués afin de présenter une analyse haut-niveau d'un système d'information minier. Finalement, l'application de techniques structurées et orientées-objet au problème complexe minier est examinée.

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List of Abbreviations

ADFD	Action Data Flow Diagram
AGV	Automatic Guided Vehicle
BMP	BitMaP
CAE	Computer-Aided Engineering
CAD	Computer-Aided Design
CASE	Computer-Aided Software Engineering
C-CASE	Component CASE
CFD	Control Flow Diagram
CIM	Computer Integrated Manufacturing
CNC	Computer-Numerically-Controlled (Machine)
CRC	Class, Responsability, Collaboration
CRUD	Create-Read-Update-Delete
CSF	Critical Success Factor
Cspec	Control Specification
DBMS	DataBase Management System
DDE	Dynamic Data Exchange
DDL	Data Definition Language
DFD	Data Flow Diagram
DOS	Disk Operating System
DPS	Data-Processing System
DSS	Decision Support System
EPS	Encapsulated PostScript
ERD	Entity-Relationship Diagram
FOREMAN	Future ORE MANufacturing
FMS	Flexible Manufacturing System
GPS	Global Positioning System
GUI	Graphical User Interface

HOOD	Hierarchical Object-Oriented Design
HPGL	Hewlett Packard Graphics Library
I-CASE	Integrated CASE
IE	Information Engineering
IR	InfraRed
IS	Information System
ISP	Information Strategy Planning
IT	Information Technology
ITH	In-The-Hole (Drill)
LAN	Local Area Network
LHD	Load-Haul-Dump (Vehicle)
MIS	Management Information System
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
NETBIOS	Network Basic Input Output System
OLE	Object Linking & Embedding
OMT	Object Modeling Technique
OOA/D	Object-Oriented Analysis and Design
OODLE	Object-Oriented Design LanguagE
OOIE	Object-Oriented Information Engineering
OOPL	Object-Oriented Programming Language
OOSE	Object-Oriented Software Engineering
PAT	Process Activation Table
PLC	Programmable Logic Controller
Pspec	Process Specification
RAM	Random Access Memory
RFID	Radio Frequency IDentification
RD	Recursive Design
RDD	Responsability-Driven Design
SA/D	Structured Analysis and Design

SCADA	Supervisoy Control and Data Acquisition
SDLC	Software Development Life Cycle
SE	Software Engineering
SSADM	Structured Systems Analysis and Design Methodology
STD	State Transition Diagram
STT	State Transition Table
TCP/IP	Transmission Control Protocol/Internet Protocol
TPS	Transaction-Processing System
WPG	Word Perfect Graphics

1 Introduction

The Canadian mining industry is faced with the challenge of streamlining its core processes to remain competitive in a global economy whose balance has been disrupted by dramatic political changes in the former Eastern block, new economic alliances in North America (NAFTA), and open mining legislations in Central and South America. Competition is rising from the Commonwealth of Independent States as well as from Latin American countries, such as Chile, Mexico and Peru, where mineral resources are rich and often under-exploited, labor is relatively inexpensive, and regulations are less stringent [Ashcroft93] [Valenzuela93]. In fact, interesting mining opportunities, particularly in Latin America, have attracted Canadian investment overseas, threatening the future of our industry at home and inspiring initiatives such as "Keep Mining in Canada" [ROB95] [Wykes95]. In addition, over-supply combined with declining world commodity prices have decreased the profit margin of Canadian mineral and metal producers, which are no longer in a position to reduce operating costs by more traditional methods such as downsizing and improving productivity by means of mechanization and bulk mining. In most cases, the workforce has been reduced to a minimum, often overworked, and mechanization and bulk methods have reached an impasse due to the physical limitations of both the equipment and the environment in which it operates [Baiden93a] [Scoble94].

In this context, many mining companies have recognized the need for automation as a step forward in assuring the survival and competitiveness of the industry. Automation offers the possibility to increase the profit margin once more, by increasing efficiency and lowering operating costs. It is the next logical step following mechanization. However, the successful design and implementation of adequate automation applications to the mining environment can only be achieved through a systematic analysis of the overall problem and careful planning. Hence, the solution lies in fully understanding the current mining processes in order to confidently assess the present situation, isolate bottlenecks, and identify the most critical areas needing improvement and re-engineering. Concurrently, a thorough investigation of the interfaces between processes is also necessary when automating conventional mining equipment. These initial steps are essential to the consistent and integrated development of *robotic mining systems*, both in terms of software and hardware. *Systems analysis* and computer-aided software engineering tools offer the capability to analyze present and future systems, in their most abstract form (i.e. processes, inputs, and outputs) down to the specifics of their implementation. Other industries have successfully utilized these tools to assist in the development of numerous and varied applications. The mining industry is now in a position to integrate these proven techniques within its efforts to develop robotic mining.

1.1 Objectives

The primary objective of this thesis is to introduce and relate systems analysis concepts and tools to the business of mining in a robotic environment. An effort is made to address both underground and surface mining issues throughout the thesis to demonstrate the widespread applicability of this study.

1.2 Contributions

Significant contributions made by this thesis include:

i) a discussion approach to the design and implementation of mining information systems as presented through a series of case studies (Chapter 2);

ii) a concise review of the fundamentals of software and information engineering as well as structured and object-oriented analysis and design (Chapter 3);

iii) the relation of these abstract concepts to the business of mining (Chapter 3 and Chapter 5);

iv) a survey of computerized tools for systems analysis (Chapter 4) including a listing of vendors and products (Appendix A);

v) a practical example of the application of systems analysis concepts and tools to a specific mining process (Chapter 5);

vi) an extensive bibliography on the subjects of information systems for mining and systems analysis tools and techniques complete with abstracts when applicable (Bibliography);

vii) a view of mining as a process industry, rather than an "art".

1.3 Methodology

Between May 9 and December 16, 1994, the author was employed by the Automation and Robotics group of Mines Research, INCO Ltd., Ontario Division, under the direction of Dr. Greg Baiden. During this work period, a pilot project was initiated "to prove that a comprehensive systems analysis is essential to the consistent and integrated development of robotic mining [systems], both in terms of software and hardware" [Mottola94a].

1.4 Thesis Structure

This thesis is structured as follows:

i) Chapter 1: introduces the topic;

ii) Chapter 2: focuses on the evolution of information systems in mining;

iii) Chapter 3: discusses the fundamentals of systems analysis concepts and tools;

iv) Chapter 4: addresses computer-aided software engineering (CASE) tools;

v) Chapter 5: presents a system model;

vi) Chapter 6: draws conclusions and outlines recommendations for future work.

Summary sections at the end of each chapter recapitulate and provide a transition to the next chapter. The thesis also includes a Bibliography of references and related literature complete with abstracts where applicable.

2 Mining Information Systems

The present state of mining automation results from past research and development efforts focusing almost exclusively on individual machinery rather than on an overall automation strategy [Baiden93a]. Although essential to the natural progression from mechanization to automation, this machine-centered approach has lead to the introduction of advanced mining equipment which often operates in isolation because it lacks the capability to interact effectively and safely with other equipment and personnel. As progressively more complex systems are being implemented in mining operations, the problem of *integration* is becoming a logistic colossus which can no longer be harnessed with temporary solutions. Hence, the need to gain a more global perspective has become apparent and research efforts are being directed at analyzing the functionality addressed by existing and future equipment as well as the overall information requirements of a modern mine.

The successful integration of automated mining equipment involves three steps: i) data collection, ii) data transfer, and iii) data interpretation. These can be translated into: i) instrumentation, ii) a two-way communication network, and iii) an information system. The first step, data collection through instrumentation, has been extensively researched and implemented over the years on a wide variety of mobile machinery and stationary equipment, both in surface[1] and underground mines[2]. However, the importance of the second and third steps has only partly been recognized by the industry. In the context of underground mining, a high-capacity high-speed communication infrastructure was the topic of a Ph.D. thesis by Dr. Greg Baiden [Baiden93a]. Developed during extensive underground experiments [Baiden92b] [Baiden93c] and with an impressive demonstration at the 96th Annual General Meeting of the CIM in Toronto [Baiden94b],

[1] For example: equipment performance monitoring systems for haul trucks [Gould88] [ME90], shovels [ME90], and drills [Hendricks95].

[2] For example: LHD condition monitoring system [Baiden88] [Knights94b], real-time monitoring of the mining environment [Beus92].

the communication network is now in production use at INCO's Copper Cliff North Mine and Stobie Mine in the Sudbury area [Casteel95b]. In open pit operations, the widespread use of radio telemetry to link the truck fleet and other mobile machinery to a central dispatcher has laid the foundation for a similar mine-wide communication network. Modular Mining's DISPATCH® Real-Time Mine Management System [Zoschke95] and Aquila's Total Mining System™ [Peck95] are two examples of what such communication networks coupled with GPS can offer to surface mining. However, so far, there has been limited comparable research and development efforts in the study of adequate information systems to overlay and complement the communication infrastructure. Recent work undertaken by INCO Ltd. and EDS Canada in this direction has led to a high level design of core and peripheral systems needed to operate and maintain a modern underground mine [EDS93] [Baiden95]. This thesis deals with the information requirements associated with the implementation of robotic mining systems. As such, it addresses the issue of a comprehensive mining information system to meet the objectives of an integrated automation strategy.

This chapter is based on a literature review of information systems in mining. It defines the nature and functionality of information systems, reviews their evolution in the context of the mining industry through a series of case studies, and examines their application to the problem of integrating present and future mining processes, both in a surface and underground environment.

At this stage of the thesis, investigating information systems particularly from the view point of the mining industry is important to the overall objective of this study in that it provides the reader with a deeper understanding of the evolution and present frame of mind in which the industry perceives the role of computer-based information management and, consequently, systems analysis. Furthermore, by reviewing different design approaches to building mining information systems and their results, a number of lessons can be learned about the nature of the problem as well as about the technical and other issues which are of utmost importance to mining corporations.

2.1 The Nature of Information Systems

2.1.1 Definition

The most basic concept of this investigation is that of a system. The primary definition of *system* as given by the Webster's Dictionary is: "a regularly interacting or interdependent group of items forming a unified whole".[3] Hence, a system is composed of a group of units, which in turn can be considered as systems, each of which can be composed of smaller units. Furthermore, it can be argued that the system of interest is also a component of a larger supersystem, comprising other systems that form its environment. This simple analysis has led to the identification of:

i) a system of interest;

ii) its supersystem;

iii) its subsystems;

iv) and the environment with which it interacts.

Such hierarchical decomposition is a common technique utilized in the analysis of systems, regardless of their application domain, whether social, ecological, computational, or other. Returning to the definition, it is specified that the component subsystems form "a unified whole". Hence, there must be an underlying structure to the system which provides the basis for interaction and integration among subsystems. This structure is defined by the hierarchical as well as behavioral relationships that exist between subsystems, such as sequence, interdependence, and triggering [Nordbotten85].

The primary definition of *information* as given by the Webster's Dictionary is: "the communication or reception of knowledge or intelligence".[4] The concepts of knowledge and intelligence both imply that the message communicated has been interpreted and converted into something useful, namely information [Nordbotten85]. Traditionally, this element of communication and interpretation would be attributed to a human recipient,

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3 Webster's Ninth New Collegiate Dictionary, Mirriam-Webster. Springfield, Massachusetts. 1985. p. 1199.

4 Ibid. p. 620.

but, in the context of a modern computer-based *information system* (IS), the conversion of raw data into information is achieved before it is presented to the user, thus providing value-added manipulation of data. However, the first information systems were exclusively data-oriented and their function was to store, retrieve, manipulate, and display data. Application domains included inventory control, banking, payroll, and the like, with a typical example being an airline reservation system. The conversion was then performed by the user and, in light of our modern definition, those systems should be more accurately termed *data-processing systems* (DPS), since the information aspect was external to the system itself.

2.1.2 Functionality

The traditional functionality of an information system comprises the areas of transaction processing, management reporting, and decision support [Whitten89]. Transactions are business events such as purchase orders, customer invoices, sales receipts, and the like. *Transaction-processing systems* (TPS) are computer-based systems which receive, validate, process, store, and produce transactions according to a specified set of instructions. Due to the well defined and repetitive nature of transaction processing, this application was the first to be implemented in computer-based data-processing systems in the early-60s. Management reporting is the natural extension of transaction processing, whereby the data that was captured and stored could be used to produce information of value to managers, and, for this reason, this type of computerized application was termed *management information system* (MIS). The original concept of MIS introduced in the early-60s envisaged a single, large scale, integrated system supporting all levels of management decisions. As companies realized that such a total system could not be developed due to its lack of flexibility and difficulty to evolve, the concept was reduced to a more realistic definition involving subsystems with varying degrees of automation and delivering timely and accurate information. *Decision support systems* (DSS) were then introduced as a third generation of information systems applications specifically tailored to the needs of decision-makers. These systems became especially popular with the advent of personal computers and the possibility for managers to obtain quick customized information at their fingertips. Examples of decision support systems include spreadsheet programs, simulators, and expert systems [Whitten89]. Recently, a new category of decision support systems has emerged from the growing use of networks in corporations. As more and more people are connected on local and wide area networks, workgroup computing allows them to work together on projects easily and seamlessly, by accessing, tracking, updating, and sharing a wealth of information as well as communicating and managing more effectively. Examples of such workgroup applications are Lotus Notes™ and the popular electronic mail, commonly known as e-mail [Norton95].

2.2 Evolution of Mining Information Systems

When discussing the evolution of information systems in mining, a distinction must be made between generic systems, often ported from other industries, and unique applications to the business of mining. Generic systems, including for example payroll, accounting, and maintenance, are common to a number of industries and have been introduced in mining with little or no customization. On the other hand, unique applications, such as mine planning, orebody modeling, and rock mechanics, are specific to this business and have been developed accordingly.

Over the years, a number of vendors have developed mining software to fulfill the need for unique applications. However, their efforts to provide the industry with a set of reliable, flexible, and standard computerized tools have been hindered by the widely varying nature of orebodies and mining operations in conjunction with a relatively small customer base. In other words, the cost of developing a complex all-inclusive mining software package to accommodate for a wide variety of specific requirements is prohibitive given the restricted marketplace. As a result, vendors have been specializing in providing smaller, robust applications targeted to meet the requirements of a particular field. This, in turn, has led to an array of products which do not interface smoothly, if at all, and often store data in proprietary file formats, causing engineering departments at mine sites to become internally disjointed and obstructing the flow of information.

This problem will become apparent as the evolution of mining information systems is discussed through a series of case studies in the following sections. These have been chosen from an important number of cases primarily for being representative of corporate strategies to introduce and implement the computerization of processes related to the business of mining. Each case study presents an interesting view point as well as lessons learned form the experience.

2.2.1 Data-Processing Systems

The history of mining information systems began with the introduction of data-processing systems in the mineral industry in the early-60s to mid-70s. Originally mainframe-based, these systems supported a variety of activities, as reported by Ben Seegmiller [Seegmiller73] in the first edition of the SME Mining Engineering Handbook [Cummins73]. The areas in which computers and data processing systems were utilized in 1970 comprise: surveying, ore reserves, mine planning, production scheduling, equipment selection, materials handling, construction scheduling, drilling and breaking, ventilation, rock mechanics, on-line control, ore dressing, inventory, maintenance, financial analysis, and accounting. Other computer applications used to a lesser extent included geological and geophysical data analysis, statistical and trend analysis, resource and manpower scheduling, production forecasting and control, open pit optimization, drillhole records, power-line design, and metallurgical data analysis. These tasks were accomplished by means of owned, rented, or time shared computers such as the CDC 6600 (Control Data Corporation, 1963) and IBM 360 (International Business Machines, 1964) [Seegmiller73].

2.2.2 Typical Management Cost Control System

The same Handbook [Cummins73] features a case study by William Wraith [Wraith73] in which the implementation of a late-60s computer-based "management cost control system" for an iron ore mining company is described in detail. As the primary purpose of this system was "to help maximize profits by reducing costs and expenses in all areas of the mining company" [Wraith73], it is an example of an early management information system (MIS) customized for the mining industry. The system, based on an IBM 360 Model 25, consisted of five main subsystems:

i) Responsibility Reporting: for monitoring the effectiveness of the four-step cost control cycle, namely plan, report, analyze, and correct;

ii) Performance Reporting: for timely evaluation and control of plant and equipment performance in mine and beneficiation operations;

iii) Supply Inventory Controls: for improved inventory control performance, improved purchasing performance, and reduced clerical effort;

iv) Capital Project Controls: for evaluating and controlling current capital projects, in relation to budgeted costs and completion schedules;

v) Detailed Maintenance Controls: for controlling and scheduling maintenance activities of all types [Wraith73].

Hence, this system was designed to gather, sort, and analyze large volumes of data about the status of capital and operating costs, inventories, maintenance schedules, and production statistics. At the time, such computer-based system signified a dramatic improvement in the availability and transfer of critical data within the corporation, data which, until then, was handled exclusively manually. However, the limited hardware capabilities and data-processing nature of this early MIS precluded the possibility of turning data into information before it was presented to the user in the form of printed summary reports [Thompson79]. In fact, despite numerous advances and upgrades in hardware and software, the countless reports generated by this kind of legacy system still plague mining corporations today.

2.2.3 Newmont Mining Corporation

A specific example of the evolution of MIS within the mining industry was reported by Thomas Van Riper and Jean-Michel Rendu [VanRiper89] in a conference paper describing the historical development and philosophy of information systems at the Newmont Mining Corporation. Much like the iron ore producer of the previous case study, Newmont entered the world of electronic data-processing in 1968 with the installation of an IBM 1130 at its New York headquarters. Initial applications included ore reserve estimation, pit design, and basic financial programs. During the period of 1972-1978, the IBM equipment was replaced by Digital Scientific computers linked to Sperry remote job entry stations at various mine sites. Selected primarily for its speed and engineering capabilities, the new hardware laid the foundation for the "Newmont data network". Further expansion in 1979 established two Data Centers equipped with Burroughs B6800 systems in Tucson, Arizona, and Danbury, Connecticut, to support New York headquarters and field locations. The hardware was then upgraded to B7800 and on-line services for remote mining operations were added. However, the basis for Newmont's 1989 information system was introduced in 1984 with the replacement of remote job entry stations by Burroughs A-Series minicomputers and the installation of LINC, Burroughs' fourth generation programming language, and the Burroughs Network Architecture (BNA) for mainframe to mainframe communication. These systems effectively linked Newmont's central and remote locations and provided the capability to deliver applications for multiple users in a timely fashion. At the time, these applications included:

i) Financial Systems (e.g. accounting, payroll);

ii) Support Systems (e.g. materials management, maintenance, mine and mill operations statistics);

iii) Production Systems (e.g. laboratory, exploration drillhole database, blasthole database);

iv) Geological Systems (e.g. geological data collection, display, and interpretation);

v) Deposit Modeling Systems (e.g. geostatistical models);

vi) Mine Planning Systems (e.g. pit optimization, mine planning);

vii) Mine Operations Systems (e.g. ore control);

viii) Statistical Systems (e.g. quality assurance, experimental design);

ix) Specialized Systems (e.g. geophysical analysis) [VanRiper89].

Newmont's decision in 1979 to select Burroughs as its mainframe vendor shaped and facilitated the evolution of the architecture of its corporate information system over the next ten years. By committing to Burroughs hardware, network architecture, and fourth generation programming language, Newmont considerably narrowed the focus of its IS department to catering the needs of the whole corporation rather than expending efforts in a constant re-evaluation of fast changing computing technologies, a limiting choice that proved to be effective given the time period of 1979-1989.

2.2.4 Corporate Solution for Technical Computing

In a 1989 Mining Magazine article, Simon Houlding and Ed Rychkun [Houlding89] identified four factors as being the cause for the present inadequacy of technical computing in the mining industry. Firstly, the computer technology explosion of the 70s and 80s resulted in an array of non-standard systems, creating a "platform for chaos". Configuration of equipment, operating systems, networks, communications, and software became a monumental task which precluded the implementation of an integrated strategy. The focus was forcefully shifted on the solution of isolated parts rather than on the achievement of an homogeneous whole. Secondly, the inability to deal with this technology explosion also affected the workforce. Mining professionals were struggling to keep up with the fast-paced progression and proliferation of hardware and software systems, often making uninformed decisions at an unqualified level. Thirdly, the focus on individual systems brought about an inherent underestimation of the larger problem, that is an effective computing solution for the entire corporation. Isolated working solutions did not provide for a smooth flow of information between departments. Finally, the life-cycle of a system was an evolutionary process which followed the learning curve of the end users, from training and acceptance, to expansion, to enhancement.

Unawareness of how the solution should have evolved over time reduced the payback of systems which became prematurely obsolete [Houlding89].

Houlding and Rychkun offered a corporate solution for technical computing in the 90s based on the primary elements of data, process, results, and flow. At any level of the corporate hierarchy, data is gathered, then processed, and the results are passed on to another level, therefore allowing only a portion of the data to flow out, the public domain, while retaining the rest, that is the private domain. Their corporate solution highlighted:

i) the effective conversion of data into useful information (results) at each level;

ii) a minimal flow of public information;

iii) the efficient sorting and storing of private data for local access;

iv) and the proper management of the corporate information base for global access.

They promoted the importance of considering management objectives, technical functionality, operational efficiency, and cost effectiveness on the same level, to achieve a truly integrated solution that spans all internal boundaries and provides a transparent flow of information. The issues discussed in this article regarding the integrity, up-keep, and distribution of the information as well as the implementation of a corporate mining information system still remain current and pressing today. However, Houlding and Rychkun presented the mine planning function as "the vital ingredient in the pyramid of inter-disciplinary information that leads towards the corporate solution and its benefits" [Houlding89]. It can be argued that, although the data and information generated from the various geological, surveying, and planning activities are certainly vital to the business, centering an enterprise-wide information system upon a single set of activities can lead to overlooking other important areas which may be prone to bottlenecks, such as equipment maintenance. Instead, the system should incorporate a balanced attention to all primary and secondary processes associated with the business of mining, proportionately to their impact on the bottom line and emphasizing on integration and the transparent flow of information.

In spite of this observation, Houlding and Rychkun's focus on mine planning is not an isolated case of bias towards this significant activity in the process of mining. In fact, an evident trend has surfaced in the industry whereby the need for integrated computerized systems has sprung from the geology and mine planning departments and propagated outwards to all other areas. These departments were forced to be the first to recognize the problem due to their use of a wide variety of computerized tools to assist in performing the complex tasks of surveying, ore reserve estimation, geological modeling, mine design, short-, medium-, and long-range planning and scheduling, to name a few.

2.2.5 Newmont Gold Company

For instance, the evolution of the Newmont Mining Corporation information system described earlier may be a typical example of how mining companies introduced computing technology into the business. Originally located at the head office, mainframes were gradually installed at strategic data centers servicing the whole corporation. However, this configuration severely limited access time and quality for Newmont's remote mine sites, even after the New York headquarters and the Tucson and Danbury data centers were consolidated and relocated in Denver, Colorado, later in 1989 [VanRiper89]. For this reason, the expanding Newmont Gold Company, exploiting the rich Carlin Trend in Nevada, began to investigate new hardware and software solutions to satisfy its growing short-range planning, engineering, and ore control needs, progressively leading to the "integrated production information system" described by Gary Flye [Flye88] and Stephen Winkelmann [Winkelmann90].

Between 1988 and 1989, the Newmont Gold Company undertook a comprehensive evaluation of its computing needs with respect to the responsibilities assumed by the mining engineering department. These were:

i) Short-Range Planning (e.g. annual and monthly production plans);

ii) Engineering Systems (e.g. ore control, production reporting, surveying);

iii) Project Engineering (e.g. waste disposal, stock piles and leach pads design, equipment selection);

iv) and Geotechnical and Hydrological Engineering (e.g. slope stability, dewatering) [Winkelmann90].

As a result, the emphasis was shifted from mainframe applications towards software for mini- and microcomputers because of their speed and graphics capabilities. In particular, Newmont Gold developed its own mine planning and ore control systems in-house to run on Silicon Graphics Iris™ workstations. The mine planning software allowed Newmont's engineers to perform both short- and long-range planning as well as deposit modeling and pit design. The long range plan, prepared in Denver using an inverted cone algorithm with a Lerchs-Grossman optimization subroutine, was broken down on an yearly and monthly basis by the short-range planning department in Carlin. The ore control system comprised automatic tracking of assays with bar codes, electronic collection and transfer of surveying data to the mainframe database via field recorders, geological krieging of polygons, month-end reconciliation of the geological model with the actual mined polygons, and stockpile inventory book-keeping. The installation in 1989 of Modular Mining's truck dispatching system in the Gold Quarry pit brought additional functionality to the ore control system, allowing the mine to monitor more closely the production of ore with respect to material type. Other commercial software utilized by Newmont Gold as part of the mine planning and ore control systems included Surpac™, to review and store surveyed shapes, and AutoCAD™, to enhance and print Iris™-generated mining plans and topographical maps. Smooth transfer of data between the Iris, Surpac™, and AutoCAD™ software systems was under investigation in 1990 [Winklemann90].

2.2.6 Barrick Goldstrike Mines

Unlike its neighbor Newmont Gold, Barrick Goldstrike Mines Inc. never relied on traditional centralized mainframes to perform engineering computing functions, mainly due to its relatively young age. In fact, Toronto-based American Barrick Resources Corporation acquired the Goldstrike mine, located in the Carlin Trend near Elko, Nevada, in 1986. With few preconceived ideas about computing and a strong confidence in its engineering group, Barrick Goldstrike performed all mine engineering functions on-site, including reserve estimation as well as strategic and long-range planning. The company's approach to developing integrated mine planning and production systems was described by Chris Bostwick in a recent conference paper [Bostwick93]. Until 1988, a Micro Vax II was alone responsible for assisting with ore control, surveying, reserve estimation, and assay tracking. American Barrick's aggressive planned development of the Goldstrike property called for more powerful hardware and software, and, in 1989, Sun Microsystems SPARC™ workstations were purchased to service Modular Mining's truck dispatching system. These Unix-based workstations quickly became the computing platform for a number of off-the-shelf commercial packages and in-house software developments that followed. In fact, by June 1993, the engineering department was equipped with 16 such workstations running over an Ethernet™ network. Hence, the company established a powerful distributed computing environment and involved its users, the engineering staff, to proactively commit to a "computer-assisted engineering environment" [Bostwick93]. At the same time, the accounting, purchasing, payroll, warehousing, and mill and mine maintenance functions were also transported to a similar SPARC™-based distributed environment.

While the hardware solution appeared to be clear, Goldstrike's requirements in terms of orebody modeling, mine planning, ore control, and equipment evaluation forced the company to complement commercial software packages with applications developed in-house. Due to the relative strengths and weaknesses of each package, Goldstrike opted to utilize distinct software systems in each of its main engineering areas, namely, orebody modeling, pit planning and scheduling, ore control, surveying, and technical drawing. This decision brought about the obvious problem of data transferability and compatibility between packages, which required extensive development of interface programs to allow for an adequate flow of data. Despite this difficulty, the engineering staff of Goldstrike favored the functional diversity provided by merging carefully chosen off-the-shelf packages with customized software. The resulting computer-aided mine planning and production system described by Bostwick comprised the following areas:

i) Mine Modeling: to model the orebody including gold reserves, cut-off grades, and acid-generating properties of waste (performed using MEDSystem™);

ii) Long-Range Planning: to design pit layouts with respect to a floating-cone economic analysis at various gold prices (performed using Q'Pit™);

iii) Equipment Evaluation: to determine truck fleet requirements based on haulage networks with route profiles and cycle times (performed using a customized utility within Q'Pit™ for generating route profiles, the Komatsu-Dresser ESP program for calculating cycle times, and combining the results in a Lotus spreadsheet);

iv) Short-Range Planning: to coordinate the movement of drilling and loading equipment and sequence the drill-blast-load cycle on a daily basis (performed using a customized utility within Q'Pit™ which produces a spreadsheet of daily shovel capacities);

v) Ore Control: to estimate the grade of blasted rounds and assign the material to the correct destination (performed using MEDSystem™ for krieging, MEDS Interactive Graphics Planner™ for grouping blocks in minable units, and DISPATCH® for routing trucks to the appropriate location);

vi) Truck Dispatch: to control and optimize equipment allocation including drills, shovels, and trucks, as well as for production reporting and equipment performance monitoring (performed using DISPATCH® with customized extensions) [Bostwick93].

The philosophy that Barrick Goldstrike Mines chose to develop its own mine planning and production system was founded on the principles of openness and partnership [Bostwick93]. By considering alternative approaches to performing traditional tasks, the engineering staff opened to new possibilities, utilizing various computerized tools to improve the quality and flow of their work. By establishing a climate of partnership with Modular Mining Systems and the developers of Q'Pit™, Goldstrike benefited from a highly customized and prompt service which resulted in the implementation of product extensions tailored to the needs of the operation. However proactive, this philosophy unfortunately did not yield an overall integrated solution, mainly due to the problem of data transferability and compatibility between numerous and diverse applications. In addition, the tendency to automate manual repetitive tasks still prevailed despite the effort "not to force the application to mimic the methodology previously employed" [Bostwick93]. For instance, the decision to base a new short-range planning system on Q'Pit™ to interactively, yet still manually, develop daily, weekly, and monthly shovel sequences defied the principle of openness cited above. The shovel sequence obtained with such a computer-aided system presents the same short-sightedness inherent to the manual method and caused by the human inability to foresee bottlenecks and critical paths of action in a complex situation and over a longer period of time. In fact, this argument was precisely the driving force behind the development of a short-range production planning software package for the Quebec Cartier Mining Company based on dynamic programming techniques to calculate a daily solution over a three month period comprising a precise drilling and blasting sequence, shovel displacements and utilization, as well as the type and quantity of material to be mined [Lestage93].

2.2.7 Endako Mine

In a similar case at the Endako Mine, an open pit molybdenum operation in British Columbia, Robert Jedrzejczak and Mike McDowell of Placer Dome Inc. recently faced the problem of integrating islands of computerized systems [Jedrzejczak93]. In fact, the main functional areas of the mine were serviced by a variety of DOS- and Unix-based systems which, individually, were fully autonomous, but, collectively, offered no means to exchange information, thus impeding the work flow, the real-time analysis of data, and, ultimately, the decision-making process. The functional areas under consideration were: i) milling operations, ii) warehouse and accounting, iii) maintenance, and iv) mine engineering. In order to smooth the flow of inter- and intra-departmental information, Endako proceeded to initiate a property-wide hardware and software rationalization with the objective to implement a "fully integrated total property management information system" [Jedrzejczak93]. The rationalization resulted in the selection of a common platform, the Sun Microsystems SPARC™ 670 MP server running under Solaris™, Sun's version of the Unix operating system. The Endako information system was founded on three main software packages: PROGRESS, a central database, ULTRAMAIN, a fourth generation applications development environment, and XPONENT, a visual editor. Specific applications designed using ULTRAMAIN and XPONENT to interface with the PROGRESS database included: materials management, purchasing, accounts payable, personnel records, maintenance management, warranty tracking, work requests, inventory, etc. With respect to the mine planning and engineering functions, the existing Unix-based Placer Dome OP39 in-house long- and medium-range planning system and AutoCAD™ for surveying, geotechnical, and short-range planning were also interfaced to the central database. The total property management information system described by Jedrzejczak and McDowell achieved a number of improvements for the Endako mine, namely: single data entry on an operation-wide basis, data access at any level, superior analysis of data, timely information flow, informed decision making, and a proactive approach to the day-to-day operation of the mine [Jedrzejczak93].

The approach taken by Endako to integrate information systems across the whole organization without focusing on a particular business process was certainly conducive to the successful implementation of an enterprise-wide knowledge base spanning functional areas as well as hierarchical levels.

2.2.8 Highland Valley Copper

Other mining companies have taken different approaches to developing mining information systems. Highland Valley Copper's large open pit operation located in Kamloops, British Columbia, opted to focus on the aspect of data acquisition at the source, that is the equipment performing the tasks of drilling, loading, and hauling. By interfacing drill, shovel, and truck performance monitoring systems with existing mine planning and production control systems, the mine enhanced the quality and flow of geological and operational data upon which other processes depended. However, the mine management information system described by Jim Gray et al. [Gray91] showed considerable weaknesses with respect to the automatic transfer and conversion of this data into information and, in fact, some data entry and most of the interpretation were performed manually. Furthermore, the Highland Valley Copper MIS comprised a variety of software systems, including Mintec's MEDSystem™, Cominco's Geological Exploration and Ore Reserve Estimation System (GEORES™), Modular Mining's DISPATCH®, and a number of in-house applications, and thus was plagued with the same data transferability and compatibility problem discussed previously. Although data acquisition is certainly an important aspect of the overall effort of implementing a comprehensive mining information system, this case is another example where an imbalanced approach has lead to less than optimal results.

2.2.9 Mount Isa Mining

In the mid-80s, Mount Isa Mining Ltd. (MIM) [Chadwick92], located in Queensland, Australia, began investigating computer-based mine planning systems to replace its paper plans, data sheets, and various other documents [Hall93]. In 1989, after carefully reviewing commercially available software packages with respect to particular requirements, it was decided that an Integrated Mine Planning System (IMPS) be developed in-house based on the MicroStation™ CAD package and Oracle® database running on a network of Intergraph Unix workstations and DOS PCs. In a first stage, the system quickly grew to accommodate for diamond drill hole data, orebody block model data, and surveying data downloaded from the mainframe database. Generation of three-dimensional surfaces constructed from interpretations of drilling sections and krieging procedures were added in a second stage, providing the basics of a mine planning system, although geological interpretations were still done off-line and transferred into the system. A third stage of the development involved the complete transfer of the existing geology and survey functions from the mainframe into the IMPS, to eliminate the need for interfaces and use of multiple systems. The resulting planning system was perceived to be a success for a number of reasons: i) the engineering and geology staff championed the system; ii) senior management was involved and committed from the beginning of the project; and iii) IMPS was regarded by all as a "technical design and database system, not just a CAD system" [Hall93].

2.2.10 Falconbridge

At the same time as Mount Isa Mining was working on IMPS, Falconbridge Ltd. Sudbury Operations, Ontario, was developing a Computer-Aided Mine Planning (CAMP) system to fill in the inadequacy of commercially available software [Campbell91]. The CAMP system was also based on a CAD platform to minimize total development time, although the selected CAD package, SilverScreen™, by the Schroff Development Corp., offered significantly different features than MicroStation™, including solids modeling capabilities and object-oriented principles. After researching CAD systems used in other industries, Falconbridge deemed these characteristics, coupled with C programming and an internal database, to be essential to the development of a CAMP system which could evolve well into the future. CAMP was implemented on a network of Unix-based Silicon Graphics Iris™ workstations and DOS PCs at the Fraser Mine[5].

Other papers of interest on the use of three dimensional modeling and solids modeling for mining applications are: [Kavouras88] on raster octree encoding for volume representations; [Mill89] on the quadtree technique for graphical display and storage of raster maps; [Houlding91] and [Houlding92] on the vector 3-D component modeling technique; and [Clarke93] on the Quintette 3-D modeling and planning system.

Also noteworthy to the discussion of the evolution of mining information systems are: a series of papers by Betty Gibbs reporting the state-of-the-art in mine planning software [Gibbs90a] [Gibbs90b] [Gibbs91b] [Gibbs92] [Gibbs94a] [Gibbs94b]; [Stokes93] on the current challenge of mining software; [Manaster91] on a mine planning package for the Macintosh® developed in-house at the Cyprus Miami Mining Corporation; [Grady90] on a mine planning and reserve modeling software system developed in-house at the Mesquite mine, Gold Fields Operating Co.; [Grant90] on a borehole information system at INCO Ltd.; and [Singhal89], [Melvin89], and [Kovach89] on mine management information systems.

[5] Interestingly, the evolution of computerized mine planning at Falconbridge Ltd., Kidd Creek Division, took a different path. In 1989 the company signed an agreement with Datamine International to jointly develop a three-dimensional underground mine design system [Taylor91].

2.3 Views on Integrated Mining Information Systems

The previous sections discussed past and present corporate philosophies for implementing information systems in mining. The pattern of evolution extracted from the case studies indicates that the mining industry is slowly recognizing the benefits of more integrated approaches and is now moving toward experimenting in this direction. In this context, the following sections discuss ideas reflecting this trend and collectively expressing what will probably be the next effort in amalgamating information technology and mining. Please note that the author's views on integrated mining information systems is presented in Chapter 5.

2.3.1 Caterpillar Total Information System

From an equipment manufacturer standpoint, Caterpillar's vision of integrated information systems for mining was described by C. Schaidle as comprising four elements:

i) *basic communications*: mobile phones and automatic data transfer;

ii) *machine health*: on-line analysis of machine vital signs;

iii) *planning and operations*: linking computer-based planning to operating machinery via a communications network in order to provide a two-way automatic information flow between planning and operations;

iv) and *control*: automatic control and guidance of mobile equipment [Schaidle94].

These elements are expected to incrementally achieve an integrated *total information system* by utilizing progressively more sophisticated technologies as they become economically feasible. Schaidle clearly expressed Caterpillar's commitment to develop and support *earthmoving in the information age*, while emphasizing the importance of creating a partnership among technologists, producers, distributors, and users of equipment in order to successfully translate this vision into reality [Schaidle?4].

2.3.2 The Digital Mine

Peter Knights and Malcolm Scoble of McGill University described their view of integrated mining information and control systems as a stepping stone toward *digital mining*, that is a type of lean mining empowered by the ability to make rapid decisions, quickly deploy equipment, and selectively extract ore [Knights95] (see also [Scoble95a] and [Scoble95b]). *Lean mining* was defined as aiming to accelerate cash flow over the life of the mine by minimizing throughput time, stockpiles, wastage, and rework. Of particular interest to this investigation is the authors' perspective on the processes and support systems involved in surface mining, of which Figure 2.1 is a representation. Although their paper focused mainly on open pit mining, most of the material discussed in it is equally applicable to underground mining.

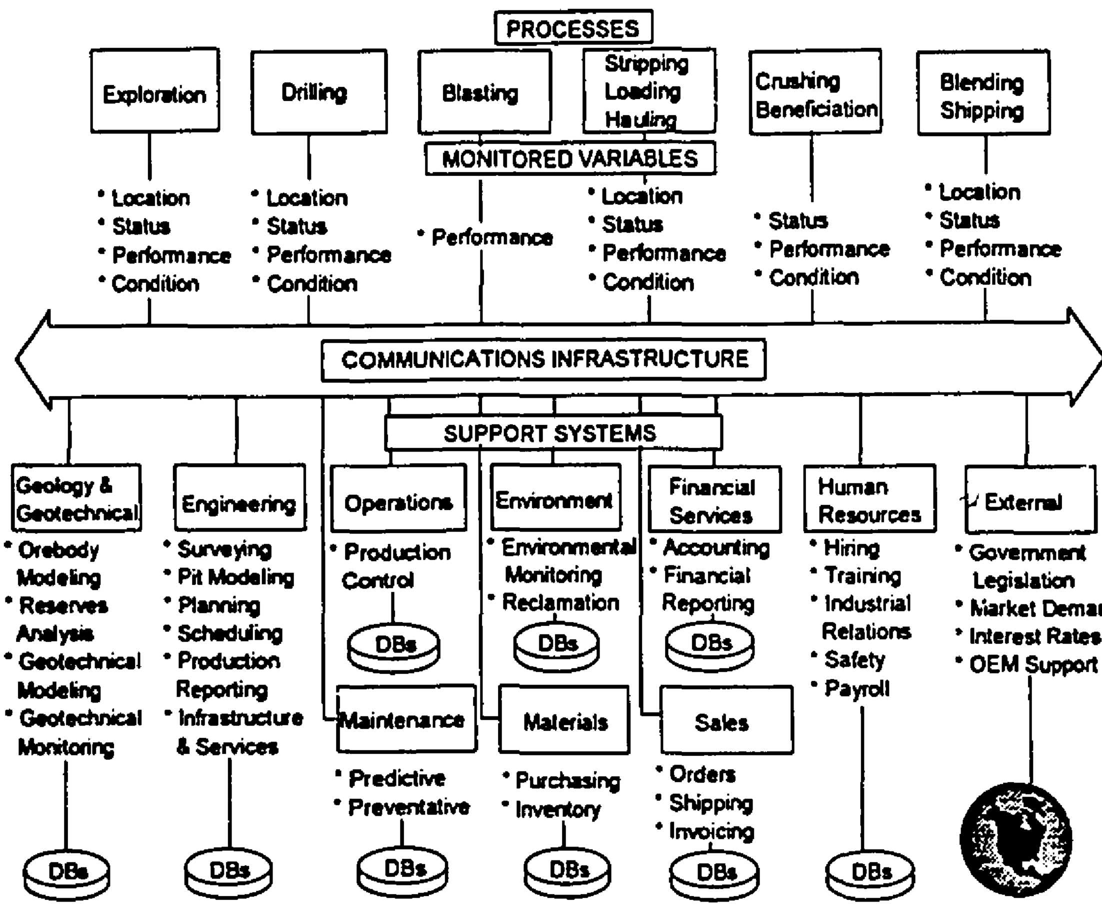

Figure 2.1: Model of Surface Mining Processes and Support Systems, from [Knights95].

Note that, in this figure, the communication infrastructure is the backbone of the overall system linking the mining processes and the support systems across the mine. Also note the presence of distributed databases servicing the support systems, instead of one central repository.

Furthermore, this paper emphasized the need to consider the operation as a whole, rather than merely a sum of its parts, that is to optimize the performance globally, rather than locally. This point concurs with the lessons learned while discussing the evolution of mining information systems and certainly results from a growing awareness within the mining industry of the need for integration to minimize the compounded effects of individual, myopic solutions. Similarly to Schaidle, Knights and Scoble identified four key areas for development towards lean, digital mining, namely:

i) *monitoring, data analysis, and diagnosis*: involving monitoring equipment location, status, performance, and health, as well as sensor fusion, filtering, pattern recognition, and diagnosis;
ii) *communications systems*: needing high-speed high-volume data transfer;
iii) *integrated support systems*: based on data exchange standards, shared database structures, and concurrent engineering;
iv) and *process and machine control*: based on real-time supervisory control and data acquisition (SCADA) [Knights95].

Finally, the authors stressed the importance of information technology planning and industry standards to facilitate the implementation of truly integrated systems across the digital mine.

The underlying inspiration for this paper and the concept of the *digital mine* originated from the manufacturing industry and its efforts to implement *flexible manufacturing systems* (FMSs), that is large, complex systems including computer-numerically-controlled (CNC) machines, robots, and automatic guided vehicles (AGVs). Gene Bylinsky, in an article in Fortune, described FMSs as the "harbingers of lights-out automatic factories operating around the clock [and] almost without workers"

[Bylinsky94]. These systems proved to be inherently vulnerable to failure and were later fragmented into smaller, more manageable cells, giving rise to *soft manufacturing*, a balanced approach to plant automation involving robots, humans, and computer networks interacting in a *digital factory*. As the name suggests, soft manufacturing relies heavily on software and, in manufacturing, software is in fact becoming more important than hardware because it serves as a "unifying communications tool" [Bylinsky94] which integrates, enhances, and capitalizes on the individual abilities of automated systems, computers, and human beings. Knights and Scoble transposed and applied the concept of the digital factory described by Bylinsky to the context of mining and termed it the digital mine. Without engaging in a lengthy discussion on the similarities and differences between the manufacturing and mining industries, it suffices to say that the latter can certainly benefit from the lessons learned by the first provided that the following be kept in mind: the manufacturing environment is entirely man-made and composed of homogeneous materials, its behavior is well understood and easily controllable, whereas the mining environment is mostly natural, heterogeneous, and largely unknown and its behavior is only partially understood and somewhat controllable.

2.3.3 CRA Advanced Mining Systems

Michael Richmond and Gary Lye of Conzinc Rio Tinto Australia (CRA) Pty. Ltd., a subsidiary of Rio Tinto Zinc (RTZ) Ltd., have stated that "the high leverage points in mining operations lie in continuous and automated mining and integrated processes where each process is systematically treated as part of a wider whole" [Richmond94]. As described by Richmond and Lye, CRA's view of integrated mining information systems, collectively termed *advanced mining systems* (AMS), includes the following:

i) mine-wide information and data acquisition systems;
ii) real-time monitoring of material flows and grade control;
iii) continuous and selective mining;
iv) responsive computerized systems for mine planning and equipment maintenance;
v) automated and teleoperated equipment;
vi) and decision support systems [Richmond94].

According to the authors, the key to integrating advanced mining systems consists in a "systematic attention to [the] information flow" [Richmond94] between a sequence of unit processes, as shown in Figure 2.2.

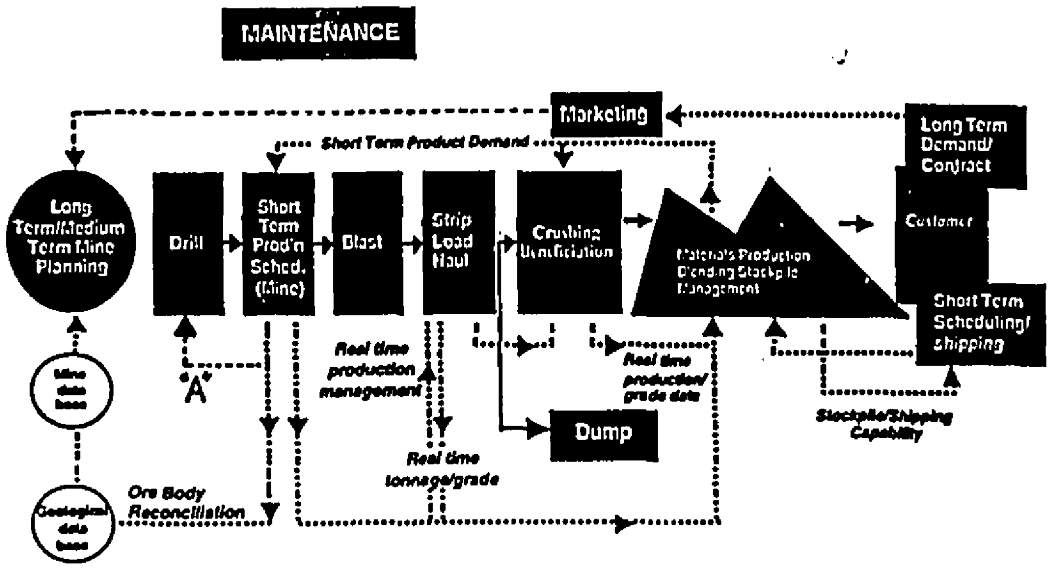

Figure 2.2: Processes and Information Flows, from [Richmond94].

When a maintenance programme is integrated within the structure of this figure, additional information flows are required to link the mine production and scheduled maintenance plans with condition monitoring data. This results in a complex and voluminous flow of information which needs effective management, analysis, and application in order to benefit the overall AMS strategy. However, the authors express little doubt as to the improved flexibility of the integrated information systems, particularly with respect to "the clear superiority in handling variability, be it introduced from either maintenance or production disturbances" [Richmond94].

2.3.4 Modular Mining Real-Time Mine Management System

In the late-70s, Modular Mining Systems Ltd. developed and implemented its first haul truck dispatching system for the mining industry under the name DISPATCH® [White87] [White89] [White92]. Originally designed for optimizing haulage in open pit mines, over the years this product has evolved into a *real-time mine management system* equally applicable to underground operations [Zoschke95]. In addition to optimized truck or LHD assignment between loading and dumping points, the present DISPATCH® system provides the following:

i) a *communications network* across the mine;

ii) *equipment location* given by radio beacons or a satellite global positioning system (GPS) on surface and infrared (IR) transponders or radio frequency identification (RFID) tags underground;

iii) *condition monitoring* of equipment vital signs;

iv) event-driven *simulation* for evaluating "what-if" scenarios;

v) and extensive *reporting and accounting* capabilities for production, maintenance, and inventory purposes (e.g. tires, fuel, lubricants, etc.) [Carter94] [White94a] [Zoschke95].

These features form a solid framework for integrating mining processes other than the load-haul-dump cycle, since other types of equipment, such as drills, may be linked to the communications network and benefit from the capabilities of DISPATCH®. Ideally, all the mobile and stationary equipment should be linked to a similar mine management system in order to provide a total monitoring solution responding to the needs of the entire mine.

2.3.5 Aquila Total Mining System™

Indeed, this approach has been followed by Aquila Mining Systems Ltd., a young, dynamic Canadian company which is developing the basis for "a comprehensive real-time monitoring, control, and information system [for open pit mines] called the Total Mining System™ or TMS™" [Peck95a] [Peck95b] [Aquila]. Jonathan Peck and Jim Gray described the principal elements required to implement the TMS™ concept as including:

i) a bi-directional *communications network* with adequate responsiveness and bandwidth to accommodate current as well as future transmission needs, including voice, video, and data signals;

ii) on-board *machine condition monitoring*, control, and positioning (GPS);

iii) a reactive *production planning and control system*;

iv) a flexible *database management system* (DBMS);

v) and an open-architecture, object-oriented *mine modeling system* [Peck95a].

Figure 2.3 below illustrates the TMS™ design concept.

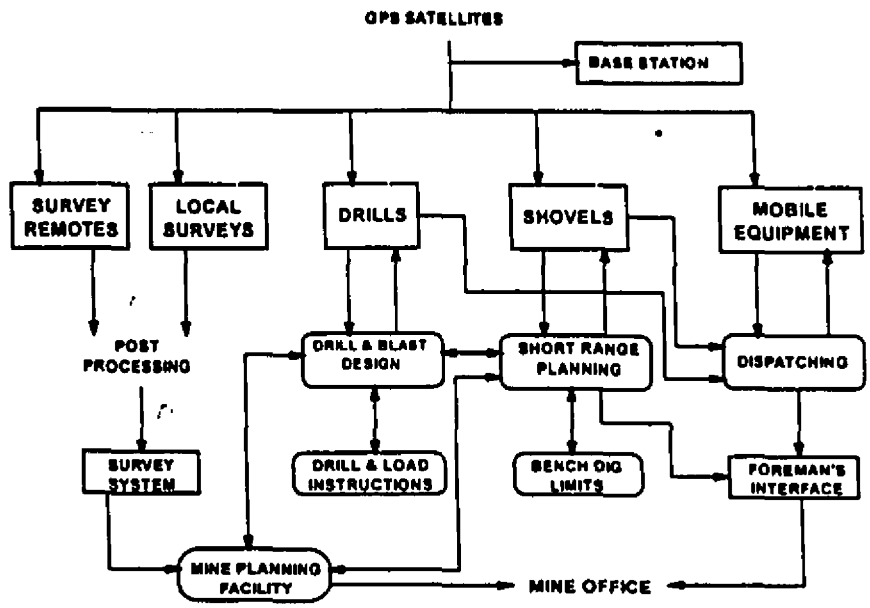

Figure 2.3: TMS™ Design Concept, from [Peck95].

Aquila's TMS™ strategy aims to improve productivity by favoring proactive planning "through a better two-way information flow between each component of the operation" [Peck95a]. As such, this system will provide the basis for integrated mining information systems in open pit mines.

For example, Fording Coal Ltd. recognized the potential of utilizing GPS-based systems in conjunction with equipment performance monitoring to improve the surface mining process and hence maintain a competitive edge in the marketplace. Fording recently installed a GPS-based dispatching system by Modular Mining Systems Ltd. at the Greenhills mine and a GPS-based surveying system with equipment by Ashtech at the Fording River mine[6]. In addition, Fording is actively supporting and participating in Aquila's TMS™ concept of integrated systems [Wusaty95].

[6] Also on GPS, see [AvCan].

2.3.6 INCO FOREMAN Project

The Future Ore Manufacturing (FOREMAN) Project of INCO Ltd. is an exemplary on-going effort on the part of a large Canadian mining company to seamlessly integrate processes and systems across the mine. FOREMAN was initiated in 1989 at the Copper Cliff North Mine with "the goal of developing an information system as the basis for automated systems for underground hardrock mining" [Baiden92b].

The first phase of the project, termed FOREMAN I, was completed in early 1993 and involved the development of a communications network capable of supplying voice, video, and data services underground. A broadband network with a leaky coaxial antenna system was developed to provide the large bandwidth of bi-directional communication required for these services. A considerable portion of the mine was covered by the network allowing phones, programmable logic controllers (PLCs), computers, video cameras, and radios to be connected to the system, thus enabling the teleoperation and, later, automatic guidance of mobile equipment from surface [Baiden92b] [Baiden93a] [Baiden93c] [Baiden94b].

The second phase of the project, termed FOREMAN II, is still on-going and aims to develop a comprehensive information system required to integrate all the processes related to mining across individual operations and the entire corporation. To accomplish this, EDS Canada is undertaking a series of information technology (IT) planning activities[7] for FOREMAN II comprising:

i) a high level requirements analysis [EDS93];

ii) a statement of technical direction (IT policy) [EDS94d];

iii) a technology business case [EDS95a];

iv) an IT architecture [EDS95b];

v) and an IT implementation plan.

Although the detailed findings of these studies cannot be discussed here, Figure 2.4 below illustrates the major systems required by FOREMAN II.

[7] On the importance of IT planning, see [Thomas91], [Connell93], and [Devine94].

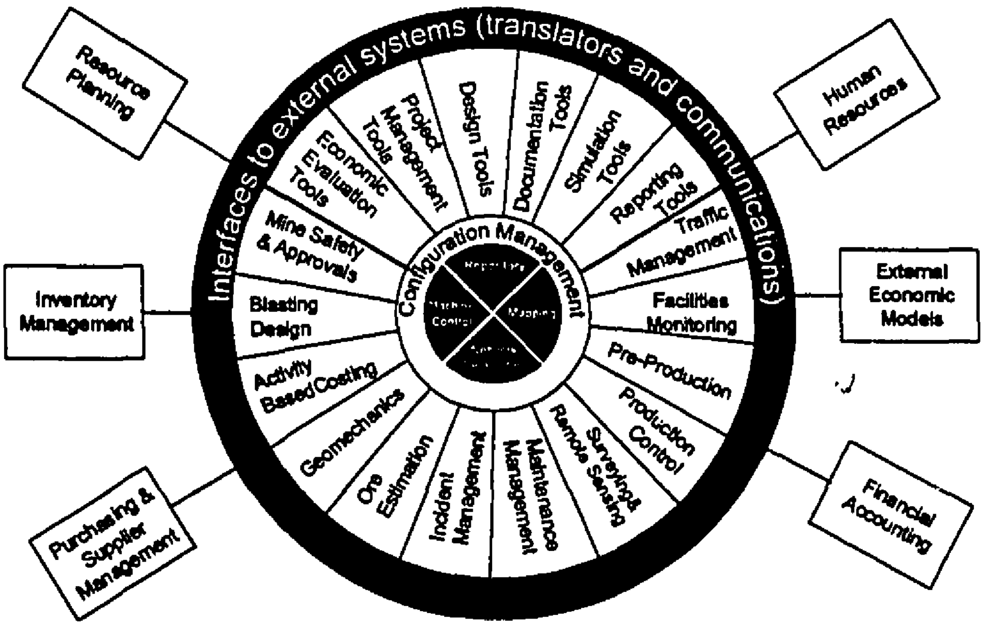

Figure 2.4: FOREMAN II Wheel, from [Baiden95].

In summary, the "FOREMAN wheel" comprises the following:

i) *core systems*: including database management (repository) for storing information, three-dimensional solids modeling for mapping the underground environment (mine workings, geology, etc.), systems operations and network management (SONM) for monitoring the communications network and the strategic systems, machine control for teleoperating and automatically controlling equipment, and configuration management for integrating and coordinating the flow of information between all core and strategic systems;

ii) *strategic systems and tools*: facilitating specific processes related to the design and operation of a robotic mine;

iii) *external systems*: interfacing with the core and strategic systems, but lying beyond the scope of FOREMAN II [EDS93].

Interestingly, a similar configuration to this one was described by Simon Houlding in 1992 as an "onion-skin" structure consisting of "a core of 3D modeling and system functions accessed by a layer of applications modules which are in turn driven by a graphics user interface" [Houlding92]. The striking similarity between the FOREMAN II wheel and Houlding's onion-skin structure serves to prove that this layered, concentric system design, based on solids modeling and a central database, offers a sound and logical framework for building integrated mining information systems.

Finally, the importance of the overall INCO FOREMAN effort must be emphasized as a unique, visionary, and substantial undertaking towards securing the competitiveness of the Canadian mining industry well into the future.

Other views and issues regarding the future of integrated mining information systems are: [Mason90] on information systems for the corporation; [Morrison95] on the importance of supplementing technological efforts with an adequate change in management philosophy; [Scoble94] and [Moss95] on the role of rock mechanics in the future of information systems for production management; and [TEKES94], [Baiden94a], and [Hatch94] on overall mining automation strategies.

2.4 Summary

This chapter has provided a definition of information systems and reviewed their evolution in the context of the mining industry through a series of case studies. The following points summarize the computing philosophies presented:

i) the need to consolidate data into meaningful reports, and, later on, to convert this data into information;

ii) the impact of information systems, no matter how primitive, on cost control;

iii) the efficient management of the corporate information base;

iv) the migration from mainframe to networked systems, be it workstation- or PC-based;

v) the development of in-house software applications to complement commercially available packages;

vi) the focus on individual solutions creating isolated systems;

vii) the problem of data transferability and compatibility;

viii) the tendency to automate existing processes leading to shortsighted approaches;

ix) the emphasis on mine planning and geological modeling;

x) the importance of enterprise-wide standards for hardware, software, and data;

xi) the need for reliable data acquisition systems.

In addition, a number of prominent views were presented to outline the probable future of integrated mining information systems. In summary, these collective visions highlight the importance of:

i) a mine-wide high-speed high-volume *communications network*[8];

ii) *machine monitoring*, including location, and the analysis and diagnosis of performance and condition;

iii) *machine control*, either by means of automation or teleoperation[9];

iv) *process monitoring and control*, based on real-time data acquisition systems;

v) *integrated decision support systems*, to effectively relay information between the engineering and operations areas;

vi) a flexible *repository* to store and manage the information base[10];

vii) event-driven *simulation* for evaluating "what-if" scenarios;

viii) optimizing the performance globally, rather than locally;

ix) industry standards and open systems[11];

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8 Additional sources on communications networks other than the ones presented in this chpater: [Baiden93a], [Hackwood93], [Hackwood94].

9 Additional sources on machine monitoring and control: [Baiden88], [Gould88], [ME90], [Baiden92c], [Knights93], [Knights94b], [Dasys94], [Grenier94], [Hendricks95], [Poole96].

10 Additional sources on database management systems: [Kay94].

11 Additional sources on industry standards and open systems: [Champigny91] [Sas94] [Federchuck95].

x) as well as forming a partnership among equipment manufacturers and mining companies to jointly translate this vision into reality.

Finally, it is important to note that the fundamental difference between the traditional information systems discussed in Section 2.2 and the integrated information systems of Section 2.3 resides in the ability to control cost versus process. Real-time data acquisition and analysis offers the capability to react virtually instantaneously to changing conditions, thereby controlling the impact on the process while it is being affected. Delayed information processing hinders this ability to react in a timely matter, hence resulting in cost control after the fact[12].

[12] See [Bascur93] on bridging the gap between cost control and process control.

3 Fundamentals

The primary definition of *analysis* as given by the Webster's Dictionary is: "the separation of a whole into its components parts; an examination of a complex, its elements and their relations"[13]. Analysis is understood as the iterative breakdown of a problem into subsequently lower-level problems, until manageable, relatively simple problems are defined. This process is fundamental to the concept of *systems analysis* which utilizes decomposition to reduce the apparent complexity of systems and thus facilitate their design and implementation [Topper94]. This definition is also consistent with that of a *system* given in Chapter 2.

Systems analysis employs numerous techniques and tools to achieve its goal. This chapter reviews the fundamentals while attempting to relate them to the business of mining in a robotic environment. It begins with a discussion of the discipline of software engineering (SE) and proceeds to introduce the methodologies of information engineering (IE), structured analysis and design (SA/D), and object-oriented analysis and design (OOA/D). It concludes with a presentation of computer-aided software engineering (CASE) tools to assist in the analysis of systems and provide a background for Chapter 4. Further correlation of the concepts presented in this chapter to the thesis topic can be found in the discussion of the system model presented in Chapter 5.

3.1 Software Engineering

In a robotic mining environment software is an important driving force behind complex systems. For instance, the smooth navigation, coordination, and control of autonomous mobile machinery depends on well planned software components that integrate the individual functionality of each machine within the overall logistics of the mining

[13] Webster's Ninth New Collegiate Dictionary. Mirriam-Webster. Springfield, Massachusetts. 1985. p. 82.

operation. The planning, design, and construction of software systems is regulated by the discipline of software engineering.

Software engineering (SE) encompasses methods, tools, and procedures enabling engineers to structure and control the software development life cycle. Briefly, *SE methods*, or *techniques*, (e.g. IE, SA/D, OOA/D) provide the technical specifications of how to develop software and *SE tools* (e.g. CASE) the automated support for these methods; *SE procedures* enable the timely development of software through quality control and project management. The development of software systems through methods, tools, and procedures is in turn regulated by *SE processes*, or *paradigms*, life cycle models such as the waterfall model and the spiral model [Boehm88], which describe the overall logistics of the development effort and therefore the nature and behavior of the software development life cycle. Figure 3.1 below illustrates the relationship between these software engineering components.

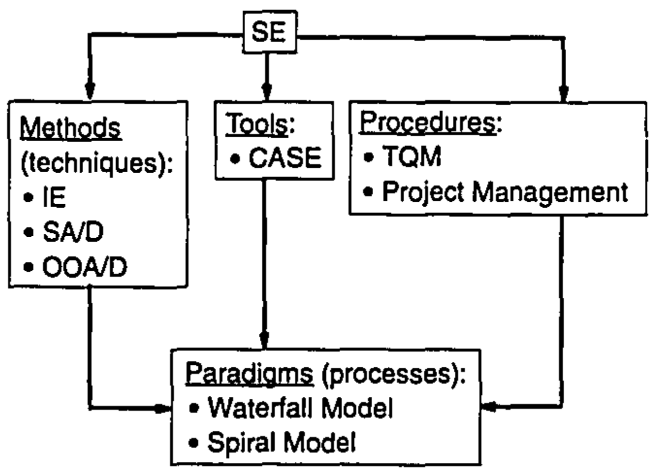

Figure 3.1: Software Engineering Components.

Independently from the process chosen, the *software development life cycle* (SDLC) comprises the following core phases:

i) *Analysis*: involves defining system requirements and functionality, as well as the interactions between major sub-systems and the "outside world";

ii) *Design*: translates the logical model, built during analysis, into a physical model of the system which can be assessed before coding begins; the design phase can be broken down into preliminary (high-level) and detailed (low-level) design, depending on the level of procedural detail, data structure, architecture, and interface characterization specified;

iii) *Construction*: consists of coding the design specifications into a machine-readable language;

iv) *Testing*: ensures that the software performs satisfactorily;

v) *Maintenance*, or *evolution*: manages the changes made to the software once the product is delivered;

vi) *Documentation*: produces a record of the software development process, system requirements, design specifications, etc. [Pressman92].

These life cycle steps are essential to the development and implementation of coherent software systems, regardless of the application to which they are destined. In fact, taken out of the software context, these conceptual steps form the building blocks necessary to design and construct a variety of tools, from mechanical devices to electrical components, or on a higher level of abstraction, even processes such as mine planning or ground support.

As discussed in Chapter 2, the heart of the robotic mining environment resides in an information system which manages and compiles data from a number of sources. Understanding the nature and characteristics of the information to be manipulated is therefore of capital importance to the development of such a system. Software engineering can assist in the analysis of information requirements by means of techniques such as Information Engineering (IE), Structured Analysis and Design (SA/D), and Object-Oriented Analysis and Design (OOA/D). The latter is rapidly gaining in popularity and may very well surpass more traditional methods in the near future. The following sections describe these methodologies.

3.2 Information Engineering

The term *information engineering* (IE) was coined in the early 1970s by James Martin. In his own words, information engineering is defined as "an interlocking set of automated techniques in which models are built up in a comprehensive knowledge base and are used to create and maintain [information] systems" [Martin89]. It is important to note that, while software engineering focuses on one project, information engineering examines the enterprise as a whole.

In fact, IE begins with a top management view of the enterprise by conducting an information strategy plan and progresses downward into greater detail through the analysis of a particular business area, and the design, construction, and, later maintenance of a system which implements selected processes of the business area. Hence, the four stages of information engineering are:

i) *information strategy planning*: concerned with top management goals, critical success factors, and the strategic use of technology to create new opportunities or a competitive advantage;

ii) *business area analysis*: concerned with the processes and data flows necessary to run a selected business area;

iii) *system design*: concerned with the implementation of selected processes in a particular business area;

iv) *construction*: concerned with the coding of the design [Martin89].

It must be noted that the information engineering discipline requires that most of the time be spent on planning, analysis, and design, rather than on execution. This ensures that the systems built as a result of this process accurately meet the business needs which motivated their development. In addition, the design and construction phases are linked by means of prototyping to facilitate the validation by end users. Figure 3.2 illustrates the four stages of information engineering.

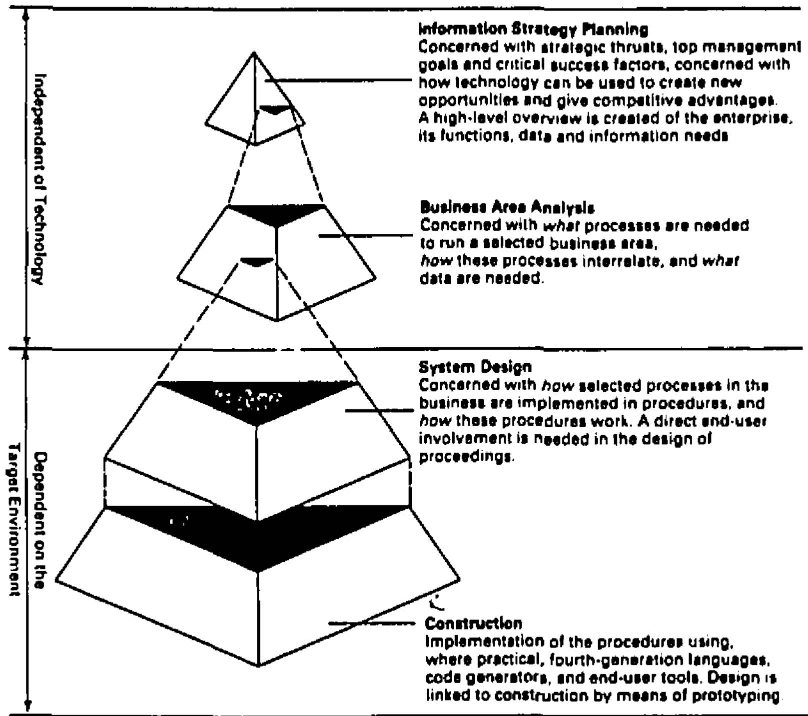

Figure 3.2: Four Stages of Information Engineering, from [Martin89].

The information generated throughout the investigation is collected in an *encyclopedia*, a computerized repository which helps control the accuracy and validity of the knowledge base. It is precisely these characteristics which distinguish the encyclopedia from the data dictionary (discussed later in Section 3.3.4) since the latter does not store the meaning represented in diagrams and thus cannot enforce consistency within the model beyond nomenclature [Martin89].

In the context of mining, IE can assist in gaining a more comprehensive understanding of our business by zooming in on problem areas from a wider perspective. In this respect, IE is analogous to utilizing satellite images or aerial photography to identify potential mineralization. On the other hand, structured and object-oriented techniques are concerned with the detailed analysis and design of specific systems, analogously to exploration drilling, which provides insight on the nature of the mineral deposit, and mine planning, which addresses the subsequent layout and design of the operation.

Since the focus of this thesis is on systems analysis, a more detailed discussion of the first two stages of information engineering follows.

3.2.1 Information Strategy Planning

Information strategy planning (ISP) creates an overview model of the enterprise through a series of activities designed to analyze the goals and information needs of the corporation. These activities are:

i) *organizational decomposition*: compile a computerized organizational chart complete with all business units, respective managers, and geographic locations;

ii) *functional decomposition*: identify the major business functions and decompose into lower-level functions and their processes;

iii) *mapping*: create a number of matrices mapping functions to organizational units, geographical locations, and executive involvement;

iv) *goal-and-problem analysis*: identify both long-term and short-term (tactical) goals as well as associated problems and map these against organizational units;

v) *critical success factor (CSF) analysis*: identify and measure factors which are critical to the success of the enterprise and its business areas;

vi) *technology impact analysis*: compile a list of potential technological changes which may impact the enterprise and relate these to business opportunities and competitive threats;

vii) *strategic systems analysis*: identify the systems which enable the corporation to achieve a direct advantage over its competition;

viii) *entity-relationship analysis*: identify the relationships between entities (items about which data is stored);

ix) *affinity analysis*: establish the degree to which certain entities or processes associate with one another and form groupings of affiliated items [Martin90a].

3.2.2 Business Area Analysis

Business area analysis establishes a detailed framework for building an information-based enterprise by analyzing in detail each business area identified during the information strategy planning. It uses diagrams and matrices to model the data and processes vital to the enterprise and understand the relationships which characterize them. These diagrams and matrices are:

i) *data model diagram*: for a particular business area, expands upon the entities identified during the ISP by adding attributes and normalizing the data (i.e. synthesizing data items into data structures);

ii) *process decomposition diagram*: decomposes the business area functions established during the ISP into a hierarchy of processes;

iii) *process dependency diagram*: maps the dependencies between processes, the predecessors and successors (similarly to a flowchart);

iv) *process-data matrix*: maps the processes against the data, showing which processes create, read, update, or delete (CRUD) which data [Martin90a][14].

As part of the FOREMAN Project discussed in Chapter 2, Section 2.3.6, EDS Canada recently conducted a study on behalf of INCO Ltd. [EDS93] which clearly illustrates the breadth of *information strategy planning* and *business area analysis* as well as their applicability to the business of mining. Through numerous interviews with key personnel, this study documented INCO's business objectives and critical success factors (CSFs) for robotic mining. It then compiled a business model comprising a functional decomposition and description of the processes involved in an underground hardrock mine. The intent of this model was to assist in the re-engineering of underground mining processes with respect to robotic systems. The type of information required and produced by each process was also identified and a "blueprint" of the distribution of both information and systems within the business was drawn [EDS93].

[14] For an example CRUD matrix applied to mining systems, see [TEKES94].

3.3 Structured Analysis and Design

Tom DeMarco popularized the term "structured analysis" in 1979 by introducing the notation and techniques necessary to create information models [DeMarco79]. *Structured analysis* employs modeling tools and process decomposition to build a functional requirements document comprising data flow diagrams (DFDs), entity-relationship diagrams (ERDs), a data dictionary, and process specifications (Pspecs). *Structured design* utilizes functional partitioning and hierarchical decomposition in a top-down fashion to build a system exhibiting *high cohesion* and *low coupling*, that is with a strong functional association within a single module and weak dependence between separate modules. The chief representation of structured design is the structure chart and program logic representation for the individual modules [Topper94].

Variations on the method proposed by Tom DeMarco were later suggested by Meilir Pages-Jones [Pages-Jones80], Chris Gane and Trish Sarson [Gane79], and many others, but did not provide an adequate notation to address the control and behavioral aspects of real-time engineering problems. These deficiencies were addressed by Paul Ward and Steve Mellor [Ward85a] [Ward85b] [Mellor86] and Derek Hatley and Imtiaz Pirbhai in the mid-80s [Hatley87]. A recent variation on structured analysis that is widely used in the United Kingdom and Europe is SSADM or Structured Systems Analysis and Design Methodology described by Cutts [Cutts90] and Hares [Hares90]. A modernized treatment of structured analysis has been published by Yourdon to accommodate for the use of CASE tools [Yourdon89].

Generally speaking, structured analysis techniques comprise the following activities:

i) functional decomposition, or *process modeling*;

ii) data flow analysis, or *data modeling*;

iii) *entity-relationship analysis*;

iv) control flow and state transition analysis, or *behavior modeling*.

These are complemented by a data dictionary, process specifications, and control specifications. The following sections briefly describe these concepts as well as the notation and characteristics of a few methodologies of interest to this investigation.

3.3.1 Data Flow Diagram

A *data flow diagram* (DFD) is a modeling tool which allows to represent a system as a network of functional processes connected to one another by pipelines and data stores. The major components of a DFD are:

i) *processes*: transforming input data flows into output data flows;

ii) *data flows*: representing data in motion between a source and a destination;

iii) *data stores*: modeling a collection of data at rest;

iv) *terminators*: representing external entities with which the system communicates.

A *context diagram* is a data flow diagram in which a single process represents the entire system being modeled. It highlights several important characteristics of the system, such as: the people, organizations, or systems with which the system communicates (terminators); the data received from the "outside world" that must be processed by the system; the data produced by the system which must be sent to the "outside world"; and the data stores shared between the system and the terminators [Yourdon89].

There exists two principal notations for the data flow diagram, that is the Gane and Sarson notation and the DeMarco-Yourdon notation.

a) Gane and Sarson

Chris Gane and Trish Sarson described the DFD notation as follows: processes are represented by rectangles with rounded edges; data flows by arrows; data stores by open-ended rectangles; and terminators (external entities) by double squares [Gane79].

b) DeMarco-Yourdon

Tom DeMarco, and later Edward Yourdon, described the DFD notation as follows: processes are represented by circles (bubbles); data flows by arrows; data stores by a pair of horizontal lines; and terminators (external entities) by rectangles [DeMarco79] [Yourdon89].

3.3.2 Entity-Relationship Diagram

In contrast to the DFD, which for the most part illustrates data in motion, the *entity-relationship diagram* (ERD), created by Peter Chen [Chen76], illustrates data at rest. In fact, the ERD (sometimes referred to in the literature as an "information modeling" tool) offers a more detailed picture of the data stores represented in the DFD and specifies the relationships between data entities independently of the processes performed [Whitten89]. In this respect, the ERD is quite different from the DFD, which models the functional characteristics of the system, as well as from the state transition diagram (STD), which models its behavior. The major components of an ERD are:

i) *entities*: representing real or abstract items about which data is stored (data elements);

ii) *relationships*: describing associations between entities;

iii) *connections*: specifying the cardinality of relationships (zero-to-one, one-to-one, one-to-many, zero-to-many, etc.).

In addition, *hierarchical indicators* connect super-entities to their sub-entities via an unnamed relationship and *associative indicators* link a number of related entities. Entities are represented by rectangles, relationships by diamonds, and connections by lines labeled with special symbols [Yourdon89] [Pressman92]. Complementing the ERD, *data elements*, or *attributes*, characterize entities by providing their detailed components as well as the *keys* which differentiate one instance of an entity from another.

3.3.3 Real-Time Extensions

With a growing proportion of software applications being time-dependent and requiring a quick response to inputs, a distinction must be made between on-line and real-time systems. The response time of on-line systems, no matter how speedy, is driven by non-functional requirements such as the user need for rapid access to information. On the other hand, the very nature of real-time systems require that inputs be gathered and processed sufficiently quickly to affect the environment virtually at that same time. Hence, *real-time systems* perform high-speed data acquisition and control under severe time and reliability constraints. Examples of real-time systems application domains include process control, industrial automation, aerospace, military, and medical and scientific research [Pressman92] [Martin67] [Hinden83].

To accommodate for the analysis of real-time systems, Paul Ward and Stephen Mellor [Ward85a] [Ward85b] [Mellor86] and Derek Hatley and Imtiaz Pirbhai [Hatley87] proposed extensions to the basic notations of structured analysis described above. These *real-time extensions*, described in the following sections, allow the representation of control flow and control processing in addition to data flow and data processing to model the behavior of real-time systems.

<u>a)</u> <u>Ward and Mellor</u>

The Ward and Mellor extension, based on the notation for DFDs proposed by Tom DeMarco [DeMarco79], offers the modeling support for characteristics specific to real-time systems, namely:

i) *continuous data flows*, as opposed to discrete data flows occurring sporadically;

ii) *control flows*, which trigger control processes and other events;

iii) *control processes*, which transform control flows;

iv) *control stores*, where control flows are stored;

v) and *multiple processes*, that is a number of equivalent instances of the same transformation which are sometimes needed in multitasking situations [Pressman92] [Ward85a].

b) Hatley and Pirbhai

The Hatley and Pirbhai extension focuses less on the creation of additional graphical symbols and more on the representation and specification of the control aspects of the system. A similar control flow is provided (dashed arrow), but the controls are modeled separately from the data in a *control flow diagram* (CFD) containing the same processes as the DFD, but showing control flow rather than data flow. In the CFD, notational references (solid bars) link the control flows to a *control specification* (Cspec) which defines how the process is controlled; similarly, *process specifications* (Pspecs) define the inner workings of processes represented in the DFD. *Data conditions* (dotted arrows) from Pspecs assure the connection between the process model (DFDs and Pspecs) and the control model (CFDs and Cspecs), whereas *process activators* contained in the Cspecs link the latter to the first. Figure 3.3 below illustrates how the process and control models relate to one another. Note that data conditions occur whenever an input data flow to a process in the DFD results in an output control flow defined by a control specification in the CFD [Pressman92] [Hatley87].

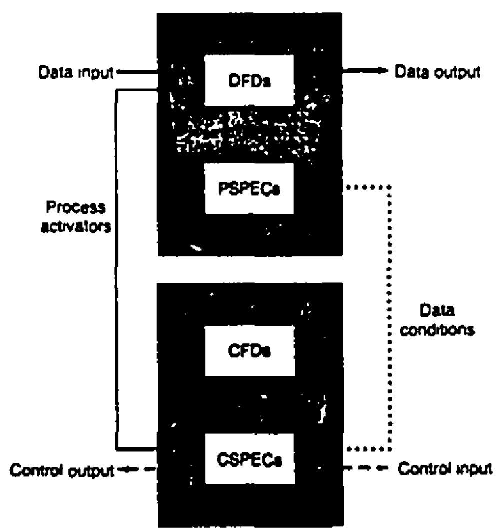

Figure 3.3: Correlation Between the Process Model and the Control Model, from [Pressman92].

The control specification (Cspec) contains diagrammatic and tabular representations of the behavior of the system, namely the state transition diagram and the process activation table. The control signals flowing into and out of the Cspec bars in the CFDs are the primary elements of these modeling tools. The *state transition diagram* (STD) depicts the events (controls) that cause the system to change state and the processes which are activated as a result of these events. A *state* is defined as "a mode or condition of being"[15]. In an STD, states are represented by rectangles and *transitions* between states are drawn as arrows. Each arrow is labeled with an expression of the type [event/action], where an *event* causes the transition between one state and another and an *action* is triggered as a result of the event. *Process activation tables* (PATs) show the circumstances under which the processes in a DFD are enabled and disabled. The actions from the STD are listed in the process activation table along with the processes which they affect. The table is completed with zeros and ones according to whether the action enables (1) or disables (0) the process [Hatley87].

3.3.4 Data Dictionary

The data dictionary, also referred to as the *requirements dictionary*, is a textual supplement to the diagrams (DFDs, ERDs, CFDs, STDs) and tables (PATs) produced as a result of the structured analysis of a system. Edward Yourdon defined the *data dictionary* as being: "an organized listing of all the data elements that are pertinent to the system, with precise, rigorous definitions so that both user and systems analyst will have a common understanding of all inputs, outputs, components of [data] stores, and intermediate calculations" [Yourdon89]. The data dictionary must contain the following information:

i) *names*: of data and control flows, processes, data stores, terminators, etc.;

ii) *descriptions*: of what these names represent;

iii) *types*: of data, such as character or real, continuous or discrete;

iv) *composition*: of packets of data elements in motion (flows) or at rest (stores);

[15] Webster's Ninth New Collegiate Dictionary. Mirriam-Webster. Springfield, Massachusetts. 1985. p. 1151.

v) *values*: of data elements, their range, units, and meanings.

For instance, each entry in the data dictionary describing a process should include a unique name, description, input and output data flows, and process logic. Entries for data flows should include a unique name, description, input and output processes, data elements, values, and so on. The notation used to develop a content description for a data item entry enables the analyst to represent composite data in one of three ways:

i) as a *sequence* of data items (e.g. $item_0 = item_1 + item_2$);

ii) as a *selection* from among a set of data items (e.g. $item_0 = [item_1 \mid item_2 \mid item_3]$);

iii) as a *repetition* of data items (e.g. $item_0 = \{item_1\}$).

Optional data items are denoted by parenthesis (e.g. $item_0 = (item1) + item_2$), key data items are identified by a preceding @ sign (e.g. $item_0 = @item_1 + item_2$), and comments are delimited by asterisks (e.g. *this is a comment*). The data item is expanded until all composite data items have been represented as data elements, that is items that require no further expansion. In this manner, the data dictionary defines entry items unambiguously. For large computer-based systems, such requirements dictionary grows rapidly in size and complexity and quickly becomes difficult to maintain manually. For this reason, the use of computerized tools is recommended (see Section 3.5) [Pressman92] [Yourdon89].

3.3.5 Process Specification

The purpose of a *process specification* (Pspec) is to define the inner workings of each elementary process in a DFD. Also referred to as mini-spec, for miniature specification, the Pspec can be constructed by means of a variety of tools, such as structured English, decision tables, flowcharts, and so on. Narrative English is avoided due to its inherent ambiguity and predicate calculus is seldom utilized due its highly mathematical format. Process specifications are only developed for the bottom-level processes in a hierarchical set of DFDs, since the Pspec for a higher-level process consists in its lower-level DFDs [Yourdon89].

3.3.6 Structure Chart

Once the structured analysis of a system is complete, the resulting data flow diagrams (DFDs), entity-relationship diagrams (ERDs), control flow diagrams (CFDs), state transition diagrams (STDs), data dictionary, process specifications (Pspecs), and control specifications (Cspecs) are used to create an architectural model for the system comprising a hierarchy of modules. The *structure chart* is one common graphical technique for modeling program structure during the design phase. Structure chart *modules* are represented by rectangles (e.g. subroutines or procedures) and module *invocations* by arrows (e.g. subroutine calls) passing either data flows (depicted by a small circle on the tail of the arrow) or control flows (depicted by a small darkened circle on the tail of the arrow) between modules. Structure chart modules are presumed to execute in a top-to-bottom, left-to-right sequence [Whitten89] [Yourdon89].

3.4 Object-Oriented Analysis and Design

Object-oriented concepts originated in the late 1960s with the development of the Simula programming language [Dahl73] and progressively evolved with the work of several researchers while developing object-oriented programming languages (OOPL) such as Smalltalk [Goldberg84] [Lalonde94], Eiffel [Meyer92], Ada [Booch94b], Objective C [Cox91], and C++ [Stroustrup91]. While, at first, object-orientation may appear to be nebulous, its concepts are actually simple and compact in nature. In fact, we live in an object-oriented world, where physical objects display certain characteristics and behaviors, and where similarity is commonly recognized and categorized. This process of classification, in conjunction with object attributes and behavior, forms the basis for object-oriented technology.

An *object* is an entity comprising attributes, a set of predictable behaviors, and which communicates with other objects via messages. A *class* is a grouping of objects that share functionality and information, and each object is a unique *instance* of its class. Operations, or functions, specific to an object or class are called *methods*; these determine the actions triggered by a message and corresponding responses. *Inheritance* is the sharing of object attributes and methods among classes based on a hierarchical relationship: it allows child entities (objects or classes) to reuse data and functions from parent entities. Conversely, *information hiding*, or *encapsulation*, precludes certain methods to be shared among entities, so that individual objects can be internally modified without affecting the behavior of related objects. *Polymorphism* enables a single message to trigger different actions when received by different objects [Rumbaugh91] [Topper94].

Essentially, object-oriented techniques differ from structured techniques in that data and methods are encapsulated locally within an object and not in a central database. The information stored in the objects is accessed and updated exclusively via messages passed between objects [Topper94]. Perhaps even more fundamental to what differentiates these techniques is the fact that object-orientation begins with mapping the real world in objects and classes and then proceed to encapsulate methods, attributes, and data within, whereas structured techniques begin with modeling the processes and associated data flows and then proceed to group them in structures. Hence, object-orientation ensures a direct representation of the problem domain by first characterizing what is commonly recognized, that is the abstract and physical objects making up the real world. As a result, object-oriented software is more adaptable to evolving requirements because it is based on the stable, underlying framework of the problem domain itself, rather than on the changeable, immediate functionality of the system [Rumbaugh91].

Briefly, the goal of *object-oriented analysis* (OOA) is to build an *object model* identifying a correct set of objects complete with attributes, methods (functions), and relationships. *Object-oriented design* (OOD) groups objects into classes, defines massaging protocols, data structures, and procedures [Topper94].

Schools of thought regarding object-oriented analysis and design (OOA/D) include:

i) Grady Booch: [Booch94a];

ii) Sally Shlaer and Stephen Mellor: Object-Oriented Systems Analysis (OOSA) and Recursive Design (RD) for real-time systems [Shlaer88] [Shlaer92];

iii) Rebecca Wirfs-Brock et al.: Responsibility-Driven Design (RDD) [Wirfs-Brock90];

iv) Peter Coad and Edward Yourdon: OOA [Coad91a] and OOD [Coad91b];

v) James Rumbaugh et al.: Object Modeling Technique (OMT) [Rumbaugh91];

vi) Ivar Jacobson et al.: use case-driven Object-Oriented Software Engineering (OOSE) [Jacobson92];

vii) James Martin and James Odell: Object-Oriented Information Engineering (OOIE) [Martin92] [Martin93];

viii) Hierarchical Object-Oriented Design (HOOD) [Burns94];

ix) Bran Selic et al.: Real-Time Object-Oriented Modeling (ROOM) [Selic94];

x) Derek Coleman et al.: Fusion [Coleman94];

xi) Meilir Page-Jones and Steven Weiss: Synthesis [Pages-Jones89];

xii) Ian Graham: SOMA, a semantically rich method for OOA [Graham94];

xiii) Edward Berard: object-oriented domain analysis, requirements analysis, and design [Berard93];

xiv) Donald Firesmith: Object-Oriented Requirements Analysis and Logical Design (OORALD) [Firesmith93];

xv) Brian Henderson-Sellers: object-oriented knowledge [Henderson-Sellers92] [Henderson-Sellers94];

xvi) Wasserman et al.: Object-Oriented Structured Design (OOSD) [Wasserman90];

xvii) Reenskaug et al.: Object-Oriented Role Analysis, Synthesis, and Structuring (OORASS);

xviii) Desfray: class-relationship method [Desfray92];

xix) David Embley et al.: model-driven Object-Oriented Systems Analysis (OSA) [Embley92].

It must be noted that, in the world of object-orientation, techniques developed for design are often useful in analysis, and vice versa. In fact, historically, object-oriented design preceded object-oriented analysis, which is a much more recent innovation [Graham94]. The following sections describe in more detail a number of prominent OOA and OOD methodologies which should be considered when undertaking a comprehensive systems analysis for robotic mining. These methodologies are discussed in a chronological order.

3.4.1 Booch

In 1986, Grady Booch presented what is perhaps the oldest OOD methodology in a paper describing a design approach using some of the features of the Ada programming language in an object-oriented style [Booch86]. From this point of view, Booch's original OOD was based on the principle of information hiding rather than on functional decomposition or inheritance [Graham94]. He then revised his work in 1991 to broaden his perspective and present an OOD methodology independent of any specific language [Booch94a]. It is precisely this revised approach which is discussed here.

According to Booch the four major elements defining object-orientation are abstraction, encapsulation (information hiding), modularity, and hierarchy. The latter includes the principles of classification (and thus inheritance) and composition (or aggregation). *Classification* involves the hierarchical grouping of specialized classes under a common general class, thus forming a generalization-specialization structure (e.g. general class: mobile equipment; specialized classes: LHD, haulage truck, drill, etc.); *composition* involves the aggregation of classes which are part of a more comprehensive class, thus forming a whole-part structure (e.g. whole: LHD; parts: engine, electrical system, hydraulic system, etc.). Central to the concept of object-orientation, and to Booch's perspective, is the object model. As explained before, objects are entities which combine the characteristics of process and data, since they perform functions (methods) and store the results locally. In the object model, emphasis is placed on representing abstract and physical components of the problem domain in terms of self-contained objects with well-defined behaviors. Hence, the Booch object model comprises two dimensions and four views, namely, the logical-physical and the dynamic-static pairs of models. Both dimensions are necessary to model the structure and behavior of an object-oriented system. Furthermore, each model is specified in terms of diagrams as follows:

i) *logical model*: class diagrams and object diagrams;

ii) *physical model*: module diagrams and process diagrams;

iii) *dynamic model*: state transition diagrams;

iv) *static model*: interaction diagrams [Booch94a] [Graham94].

Essentially, the *class* and *object diagrams* describe the logical, static view of a system. Since the physical view may differ from the logical, Booch distinguished class diagrams from *module diagrams*, the latter corresponding to program segments. *Process diagrams* show the communication relationships between physical devices and processes. *State transition diagrams* illustrate the dynamics of classes by modeling the events that cause state changes as well as the resulting actions. *Interaction diagrams* show the timing of methods due to the passing of messages between objects [Booch94a] [Graham94].

3.4.2 Shlaer and Mellor

Sally Shlaer and Stephen Mellor first published their OOA methodology in 1988 [Shlaer88], although their original approach could not be regarded as truly object-oriented because it totally missed the concept of inheritance, which is key to object-orientation [Coad91a]. However, inheritance was later introduced in a second book published in 1992 [Shlaer92]. The overall Shlaer and Mellor Object-Oriented Systems Analysis (OOSA) approach consists of three views:

i) the *information model*: showing objects, attributes, and relationships;

ii) the *state model*: showing the state of objects and transitions between states using state transition diagrams (STDs) and tables (STTs);

iii) the *process model*: showing the processes involved in an enhanced form of the traditional DFD, the action data flow diagram (ADFD) [Shlaer92].

This method was strongly influenced by the notation of Ward and Mellor's structured real-time extensions discussed earlier, and, as such, is widely used in the analysis and design of real-time systems [Graham94]. Shlaer and Mellor also provided a link from OOA to OOD via a language-independent notation known as OODLE (Object-Oriented Design LanguagE) comprising four tools:

i) the *class diagram*: showing the external view of a class;

ii) the *class structure chart*: showing the internal structure of the methods of a class and the flow of data and control (based on the structure chart);

iii) the *dependency diagram*: showing the relationships and invocations between classes;

iv) the *inheritance diagram*: showing the classification (generalization-specialization) of classes [Shlaer92].

As part of this method, Shlaer and Mellor support the principle of *recursive design* (RD) rather than *iterative design*, to integrate analysis models uniformly across a set of design rules (recursive approach), rather than individually converting models to design and subsequently integrating them into software (iterative approach) [Graham94].

3.4.3 Wirfs-Brock et al.

The Responsability-Driven Design (RDD) method described by Rebecca Wirfs-Brock and colleagues [Wirfs-Brock90] was based on the concepts of class, responsibility, and collaboration (CRC). Briefly, each class assumes *responsibilities for knowing* the state of its objects as well as *responsibilities for doing*, that is for performing the methods within its objects. *Collaborations* are requests (messages) between classes and objects to help fulfill a certain responsibility and *contracts* define which requests are supported by which objects [Wirfs-Brock90] [Graham94] [Jacobson92].

RDD is a simplistic method which does not cover all the issues necessary to model complex systems. However, it is a very practical method which is often used during walkthroughs of scenarios as a precursor to other OOA/D techniques, i.e. in the requirements stage [Graham94].

3.4.4 Coad and Yourdon

Peter Coad and Edward Yourdon discussed the object-oriented approach to systems analysis in a book first published in 1990 entitled Object-Oriented Analysis (OOA) [Coad91a]. In their book, the authors address four issues as being key to improving the analysis of computer-based systems: i) problem domain understanding and system responsibility definition. ii) person-to-person communication, iii) continual change, and iv) reuse. The proposed OOA methodology attempts to satisfy these issues as well as incorporate the underlying principles for managing complexity found in the more traditional approaches of functional decomposition, data and control flow representation, and entity-relationship diagramming. According to the authors, the essential elements of object-orientation are objects, classes, inheritance, and communication via messages. These elements exclusively define whether a programming language or method is truly object-oriented. The Coad and Yourdon OOA methodology encompasses these elements by merging selected concepts from the disciplines of structured analysis, object-oriented programming, and knowledge-based systems engineering to provide for the following five non-sequential activities:

i) identifying *subjects*: the problem domain is decomposed into subjects to reduce the complexity and facilitate analysis;

ii) identifying *classes of objects*: classes and their objects are identified by learning about the problem domain; classes of objects can include external systems, devices, roles, operational procedures, sites, and organizational units;

iii) identifying *structures*: two types of structures are identified for characterizing classes of objects, namely classification structures (generalization-specialization) and composition structures (whole-part); classification structures incorporate the concept of inheritance;

iv) defining *attributes*: specific characteristics add detail to the abstraction of structures and classes of objects; attributes and their exclusive services (methods) are treated as an intrinsic whole;

v) defining *services* (methods): each class of objects is equipped with methods for creating and deleting instances, updating and accessing values, and controlling the behavior of objects via messages [Coad91a] [Graham94].

Finally, the authors propose to move from OOA to OOD by progressively expanding the five layer object model with three new components, *human interaction*, *task management*, and *data management*, and transferring the results of OOA into a *problem domain component*. These components allow design-specific issues, such as graphical user interfaces, communication protocols, and database architecture, to be included in the object model. Hence, the OOA layers model the problem domain and the system responsibilities, whereas the OOD component expansions model a particular implementation [Coad91a] [Graham94]. Object-oriented design was the subject of a second book by Peter Coad and Edward Yourdon published later in 1991 [Coad91b].

3.4.5 Rumbaugh et al.

The Object Modeling Technique (OMT) of James Rumbaugh and his colleagues [Rumbaugh91] is widely regarded as one of the most complete OOA methodologies published so far. It is strongly rooted in traditional structured methods and offers a very rich and detailed notation [Graham94]. According to Rumbaugh et al., the principal elements of object-orientation are identity (defining objects), classification (grouping objects into classes), polymorphism, and inheritance. The OMT consists of building a model of the problem domain and then adding implementation details during the design of a system. It comprises the following stages:

i) *analysis*: maps the real world into a model;

ii) *system design*: organizes the objects into subsystems;

iii) *object design*: translates the model into algorithmic structure;

iv) *implementation*: converts the design into code.

The OMT uses three separate models to describe an object-oriented system:

i) the *object model*: is a static view of the objects and their relationships with classes and comprises an *object diagram*;

ii) the *dynamic model*: is a dynamic view of the system consisting of *state diagrams* showing the events and transitions between states;

iii) the *functional model*: describes the processes and associated data flows in *data flow diagrams*.

Each model contains references to the other models and all are used during the four stages described above progressively acquiring implementation detail as development advances from one stage to the next [Rumbaugh91].

3.4.6 Jacobson et al.

In a book published in 1992 [Jacobson92], Ivar Jacobson et al. described a simplified version of a proprietary method for OOA/D referred to as Objectory, for OBJECTive FactORY. Jacobson and his colleagues termed this approach Object-Oriented Software Engineering (OOSE) because it addressed the entire software development life cycle (SDLC), from analysis, to design, construction, testing, and maintenance, in an object-oriented context. This section reviews their software engineering philosophy with respect to the analysis and design phases only.

While OOSE encompasses many common ideas to other software engineering methodologies, it introduces the original concept of use cases. According to Jacobson, in a given problem domain, *actors* (earlier referred to as terminators or external entities) represent whatever interacts with the system and *users* represent the people who actually use the system. Hence, an actor represents a particular role played by a user and, in this context, can be regarded as a class, whereas users are instances of this class. When users enact specific roles, they "perform a behaviorally related sequence of transactions in a dialogue with the system" [Jacobson92]. This sequence is termed a *use case*. As software development progresses through its life cycle, this use case-driven approach directly traces the user requirements and enforces the system architecture to reflect the needs of the customer. Hence, OOSE exploits use cases as a source of quality control. This form of traceability also promotes adaptability to new requirements since system behavior can be altered by remodeling the appropriate use cases [Jacobson92] [Graham94].

The *use case model* developed at the requirements stage includes *interfaces* to the system (e.g. prototype GUIs) and a *domain object model* consisting of objects in the problem domain. These are then mapped into an *analysis model* by characterizing the domain objects into three types, *entity objects*, *interface objects*, and *control objects*, capturing respectively the information, presentation, and behavior of the system, and thus reinforcing its stability by limiting the effects of changes locally. The resulting analysis model is refined into a *design model* comprising *blocks*, that is implementations of one or more objects communicating via *stimuli*. The communication between blocks is represented in *interaction diagrams* expressing global dynamics.

3.4.7 Martin and Odell

In 1992, James Martin, the chief architect of IE, published a book with James Odell on combining object-orientation and information engineering [Martin92]. The resulting Object-Oriented Information Engineering (OOIE) methodology reflects the traditional IE pyramid structure presented in Section 3.2, progressing from enterprise-wide modeling (information strategy planning in IE), to business area analysis, to system design, to construction [Martin89]. However, where data and processes once defined the views of IE, *object structure* and *object behavior* now characterize the analysis and design phases of OOIE. In fact, object structure involves *object structure analysis* (OSA), concerned with object identification and hierarchy, and class structure design, concerned with class identification and hierarchy; object behavior involves *object behavior analysis* (OBA), concerned with object flow diagrams and event diagrams, and method design, concerned with the identification of methods [Martin93].

3.5 Computer-Aided Software Engineering (CASE) Tools

The preceding sections discussed a variety of software engineering methods for undertaking systems analysis and design. These techniques are both semantically rich and graphically elaborate, requiring contextual links between a number of diagrams, tables, specifications, and a dictionary. Furthermore, the complexity and size of modern on-line and real-time information systems continue to grow. Hence, it becomes clear that information engineering and structured or object-oriented analysis and design are best implemented in conjunction with computerized tools, commonly known as *computer-aided software engineering* (CASE) tools.

The software industry has been experimenting with CASE technology since the early 1980s. At first, CASE products were simple diagramming tools without a repository or verification checking of models. Since then, they have evolved into sophisticated tools including requirements collection and tracking, prototyping, code generation, documentation management, and even reverse engineering from existing code [Topper94]. Hence today, CASE tools offer an automatic support to the entire software development life cycle. To draw a parallel with the manufacturing industry, CASE is analogous to *computer-aided engineering* (CAE) and *computer-aided design* (CAD), in terms of analysis and design of software systems, and to *computer integrated manufacturing* (CIM) in terms of construction, testing, and maintenance. Roger Pressman, an internationally recognized consultant and author in software engineering, stated that "CASE has the potential to become the most important technological advance in the history of software development", but that "today, CASE is where CAD/CAE/CIM were in 1975". The usage of individual CASE tools is spreading rapidly across the software development industry and numerous efforts are being undertaken to integrate these tools to form a consistent environment [Pressman92].

In the present context of CASE evolution, there exists a certain fragmentation within commercially available tools. In fact, *upper* or *front-end CASE* refers to tools that support the analysis and preliminary design phases, whereas *lower* or *back-end CASE* refers to those that support detailed design, construction, and testing. CASE tools which support specific tasks within the software development life cycle and that must be used in conjunction with other products are called *component CASE* (C-CASE). On the other hand, *integrated CASE* (I-CASE) tools enforce the seamless integration of all upper and lower components and their deliverables within a common repository. By themselves, front- and back-end CASE tools provide only a portion of the overall functionality delivered by I-CASE, without the benefits of interoperability and a shared repository to manage the complexity of modeling large systems [EDS94b].

3.6 Summary

This chapter reviewed the fundamental concepts necessary to undertake a comprehensive analysis of robotic mining systems. The discipline of software engineering (SE), regulating the software development life cycle (SDLC), comprises a variety of techniques of which information engineering (IE), structured analysis and design (SA/D), and object-oriented analysis and design (OOA/D) have been discussed. Several schools of thought regarding these methods have also been presented. Finally, the scope and evolution of computer-aided software engineering (CASE) tools have been introduced to prepare the reader to the next chapter.

4 Computerized Tools

This chapter presents a survey of commercially available computer-aided software engineering (CASE) tools undertaken between August 3, 1994 and November 10, 1994 while the author was employed by the Automation and Robotics group of Mines Research, INCO Ltd., Ontario Division. The following sections describe the scope and objectives of the product survey and explain the details of the product evaluation and selection processes.

4.1 Product Survey

4.1.1 Scope

The product survey and evaluation were conducted under the scope of a pilot project aiming to prove that a comprehensive systems analysis is essential to the consistent and integrated development of robotic mining systems, both in terms of software and hardware. This premise was to be ascertained by means of a systematic analysis of the nature and behavior of processes and data flows involved in robotic mining as it is perceived today. The ultimate goal of the pilot project was to steer the Automation and Robotics group towards considering the system model as a critical component of the overall robotic mining project life cycle as well as a foundation upon which to build a commonality between future hardware and software systems [Mottola94a].

4.1.2 Objectives

Given this scope of work, the specific objectives of the product survey and evaluation required the selection of a suitable CASE tool capable of:

i) supporting the notation and semantics of different systems analysis methods, that is IE, SA/D, and OOA/D;

ii) supporting the OS/2™ or Microsoft Windows™ environments, the IBM Local Area Network (LAN) Server, and the Oracle® relational database;

iii) at a cost not exceeding $ 5,000 US.

The importance of experimenting with different systems analysis techniques originated from the fact that the software development process is enriched by the variety of methods it incorporates. Information engineering focuses on strategic planning and enterprise-wide critical success factors and information modeling. Structured techniques are strong in modeling data and processes, but propose an awkward transition from analysis to design. Object-orientation offers consistency of representation and a superior ability to model the real-world [Topper94]. Selecting a CASE tool which supports various methodologies is preferable to develop an expertise in systems analysis which, in turn, will lead to a more educated choice of a specific computerized tool when implementing the full-scale robotic mining project. Restrictions on hardware and software platforms as well as cost were dictated by INCO Ltd..

4.1.3 Strategy

The strategy followed to undertake this product survey and evaluation consisted of:

i) researching a number of CASE tools and corresponding vendors;

ii) contacting the vendors by phone and requesting product literature via fax and mail;

iii) reviewing the product literature and software demos when available;

iv) designing an evaluation form complete with selection criteria;

v) faxing the evaluation form to interested vendors;

vi) establishing weighting factors and rating values for the selection criteria;

vii) gathering and compiling the results of the survey;

viii) identifying potential candidates;

ix) holding a forum discussion within the Automation and Robotics group to select a specific software package to be purchased;

x) initiating the order and preparing an internal report [Mottola94b].

Appendix A contains a list of the vendors contacted for this CASE tool product survey and detailed forms for the top three CASE tools identified.

4.2 Product Evaluation

4.2.1 Evaluation Criteria

When looking at CASE tools, it is helpful to consider products based on a common set of functions and components. The following elements were considered in the evaluation:

i) *development life cycle*: support for the different phases of the software development life cycle (SDLC), namely planning (from IE), analysis, design, construction, testing, maintenance, and documentation;

ii) *methodologies*: support for different methodologies, namely information engineering (IE), structured analysis and design (SA/D), and object-oriented analysis and design (OOA/D);

iii) *repository*: the data store containing all the information regarding the system being developed should be shared by all the modules of the tool and provide built-in configuration management functions;

iv) *model maintenance*: addressing the functionality provided by the tool with respect to maintaining the system model;

v) *diagramming*: representing system components from different perspectives, e.g. DFD, ERD, STD, etc.;

vi) *prototyping*: the ability to simulate the functionality of the system prior to coding for the benefit of both developers and end users;

vii) *construction*: graphical user interface (GUI) construction, database schema and code generation as well as database architecture design;

viii) *documentation*: support for building a complete documentation set about the software development life cycle and system components;

ix) *interfacing*: import/export capabilities enabling part or all of the information to be transferred between CASE tools and other third party products;

x) *hardware and software platforms*: support for different hardware and software platforms and environments;

xi) *service and support*: various issues regarding the service and support provided by the vendor as well as cost data.

These items were included in the evaluation form sent to the vendors (see Appendix A). The following sections explain in detail the components of the form.

a) Development Life Cycle

The software development life cycle phases considered in this evaluation were planning, analysis, design, construction, testing, maintenance, and documentation, as explained in Chapter 3. Recall that planning (ISP) refers to James Martin's information engineering methodology and consists of defining goals and critical success factors in order to develop a model of the enterprise. This product survey focused on the analysis and design phases, with some emphasis on construction and documentation. Reverse engineering capabilities were investigated for information purposes only.

b) Methodologies

Support for the following methodologies was considered in the evaluation:

i) information engineering: Martin (enterprise modeling, process modeling, data modeling, activity decomposition, and critical success factors);

ii) structured analysis and design: DeMarco-Yourdon, Gane and Sarson, SSADM; real-time extensions: Ward and Mellor, Hatley and Pirbhai;

iii) object-oriented analysis and design: object information model, dynamic or state model, functional or process model; Booch, Coad and Yourdon, Rumbaugh et al. (OMT), Wirfs-Brock et al. (RDD), Fusion, Jacobson et al. (OOSE), Berard, Firesmith, Shlaer and Mellor (OOA and RD for real-time), Martin and Odell (OOIE).

The economic reality of CASE product development is such that these tools are generally specific to one methodology, that is the vendor has made the decision to support one technique well, rather than partially support many. Fully supporting a methodology involves more than merely providing the corresponding notation for diagramming; it should also enforce the rules and logic that drive the technique [Topper94].

c) Repository

One of the principal components of the CASE tool is the repository, where the elements of the system model are stored. It should be central to the tool modules and provide the following built-in configuration management functionality:

i) completeness and consistency checking (balancing, redundancy control) preferably in real-time or at least upon request;

ii) control for multi-user access;

iii) change and version control (audit trailing, change history).

The vendors were asked to provide the underlying file structure used by the repository, i.e. Oracle, DB2, Sybase, Ingres, Informix, or some other commercial database management system (DBMS).

d) Model Maintenance

Issues of importance regarding model maintenance were:

i) merging of separate models with no loss of information and automatic checking for completeness, consistency, syntax, etc.;

ii) integrated model views where changes made to any one view are automatically reflected into other views;

iii) distinct logical and physical models such that the first is implementation independent;

iv) model verification;

v) requirements traceability.

e) Diagramming

Diagramming is the representation of systems components from different perspectives. The following diagramming tools were considered in this evaluation:

i) data flow diagram (DFD);

ii) entity-relationship diagram (ERD);

iii) state transition diagram (STD);

iv) structure chart;

v) matrix mapping of components (e.g. create-read-update-delete or CRUD).

f) Prototyping

Prototyping is used to preview the functionality of a system prior to coding and is specially useful when building complex real-time systems. The following capabilities were considered:

i) graphical user interface (GUI) prototyping: screen mock-up;

ii) animation: replay of pre-recorded animation sequence;

iii) simulation: demonstrating the appropriate reaction to events or stimuli in real-time.

g) Construction

The following construction capabilities were considered in order to ensure a certain flexibility when undertaking later phases of the project:

i) graphical user interface (GUI) construction;

ii) database schema generation, data definition language (DDL) generation for Oracle, DB2, Sybase, Ingres, Informix, or other commercial DBMS, and database architecture design;

iii) code generation for C, C++, COBOL, Ada, etc..

h) Documentation

The capability to build a complete documentation set was regarded to be important and the following were considered:

i) text and graphical report generation;

ii) development life cycle documentation building;

iii) data dictionary;

iv) process logic specification (Pspecs, mini-specs).

i) Interfacing

Import/export capabilities enable part or all of the information contained in the repository to be transferred between CASE tools and other third party products. Interfacing also addresses Microsoft Windows™ Dynamic Data Exchange (DDE) which allows "cut and paste" to the clipboard and Object Linking & Embedding (OLE). Several file formats were investigated, such as the Hewlett Packard graphics library (HPGL), encapsulated postscript (EPS), bitmap (BMP), Word Perfect™ graphics (WPG), and others.

j) Hardware and Software Platforms

Support for these platforms and environments was surveyed:

i) hardware requirements: processor (PC or workstation), clock speed, random access memory (RAM), hard disk storage, graphical display;

ii) development platform: IBM OS/2™ Presentation Manager™, Microsoft Windows™, Microsoft DOS™, Unix™, Windows NT™;

iii) network support: IBM LAN Server, Novell, NETBIOS, TCP/IP;

iv) database support: Oracle®, DB2™, Sybase®, Ingres™, Informix®, and other database management systems (DBMS).

k) Service and Support

The following service and support issues were considered when evaluating the vendor:

i) company image: product documentation quality, number of years in business, customer installed base for the product;

ii) professional services and support: on-site training, public training, consulting, hot-line availability, newsletter, electronic bulletin board (e.g. CompuServe);

iii) cost: single user license and upgrade, annual support fee.

4.2.2 Evaluation Process

This investigation involved reviewing 25 candidate products researched through software engineering, computing, and applications development publications such as the Journal of Object-Oriented Programming, Object Magazine, PC Week, Byte, and the Microsoft Systems Journal. CompuServe was browsed for information on CASE tools and product reviews. Although the product list in Appendix A is far from being exhaustive, as there are hundreds of related products, it is nonetheless representative of the major information engineering, structured, and object-oriented CASE tools on the market in 1994. EDS, Electronic Data Systems Corporation, kindly provided a recent evaluation of upper CASE tools focusing on traditional structured analysis and design techniques and the information engineering methodology [EDS94b]. This product evaluation was consulted for insight on how to conduct such a review and was considerably modified to reflect the objectives of the pilot project and include object-oriented tools.

Due to the limited time and resources available, this evaluation was conducted solely through product literature and feedback from the vendors. However, a few vendors provided demo copies of their product; these were reviewed but not taken into account in the evaluation. For a more in-depth product evaluation, certain vendors offer limited usage of their tool in stand-alone mode, generally over a period of 30 to 60 days and at a cost.

A set of weighting factors was established in an attempt to qualify and quantify the suitability of each too. Each criteria described in the previous sections was weighted and rated as described below, and a weighted average was computed for each group of related requirements. The weighting factors were as follows:

i) weight of 5 for a highly desirable functionality;

ii) weight of 3 for a moderately desirable functionality;

iii) weight of 1 for a desirable functionality;

iv) weight of 0 when the inquiry was for information purposes only.

The overall weighted average for each individual product takes into account the relative importance of each set of criteria: for example, the support for different methodologies was weighted more heavily than the repository functionality or the construction capabilities.

The rating system employed was as follows:

i) rating of 5 when the product exceeded expectations for a specific functionality, the company had been in business for more than 10 years, the customer installed base for this product was greater than 5000, or the cost of the product was less than \$ 5,000 US;

ii) rating of 3 when the product offered acceptable functionality, more than 5 years, an installed base greater than 1000, or a cost between \$ 5,000 and \$ 10,000 US;

iii) rating of 1 when the functionality was present, but not acceptable, more than 1 year, an installed base greater than 100, or a cost greater than \$ 10,000 US;

iv) rating of 0 if the functionality was not present or not applicable.

In terms of hardware and software platforms, the preferred configuration (rating of 5) consisted of an 80486 50 MHz processor, 16 MB of RAM, 100 MB of hard disk storage, VGA display, running OS/2™ Presentation Manager™, and offering IBM LAN Server and Oracle® support.

4.3 Product Selection

Please refer to Appendix A for the detailed forms of the top three CASE tools identified:

i) Excelerator II© by Intersolv (score: 4.09);

ii) Visible Analyst© Workbench by Visible Systems Corporation (score: 3.78);

iii) and System Architect© by Popkin Software Systems (score: 3.74).

The complete product evaluation worksheet was compiled using Lotus 1-2-3™. The top three alternatives were scrutinized particularly with respect to the objectives of this product evaluation, as stated in Section 4.2.1:

First Objective: Support for different methodologies:

i) Excelerator II©: supported information engineering and major structured analysis and design techniques, plus Rumbaugh et al. and Martin and Odell; however, structured real-time extensions, such as Ward and Mellor and Hatley and Pirbhai, as well as Booch, Coad and Yourdon, and Shlaer and Mellor, were to be purchased separately and at high cost;

ii) Visible Analyst©: supported information engineering partially and major structured techniques; however, the product did not support structured real-time extensions nor object-oriented methodologies;

iii) System Architect©: supported information engineering and major structured techniques, including Ward and Mellor real-time extension; object-oriented methodologies (Booch, Coad and Yourdon, Rumbaugh et al., Shlaer and Mellor) were supported through a relatively inexpensive option module.

Second Objective: Hardware and Software Platforms:

i) Excelerator II©: OS/2™ and Windows™ versions were available as well as support for IBM LAN Server and Oracle®;

ii) Visible Analyst©: Windows™ version were available as well as support for IBM LAN Server and Oracle®;

iii) System Architect©: Windows™ version was available for System Architect© release 3.0 (OS/2™ version was being upgraded at the time); support for IBM LAN Server and Oracle® was available.

Third Objective: Cost:

i) Excelerator II©: $ 5,850 US or over $ 21,000 US with Customizer Tool;

ii) Visible Analyst©: $ 3,300 US;

iii) System Architect©: $ 2,066 US with System Architect Object module.

System Architect© was the final selection made on November 10, 1994 during a forum discussion within the Automation and Robotics group. System Architect© was chosen because of its superior assortment of methodologies available on the Windows™ platform and at a lower cost. In addition, in 1994 EDS Canada was undertaking an Information Technology Architecture study for the INCO FOREMAN project involving data and process modeling using System Architect© [EDS95b].

4.4 Summary

This chapter has described the rationale behind a CASE product survey, evaluation, and selection undertaken in 1994 on behalf of INCO Ltd.. It serves to provide an idea of the spectrum of tools available to the systems analyst as well as to justify the use of System Architect© for the purpose of this investigation and pilot project.

5 System Model

The previous chapters have set a solid framework tor illustrating the power of systems analysis specifically in the context of mining. Recapitulating, Chapter 2 explored the evolution of mining information systems through a series of case studies exemplifying different corporate philosophies and strategies. In the same chapter were also discussed recent trends towards more integrated approaches. Chapter 3 introduced the fundamentals of systems analysis in terms of software engineering, its methods, and computerized tools. Finally, Chapter 4 reported the results of a survey of commercially available computer-aided software engineering (CASE) tools conducted under the scope of a pilot project for robotic mining.

The principal objective of the present chapter consists in demonstrating the applicability of systems analysis concepts and tools to the business of mining and particularly to the development life cycle of future robotic mining systems. However, it must be noted that systems analysis should also be applied while planning for more immediate or smaller scale projects, such as hoist rope damage detection systems or plans to reduce electric consumption in mines. The chapter begins with a discussion of integrated mining information systems in terms of the present state and future vision of underground hardrock mining and the necessity to bridge the gap which separates the two scenarios by means of an intermediate stage. It then presents an overview of the information system model and a comparative study of systems analysis methodologies through a particular application case.

5.1 Mine Information System

Typically, underground hard rock mining is performed by accessing the orebody via a vertical shaft and a series of drifts and tunnels. Connection between levels is secured through a ramping system or the shaft itself. Mobile machinery is manually operated and consists of load-haul-dump (LHD) vehicles, haulage trucks, top-hammer drills, jumbo drills, and bolting machines. Stationary equipment includes fans, pumps, a crusher, hoists, and maintenance facilities.

The ultimate goal of robotic mining is to access and exploit underground resources without the need for people to enter the mine. The ore would be retrieved by a new generation of intelligent and autonomous mobile machinery linked to surface facilities via a communication network. This fleet of robotic machinery would acquire information regarding the orebody and surrounding rock mass while mining to complement the initial exploration. The information system responsible for managing and interpreting the data from different sources would be located on the surface, although parts of its functionality may be distributed between underground equipment and a number of subsystems and databases.

A technological gap exists between the conventional and robotic mining scenarios, particularly with respect to the sensing technology necessary to gather sufficient information about the rock mass with minimal supporting infrastructure. Incremental advances in mining automation have already proven the viability of teleoperation and automatic control of mobile machinery, and progression is headed towards refining these technologies to include more sophisticated and flexible capabilities [Baiden94b]. The next logical step to bridge the gap between conventional and robotic mining consists of an intermediate stage, where the stationary equipment and mobile machinery utilized today is linked to an information system via a communication network. Figure 5.1 illustrates this concept, where a mine information system interfaces with four main underground functional areas: i) mobile machinery; ii) stationary equipment; iii) mine monitoring; and iv) infrastructure.

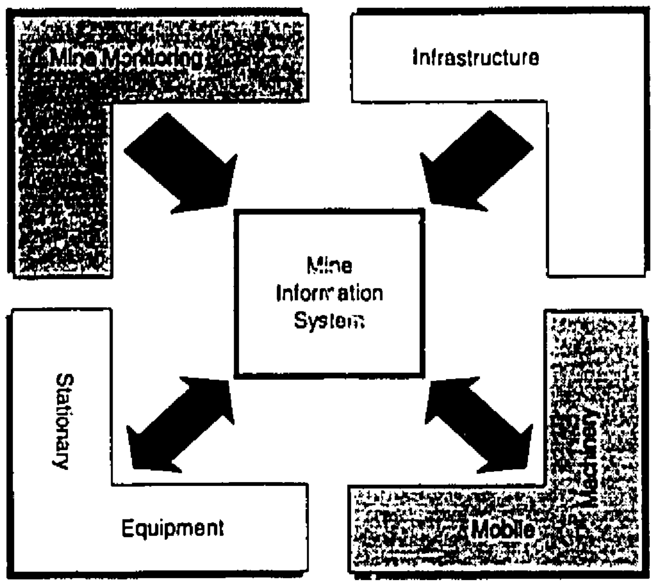

Figure 5.1:Mine Information System Overview.

Figure 5.2 offers a more detailed perspective of this diagram and the following sections describe its components.

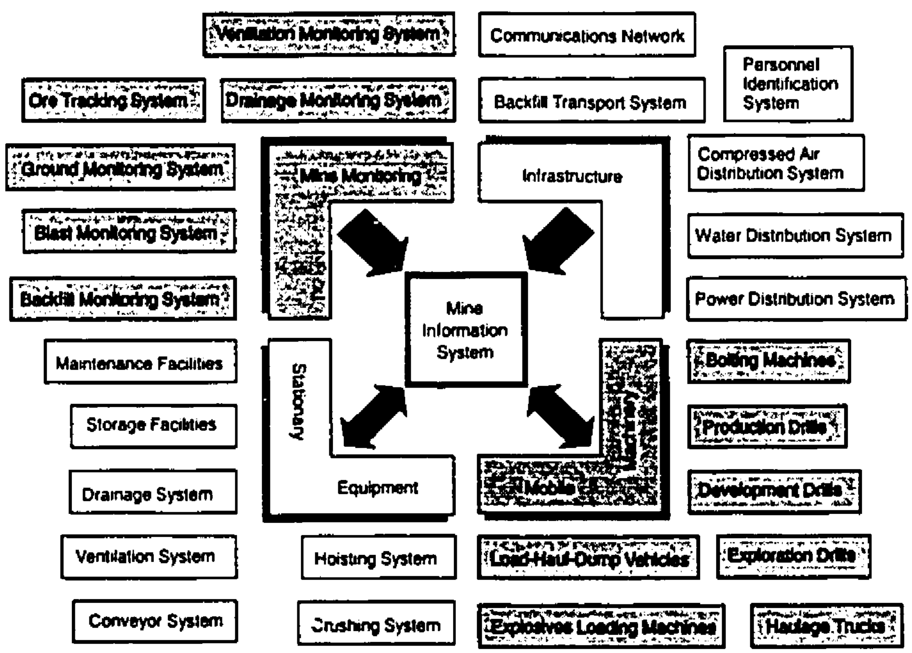

Figure 5.2: Mine Information System Components.

5.1.1 Mobile Machinery

The basic mobile machinery found in a mechanized hard rock mine essentially comprises combinations of the following:

i) *development drill*, such as a jumbo drill, to advance underground tunnels;
ii) *production drill*, such as an in-the-hole (ITH) or top-hammer drill, to drill production holes;
iii) *exploration drill*, such as a diamond drill, for retrieving core samples;
iv) *bolting machine*, to mechanically support the tunnels with bolts and screens;
v) *explosives loading machine*, to load blast holes with explosives;
vi) *load-haul-dump vehicle* (LHD) and
vii) *haulage truck*, to transport material from a loading point to a dumping point.

Assuming that all of this machinery possesses teleoperation capabilities and a minimum of automatic control, then a two-way link to the information system via a mine-wide communication system is necessary to support these functions, regardless of the task to be accomplished. In addition, effective monitoring of production parameters and vital signs can be achieved by outfitting the machines with appropriate sensors and transmitting relevant data through the network. Hence, operating mode, production monitoring, and condition monitoring are common functions needed for all mobile machinery operating in such a preliminary robotic stage.

The specifics of production monitoring vary according to the particular function of a machine. For instance, drills would collect performance parameters such as meters drilled, feed force, torque, piston blow rate, machine vibration, etc., as well as hole deviation and perhaps metal content of the rock encountered. LHDs and haulage trucks would measure tonnage, fragmentation, and perhaps sense ore grade. Cycle times, including operating, servicing (maintenance), and idle times, are an important aspect of production monitoring which determine the utilization and availability of machinery.

5.1.2 Stationary Equipment

Underground stationary equipment typically consists of the following:

i) *drainage system*: including pumps, sumps, pipes;

ii) *ventilation system*: including fans, vent doors, ducts;

iii) *crushing system*: including an underground crusher, ore bin(s);

iv) *hoisting system*: including the hoist assembly, hoist room, cage, skips, ropes;

v) *conveyor system*: including conveyor head and tail assemblies, rollers, belts;

vi) *maintenance facilities*: including garages, shops;

vii) and *storage facilities*: including warehouses, explosives storage rooms.

Production and condition monitoring data can be gathered from all stationary equipment much in the same manner as it is obtained from mobile machinery, with the exception that stationary equipment can be hard-wired to the communications network. Production variables of interest would be power consumption and throughput, such as tonnes per hour for the hoist and crusher and liters per minute or cubic meters per minute for the pumps and fans respectively. Automatic control of this equipment, with occasional manual override, allows for efficient operation and energy savings.

Storage and maintenance facilities exchange a different kind of information. Inventory tracking of supplies and parts kept underground can result in just-in-time delivery of needed materials thus reducing production delays and the need to stock up. Pre-processed condition monitoring data routed to the maintenance facility can assist in preventive maintenance of both mobile machinery and stationary equipment.

5.1.3 Mine Monitoring

The intermediate robotic stage requires that information be gathered about the surrounding mining environment, such as groundwater flows, air quality, and ground conditions. This is achieved using sensors strategically located throughout the mine and constituting the following systems:

i) a *drainage monitoring system*: for water levels, in-flow rates, chemistry, and suspended solids;

ii) a *ventilation monitoring system*: for air flows and air quality;

iii) a *ground monitoring system*: for stress, deformation, seismicity;

iv) a *backfill monitoring system*: for permeability and water pressure;

v) a *blast monitoring system*: for fragmentation, vibration, and rock mass damage;

vi) and an *ore tracking system*: for in-transit tonnage, grade, and levels (e.g. in ore passes and storage bins).

This information is valuable in monitoring the status and performance of production as well as the operating environment. Some is directly utilized as input to control stationary equipment, for example where drainage and ventilation data indicate the need to activate or shut off pumps and fans. Information related to ground conditions, backfill, blasting, and ore tracking indirectly influences mining processes such as ground support, production planning, and blast design, by characterizing the dynamic nature of the mining environment. The sensing instrumentation required to adequately and reliably provide this kind of information poses one of the greatest challenges towards achieving robotic mining.

5.1.4 Infrastructure

The principal underground infrastructure consists of:

i) a *power distribution system*;

ii) a *compressed air distribution system*;

iii) and a *water distribution system*, needed for the operation of various machinery and equipment;

iv) a *backfill transport system*, from surface facilities to mined out areas;

v) a *communications network*, providing a mine-wide electronic link to the surface;

vi) and a *personnel identification system*, for tracking the whereabouts of underground personnel.

Hence, the primary function of infrastructure components is to assure the distribution of "lines" needed for the overall underground operation. As for mobile machinery and stationary equipment, the health of infrastructure components must be monitored to ensure effective distribution throughout the mine. Also included in this category are personnel tags transmitting the location and identification of the underground workforce, possibly via a radio frequency identification (RFID) system [Knights94a] [Hind94].

5.2 Model Description

Figure 5.2 gave an overall view of the structure and flow of information in the likely transition from conventional to robotic mining. The information associated with each component block is both complex and extensive and cannot be effectively analyzed without suitable methods and tools. A systematic approach must therefore be taken to capture in detail the nature and behavior of each individual element as well as its interaction with other components of the system. Systems analysis and computer-aided software engineering tools can assist in accomplishing this task in a dynamic and constructive manner.

This following sections present a top-down analysis of the overall system model constructed using the CASE tool System Architect©. The methodology and notation utilized at this point are those of Gane and Sarson structured analysis and design described in Chapter 3.

5.2.1 Level 0 DFD: Context Diagram

As explained in Section 3.3.1, a context diagram is a data flow diagram (DFD) in which a single process represents the entire system being modeled, in this case the Mine Information System. Figure 5.3 is a context diagram for this system, showing interfaces to the four main components discussed in the previous sections, that is mine monitoring, infrastructure, stationary equipment, and mobile machinery.

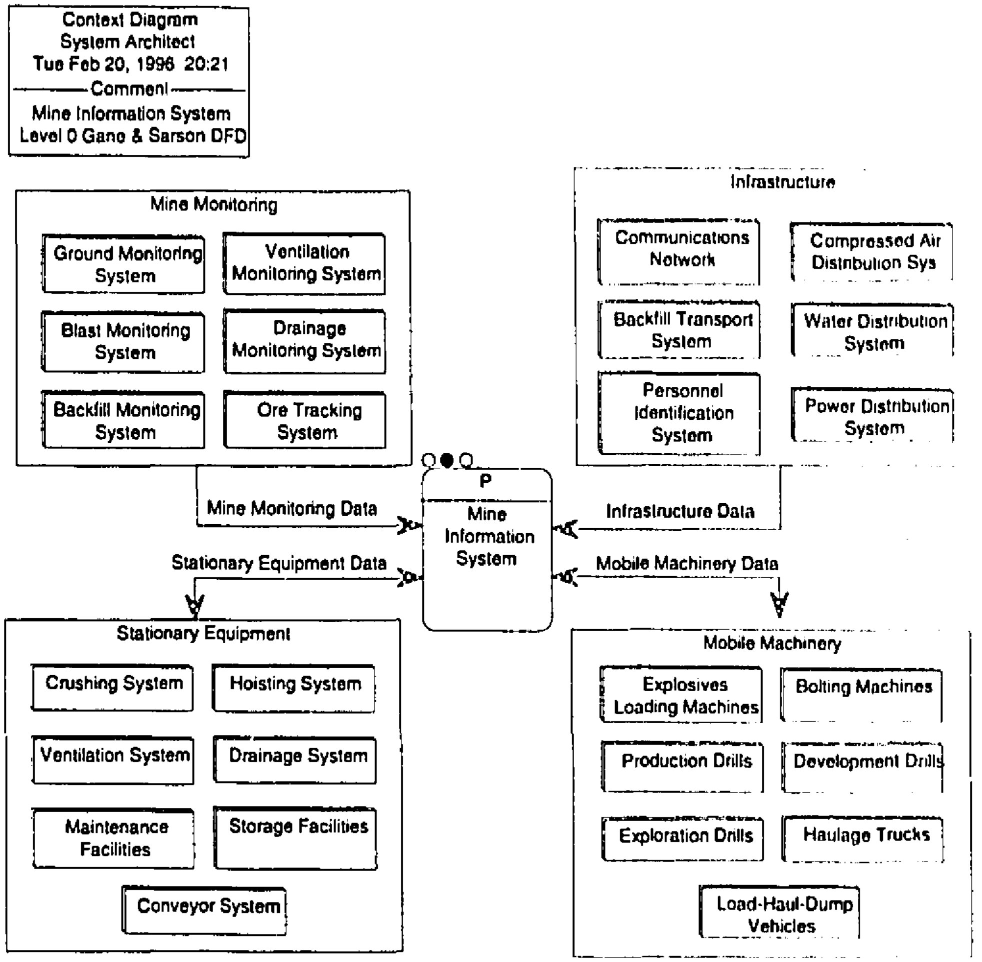

Figure 5.3: Mine Information System Context Diagram (Level 0 DFD).

The context digram is essentially the highest level of abstraction in a top-down system analysis and hence it is referred to as a Level 0 DFD. Although this figure appears to be a mirror image of the previous one, it must be emphasized that, in a CASE tool, each object (rectangle or arrow) is more than a mere graphical representation, but in fact corresponds to a database record in the CASE tool encyclopedia (repository). Hence, these objects are meaningful entities linked to one another and possessing properties and descriptions integrated within a machine-readable database. In other words, the data flow diagram constructed with System Architect© possesses an additional perspective or depth which cannot be represented on paper, but that exists within the CASE tool. This point is valid for all subsequent figures shown in this thesis and created using System Architect©. In addition, please note the three circular indicators on the top left corner of process P: these are expand indicators proper to System Architect© and not to the Gane and Sarson notation. In fact, a blackened left indicator signifies that the symbol has a dictionary comment and a blackened center indicator signifies that the symbol has a child diagram. The third indicator is not relevant at this point.

5.2.2 Level 1 DFD: High-Level Diagram

In Figure 5.4, the central process shown in the context diagram and representing the Mine Information System (process P) is expanded to illustrate its internal functionality, comprising:

i) *exploration* functions (P1), such as exploration drilling and core logging;

ii) *engineering* functions (P2), such as geological modeling and mine planning;

iii) *support* functions (P3), such as maintenance, materials management, ventilation, and drainage;

iv) and *operations*, including *development* functions (P4), such as development drilling with a jumbo drill, and *production* functions (P5), such as production drilling with an ITH drill, blasting, and material handling.

As such Figure 5.4 is a Level 1 DFD and the processes within the boundaries of the Mine Information System are numbered P1 through P5.

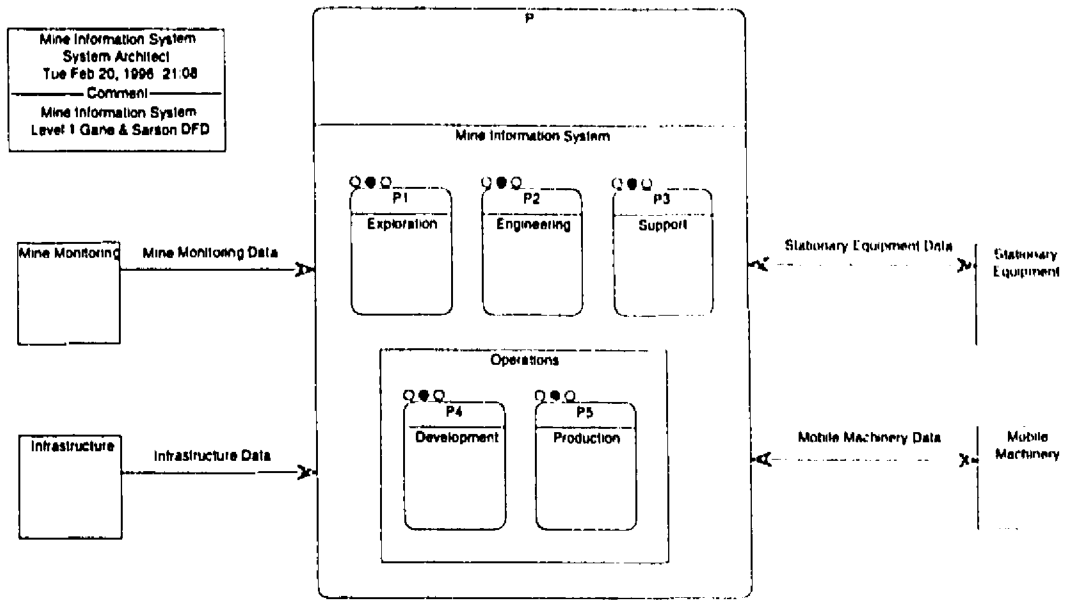

Figure 5.4: Mine Information System High Level Diagram (Level 1 DFD).

5.2.3 Level 2 DFDs

Proceeding with a top-down structured analysis of the Mine Information System, the Level 1 processes of Figure 5.4 are further expanded to produce the five Level 2 DFDs of Figures 5.5 through 5.9. Note that the sub-processes shown in these figures are surrounded by the external entities with which they communicate.

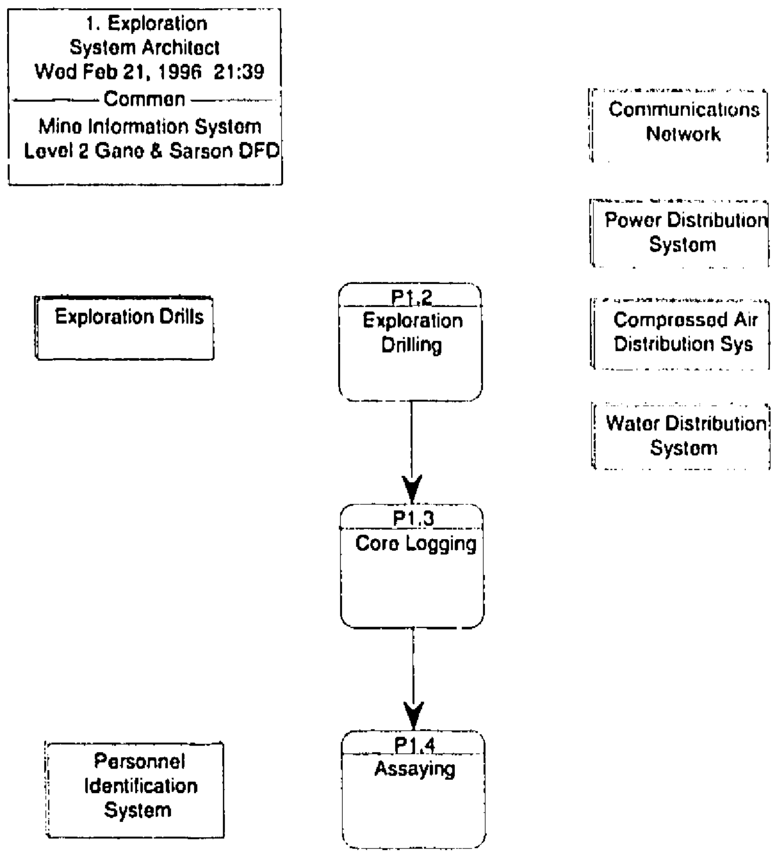

Figure 5.5: Mine Information System: Exploration (Level 2 DFD).

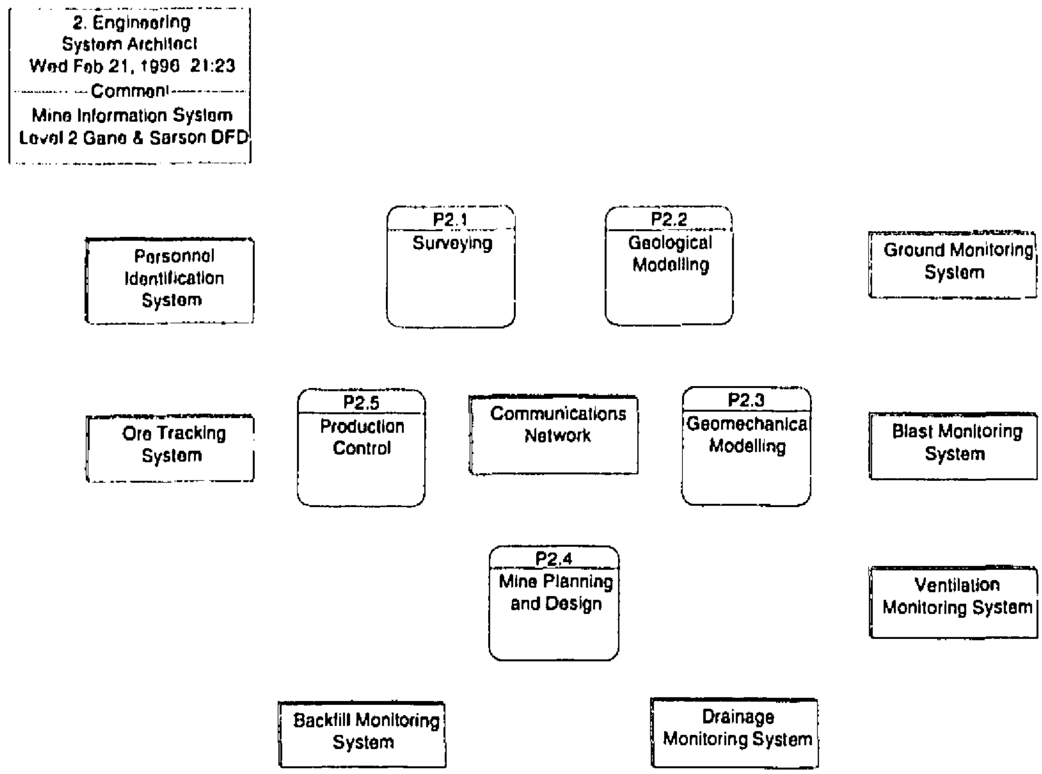

Figure 5.6: Mine Information System: Engineering (Level 2 DFD).

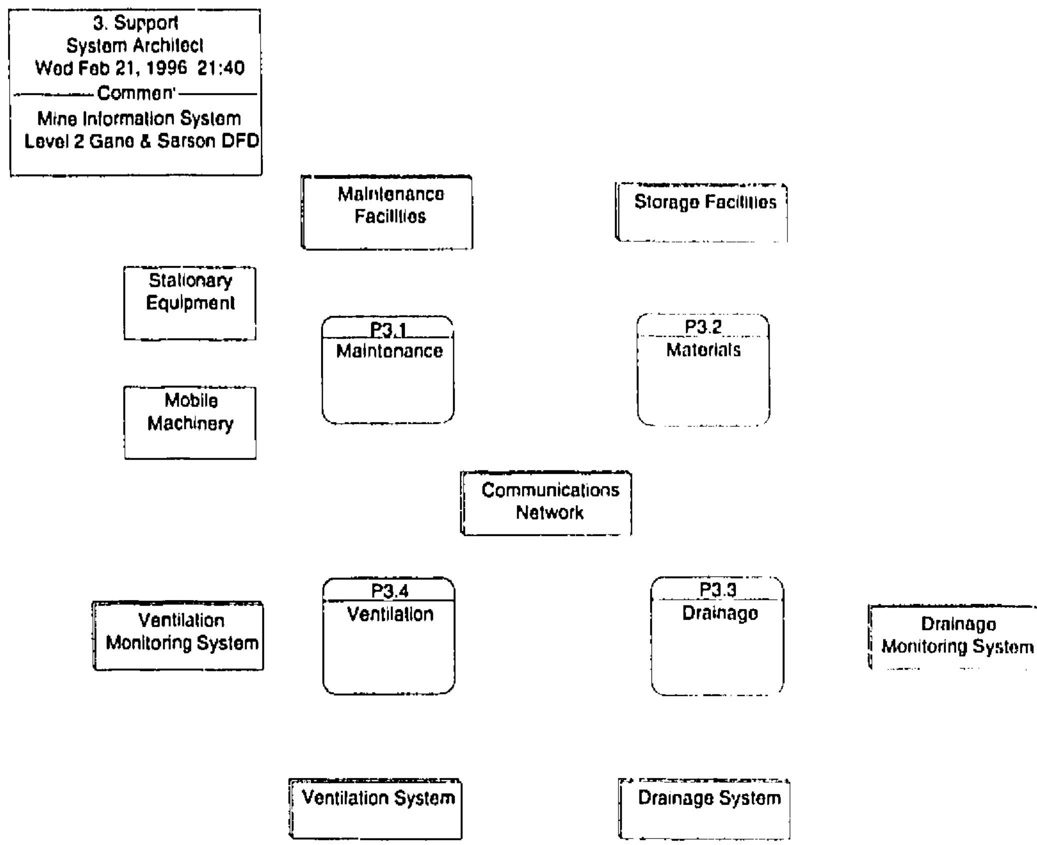

Figure 5.7: Mine Information System: Support (Level 2 DFD).

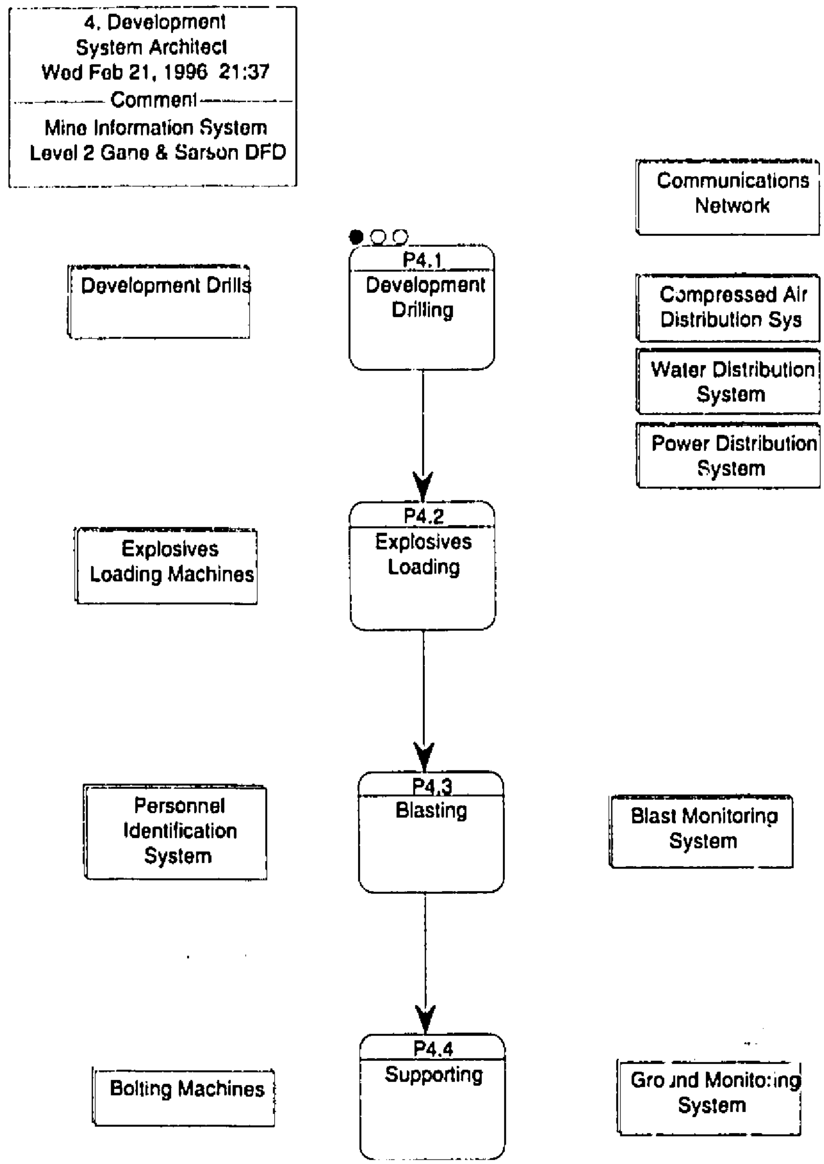

Figure 5.8: Mine Information System: Development (Level 2 DFD).

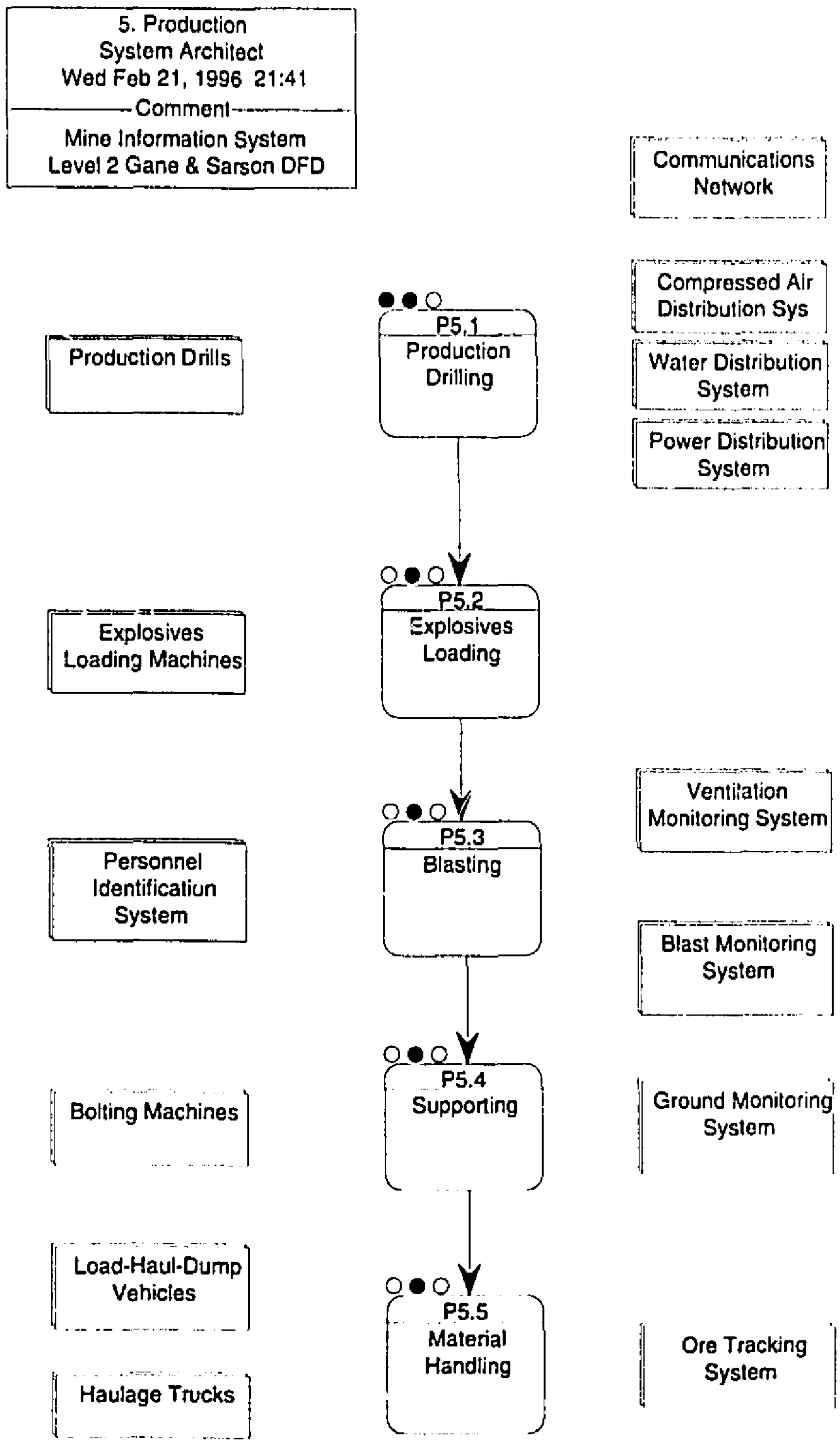

Figure 5.9: Mine Information System: Production (Level 2 DFD).

It is beyond the scope of this pilot project to expand upon all the Level 2 processes shown in Figures 5.5 through 5.9, and their associated sub-processes. These are presented to illustrate the progression of the proposed systematic approach to the analysis of mining systems. However, since the focus of this investigation is on the production cycle, process P5 shown in Figure 5.9 will be examined in detail.

The production process of underground hardrock mining can be described in terms of the following sub-processes:

i) *production drilling* (P5.1), with an ITH or top-hammer drill;
ii) *explosives loading* (P5.2), by means of explosives loading machines;
iii) *blasting* (P5.3);
iv) *supporting* (P5.4), by means of bolting machines;
v) and *material handling* (P5.5), including transport with LHDs and haulage trucks, as well as crushing and hoisting.

5.2.4 Level 3 DFDs

Each one of the processes in Figure 5.9 in turn consists of a number of sub-processes and associated information flows. Figures 5.10 through 5.14 each represent a Level 3 DFD for the processes of production drilling, explosives loading, blasting, supporting, and material handling respectively.

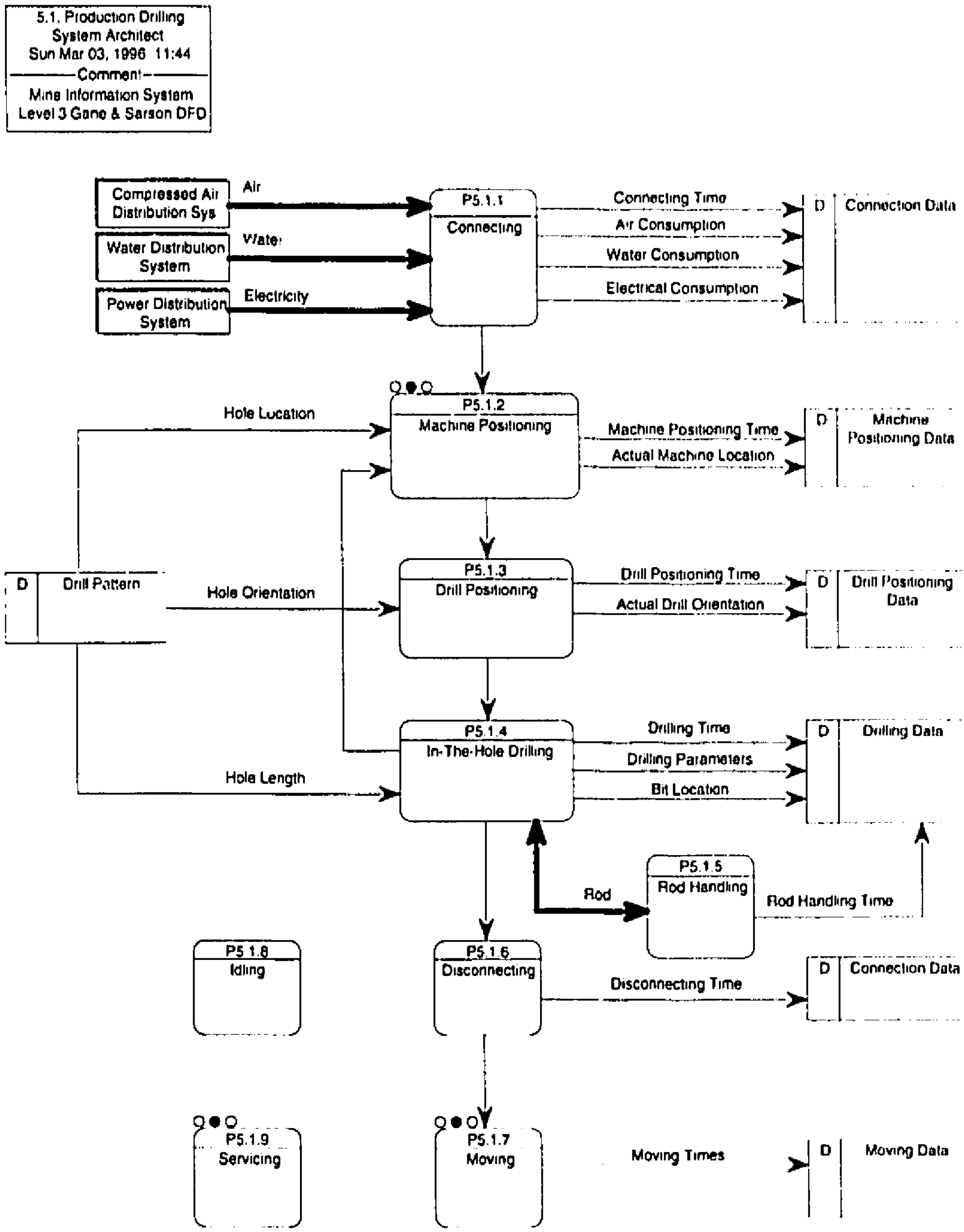

Figure 5.10: Mine Information System: Production Drilling (Level 3 DFD).

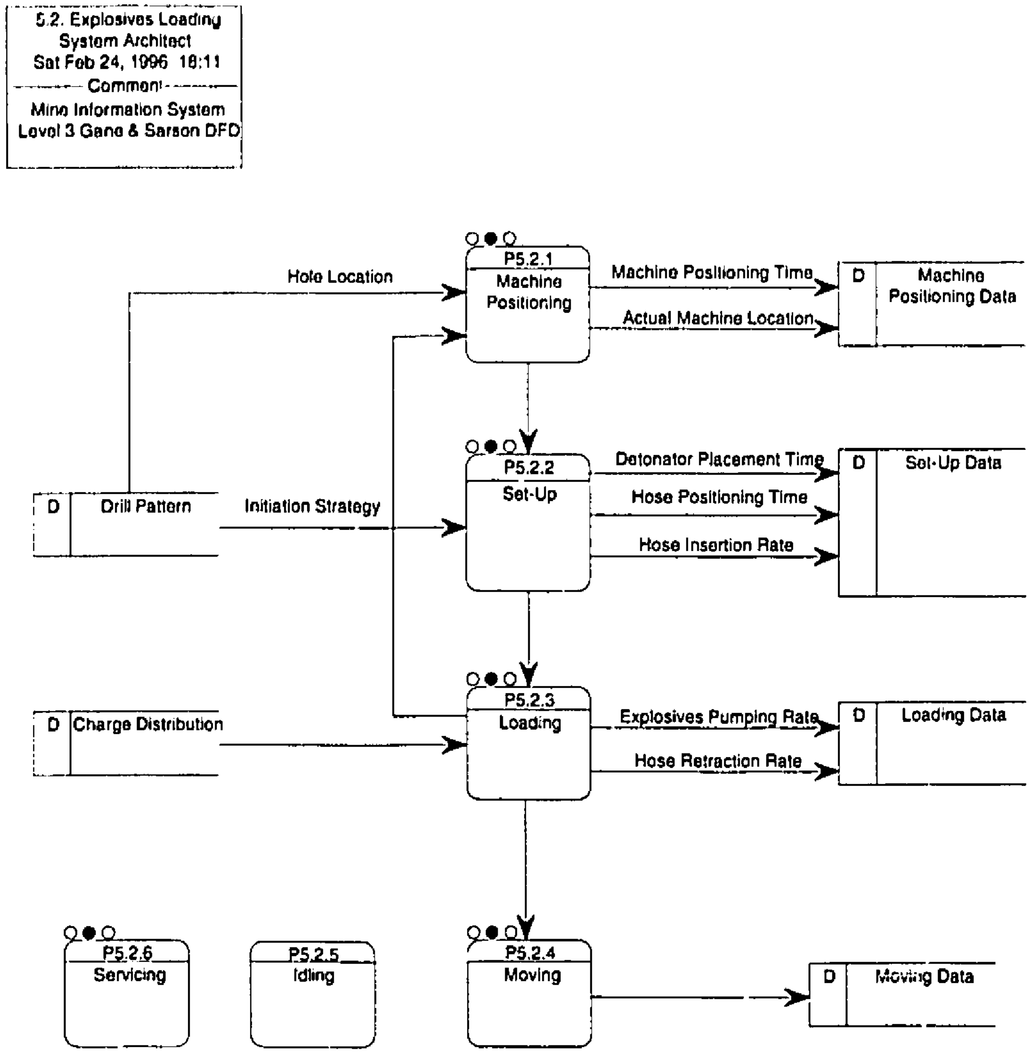

Figure 5.11: Mine Information System: Explosives Loading (Level 3 DFD).

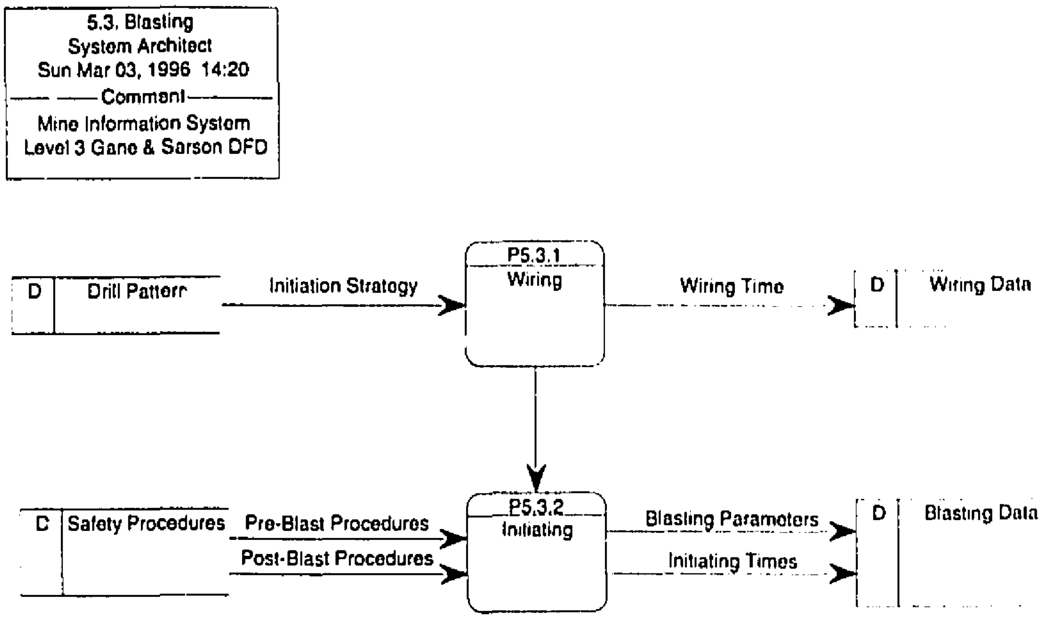

Figure 5.12: Mine Information System: Blasting (Level 3 DFD).

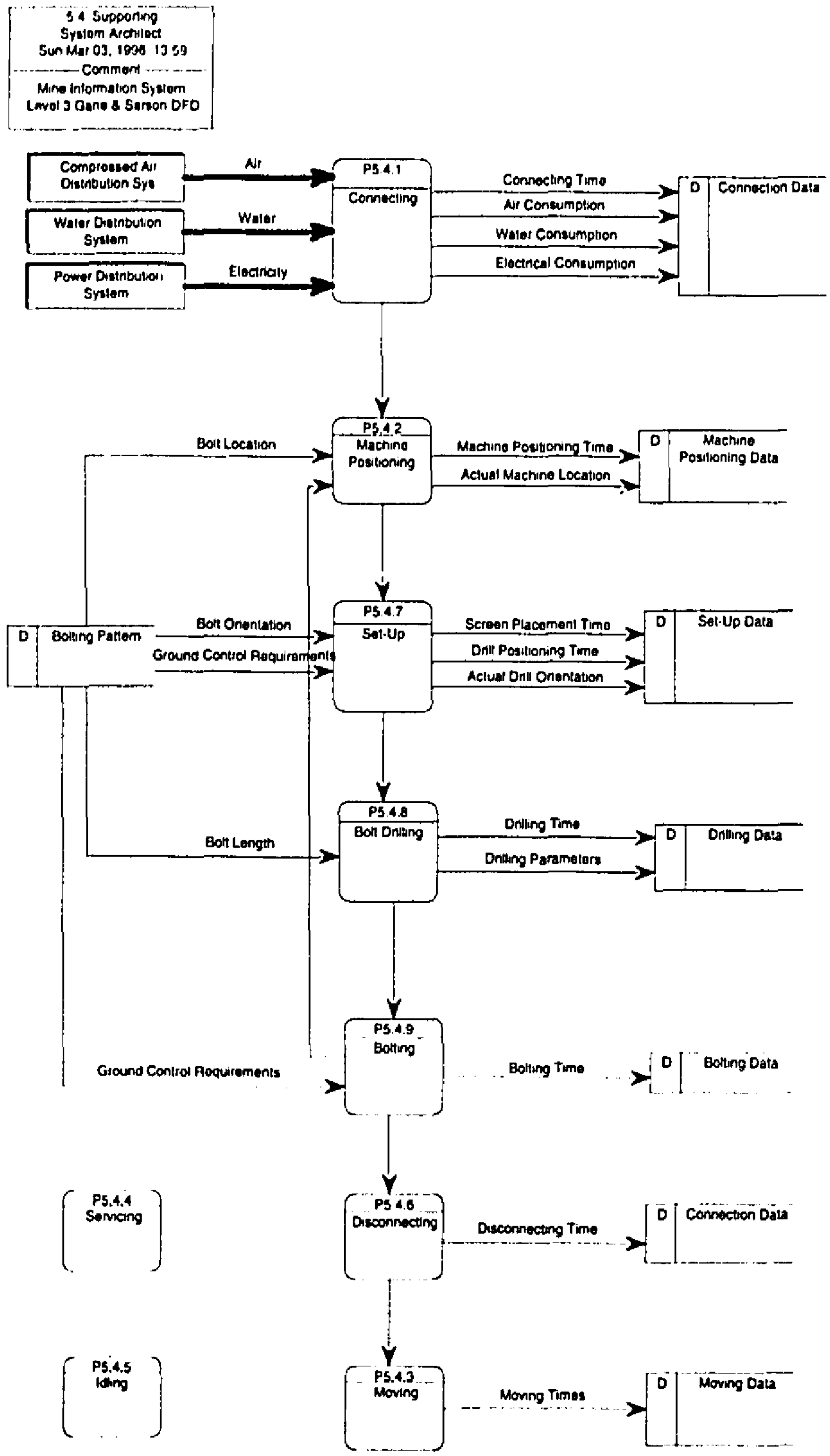

Figure 5.13: Mine Information System: Supporting (Level 3 DFD).

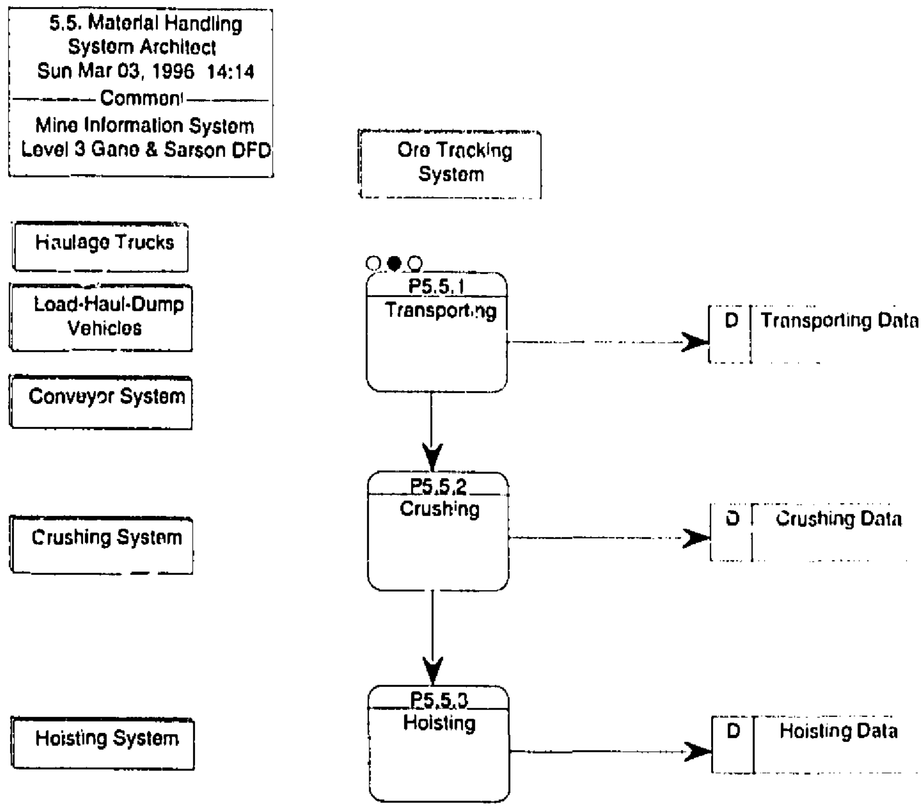

Figure 5.14: Mine Information System: Material Handling (Level 3 DFD).

Each one of these Level 3 DFDs can be further expanded into lower-level diagrams containing sub-processes and information flows, until the most elementary functions and data fows are identified.

5.3 Comparative Study of Methodologies

5.3.1 Application Case: Production Drilling

The process of production drilling has been chosen as a practical application case to effectively compare structured and object-oriented analysis and design methodologies. The following sections describe in detail the sub-processes involved in production drilling as shown on the low-level DFD of Figure 5.10.

a) Connecting and Disconnecting

Auxiliary connections are needed to provide compressed air, water, and electricity to the drill. Water flushing is used as a form of dust control and cooling while removing the drill cuttings from the bottom of the hole. The connecting time is cumulative for all three connections and is added to the time it takes to disconnect the machine from the service lines. Air, water, and electric consumption are also recorded through monitoring of these infrastructure components. The connection data gathered is relayed to the information system database via the communications network. This link is here represented by the information flows to the data store "Connection Data". This convention is used throughout the diagram.

b) Machine Positioning

The machine is positioned within the working area according to its planned location given by the pattern to be drilled. The correct machine location corresponds to the position of the drill required to collar the hole at the (x,y,z) coordinates specified in the drill pattern. Hence, machine location can be specified in terms of hole location. The positioning error can be obtained by comparing the planned versus actual location. The machine positioning time includes the time it takes to install and level the machine.

c) Drill Positioning

Once the machine is in place, then the drill is precisely positioned according to the drill pattern describing the hole orientation. For an ITH drill, the mast is positioned with respect to azimuth and dip angles. The drill positioning time includes all time periods required to achieve the proper orientation.

d) In-The-Hole Drilling

The hole is drilled to a pre-determined length specified in the drill pattern and the following performance parameters are measured while drilling: footage, feed force, torque, rotary speed, bit air pressure, bit air flow rate, piston blow rate, machine vibration, and rod vibration. Hole deviation is calculated by comparing bit location versus the planned trajectory given by the drill pattern.

e) Rod Handling

In the case of an ITH drill, where production holes can reach lengths of up to 130 meters, an automatic rod addition/removal mechanism is incorporated into the machine to extend the drill string. The rod handling time is cumulative during the drilling process and continuous when removing the rods once the hole is completed.

f) Moving

There are three means to move a drill, namely by tramming, towing, or caging. Tramming is the usual manner in which drills are temporarily displaced when blasting or moved between working areas that are on the same level. ITH drills are crawler mounted and are usually towed or carried by an LHD between levels or over long distances. When moving equipment between levels which are not connected by a ramp system, caging becomes necessary. The moving time is cumulative for these activities and includes all pre- and post-move preparation periods.

g) Servicing

Servicing encompasses three types of maintenance: routine, preventive, and breakdown. Routine maintenance, and associated downtime, consists of replacing consumables, such as bits, rods, and lubricants. Preventive maintenance involves continuously monitoring vital parameters of the machine subsystems, sounding alarms when thresholds are reached, and perhaps offering a preliminary diagnosis as part of an expert system. The time spent in performing preventive maintenance is accumulated separately. Breakdown maintenance results from a machine failure and tracks the time at which it occurred as well as the time it takes to diagnose it and repair it. This information allows the calculation of quantities such as mean time between failures (MTBF) and mean time to repair (MTTR) for a specific part and failure.

<u>h)</u> <u>Idling</u>

Idling takes into account all periods of inactivity, such as waiting for instructions.

Note that, in Figure 5.10, servicing and idling are not explicitly connected to the other sub-processes for the following reasons: firstly, in essence, *servicing* encompasses the condition monitoring aspect of production drilling and, as such, is required to continuously gather information about all the sub-process; secondly, there is no information flowing to and from *idling*, but only an event that triggers this condition. In addition, the thicker lines represent concrete material flows, such as water and rods, rather than abstract information flows.

5.3.2 Structured Analysis and Design Methodologies

As explained in Chapter 3, structured analysis involves the modeling of processes, data, and behavior through a series of diagrams, namely the data flow diagram (DFD), the entity-relationship diagram (ERD), the state transition diagram (STD), and the control flow diagram (CFD). In order for a system model to be complete, all three views must be examined. However, it is beyond the scope of this investigation to analyze the application case of production drilling with respect to entity relationship or behaviour.

5.3.3 Object-Oriented Analysis and Design Methodologies

This section briefly investigates the application of object-oriented principles to the problem domain of a Mine Information System and, particularly, to the case of drilling. System Architect© supports two OOA/D methodologies, namely Booch [Booch94a] and Coad and Yourdon [Coad91a] [Coad91b], as presented in Chapter 3. The Coad and Yourdon methodology and notation have been selected for the purpose of this exercise.

Recall that object-orientation begins with mapping the problem domain, that is the real world. Coad and Yourdon proposed to accomplish this by first identifying the classes and objects pertaining to the problem domain which can be found in the following forms:

classification structures (generalization-specialization) and composition structures (whole-part); external systems; implementation-independent devices such as sensors; events to be recorded; roles played by human beings; operational procedures; physical locations, e.g. sites; and organizational units [Coad91a].

In order to demonstrate the application of Coad and Yourdon's OOA methodology, let us consider the mobile machinery component interfacing with the Mine Information System, as shown previously in Figure 5.3. A generalization-specialization analysis of the mobile machinery super-class leads to the identification of a number of sub-classes, namely drilling machine, hauling machine, and explosives loading machine, illustrated in Figure 5.15.

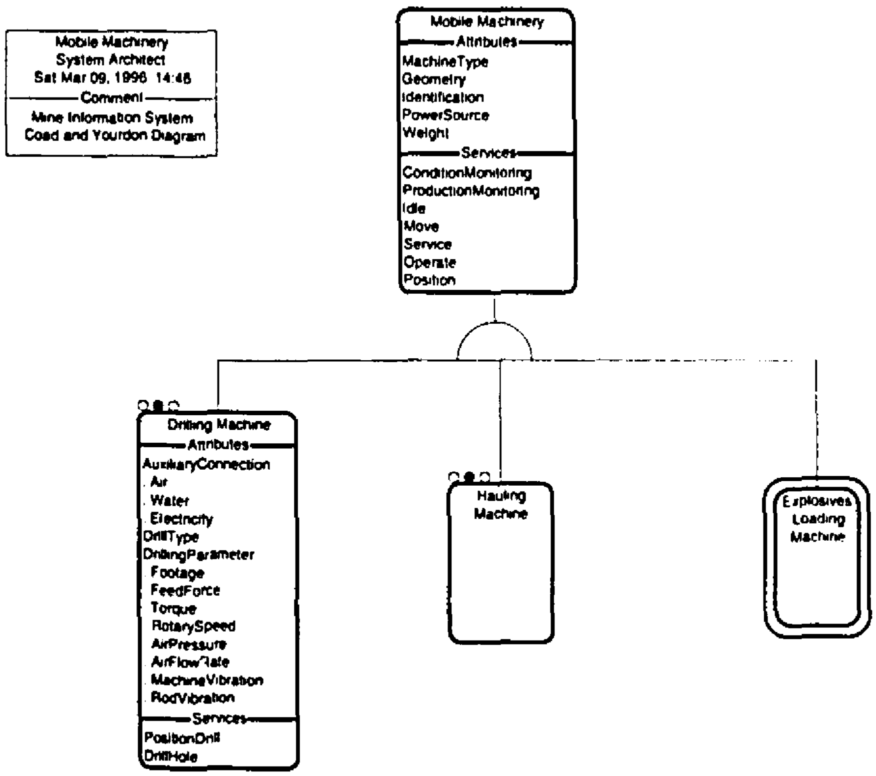

Figure 5.15: Mobile Machinery Class.

The Coad and Yourdon notation represents both objects and classes with rounded rectangles. However, a distinction is made between a class with its objects (light rectangle) and a general class whose objects are portrayed by its specialization classes (bolded rectangle). For example, drilling machine is a general class and explosives loading machine is a class with its objects. The generalization-specialization of mobile machinery also defines its class hierarchy and hence its inheritance mechanism. Consequently, the attributes and services (methods) encapsulated into the mobile machinery class are inherently passed on to its sub-classes.

Since the application case of interest is drilling, the drilling machine class is further expanded in Figure 5.16.

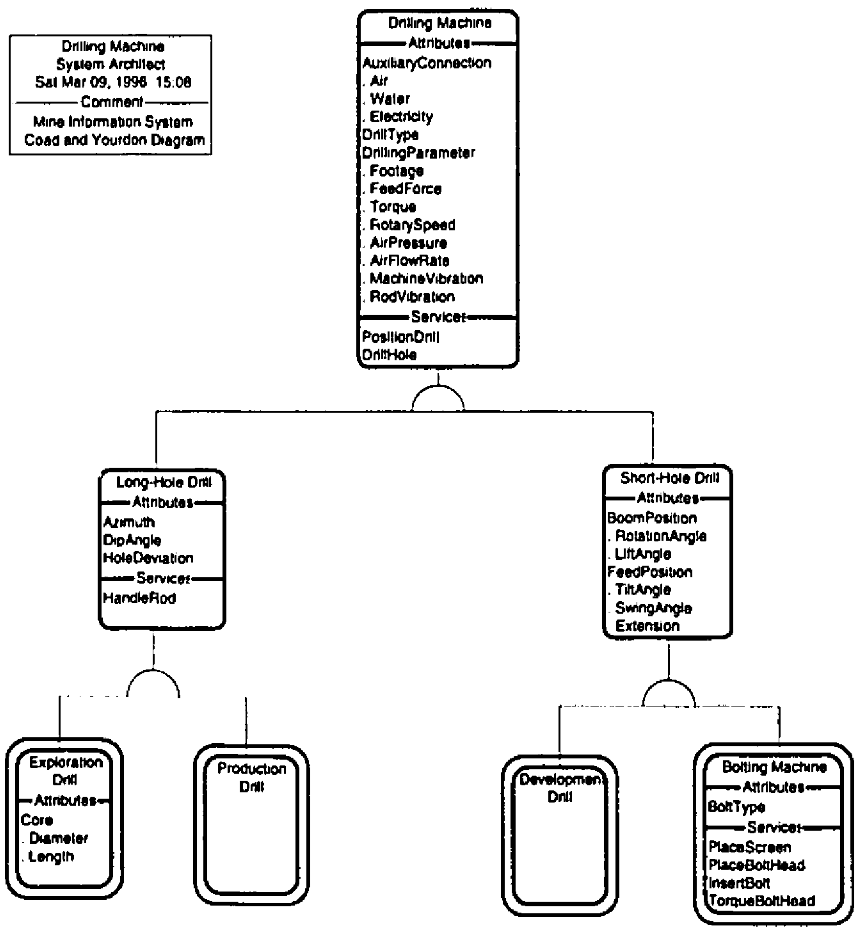

Figure 5.16: Drilling Machine Class.

Note that two generic classes have been identified, namely the long-hole drill class and the short-hole drill class. These have been introduced to group the exploration-production and development-bolting drill pairs under a common class reflecting a similar equipment configuration. Since the bolting machine includes a drill, it has been classified as a sub-class of the drilling machine with special additional functionality.

5.3.4 Discussion

The application of structured and object-oriented analysis to the process of drilling leads to the discussion of a number of issues. For instance, it is clear that the processes of production, development, and exploration drilling are very similar to one another and that, in fact, they differ only in the type of equipment utilized and the operational constraints that it imposes on the process itself. Therefore, it would be preferable to design the process of drilling at a level of abstraction which enables the application of its sub-processes to different conditions. For example, when positioning the drill to match the hole orientation specified in the drill pattern, the production drill requires azimuth and dip angle adjustments, whereas the development drill requires boom rotation and lift angles and feed tilt and swing angles. This distinction can be made deeper within the definition of the drill positioning process, rather than creating another process specifically for the development drill. Similarly, the process of servicing, including routine, preventive, and breakdown maintenance, can be tailored to cater to different types of mobile machinery and stationary equipment.

These observations call for the use of object-orientation. In the previous section, the generalization-specialization analysis of the mobile machinery class has resulted in the identification of a hierarchy of classes which, in turn, defines the way attributes and services (methods) are inherited by the sub-classes. As the classification process takes place, objects and classes acquire a progressively higher level of specialization which precludes duplication and promotes re-use.

5.4 Summary

This chapter has presented the following:

i) a high-level architecture for a Mine Information System designed to bridge the gap that currently exists between the conventional and robotic underground mining scenarios;

ii) a top-down structured analysis of the overall system model constructed using System Architect© and the Gane and Sarson methodology;

iii) the details of the production drilling process, as an application case;

iv) and a comparative study of structured and object-oriented analysis and design methodologies.

6 Conclusions and Recommendations

6.1 Summary of the Investigation

The primary objective of this thesis is to introduce and relate systems analysis concepts and tools to the business of mining, whether in a conventional or robotic environment. This investigation has addressed this objective by:

i) reviewing the fundamentals of software and information engineering as well as structured and object-oriented analysis and design (Chapter 3);

ii) relating these abstract concepts to the business of mining (Chapters 3 and 5);

iii) presenting a survey of computerized tools for systems analysis (Chapter 4 and Appendix A);

iv) analyzing a specific process to demonstrate the application and significance of these concepts and tools to mining systems (Chapter 5);

v) initiating a pilot project to prove that a comprehensive systems analysis is essential to the consistent and integrated development of robotic mining systems, both in terms of software and hardware;

vi) addressing both underground and surface mining issues to demonstrate the widespread applicability of this study;

vii) undertaking an extensive literature survey on the subjects of information systems for mining and systems analysis tools and techniques (Bibliography).

Other significant contributions made by this thesis include:

i) a discussion of different approaches to the design and implementation of mining information systems with an emphasis on evolutionary patterns and future trends (Chapter 2);

ii) a view of an intermediate stage bridging the gap that currently exists between the conventional and robotic underground mining scenarios (Chapter 5);

iii) a preliminary systems analysis of a Mine Information System interfacing with four main functional areas of the underground mining environment, namely mobile machinery, stationary equipment, mine monitoring, and infrastructure (Chapter 5);

iv) a comparison of structured and object-oriented analysis and design methodologies by means of an application case that is key to the process of mining (Chapter 5).

6.2 Conclusions

A discussion of the evolution of mining information systems from a case study perspective has set the industrial context of this work with respect to past initiatives and future directions. From this discussion, a number of important issues have surfaced which, regardless of design approach, have continuously challenged the mining industry. The fundamental issue is the *complexity* of the problem and, more precisely, the degree of difficulty involved in managing this complexity. From an engineering point of view, a number of problem-solving techniques are necessary to reduce the complexity to a manageable level. However, it is important that the techniques chosen be proven, methodical, adaptable, and offering the capability to gain both a high-level as well as a low-level understanding of the problem. These characteristics are representative of software engineering methods such as information engineering, structured analysis and design, and object-oriented analysis and design. A review of the fundamentals of these techniques has presented their inner workings as well as the rationale behind their application to the business of mining. In addition, computer-aided software engineering tools offer the automated support necessary to effectively utilize these techniques and thus manage the complexity. Finally, the applicability of both methods and tools has been demonstrated by undertaking a top-down analysis of a Mine Information System and subjecting a specific mining process to further scrutiny.

The key success factor in the analysis, design, and implementation of mining information systems is a focus on global *integration* above local functionality. Systems analysis provides the framework necessary to achieve this goal. Although considerable up-front effort is required in the preliminary stages of planning and analysis, long-term payback can be expected.

6.3 Recommendations for Future Work

Future work could include the following, to:

i) further explore the suitability of several object-oriented methodologies in the analysis and design of real-time mining information systems;

ii) translate the information captured in the system model into a database architecture for Oracle® and carry through the software development life cycle for a specific process, e.g. drilling;

iii) instrument a drill accordingly and interface it to the database via a communications network;

iv) use this platform as a test case to physically assess the benefits of systems analysis on the development of mining systems;

v) expand the system model to build a comprehensive abstract representation of the mining environment by consolidating current practices and new concepts;

vi) use this model to evaluate the impact of robotic systems on the overall mining process.

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Please note that the paragraph following the reference is an abstract or excerpt taken directly from the source with little or no modification.

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A CANMET sponsored, NRC financed project was let to INCO Ltd. to develop an underground load-haul-dump vehicle monitoring system. INCO with subcontracting to Advanced Electronic Systems Ltd. and the Ontario Research Foundation has been working on this microprocessor based monitoring system since December 1986. The system uses an on-board microprocessor and sensors which are linked to a base station computer (IBM PC AT) by radio. The main objectives of the project are to increase component life, improve safety, reduce fleet size, lower maintenance costs and aid in the diagnosing of potential problems. This paper describes the monitoring system and preliminary results.

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Underground communication infrastructure has now been developed which will allow the application of teleoperated and autonomous mine equipment. A PRECARN supported research program, the Mining

Automation Project (MAP) has been developed by INCO Ltd., Falconbridge Ltd., the Canadian Center for Automation and Robotics in Mining (CCARM), and the Queen's Center for Resource Studies (CRS). MAP will address the development of applications using artificial intelligence (AI) and Robotics based on a communication infrastructure for mining automation in the 21st century. Experimentation with real-time monitoring and control of robots in the mining environment and AI techniques will be necessary to develop the systems to enable the automated operation of a mine. This paper will discuss the process to identify, design, develop, and experiment with techniques which fit into an overall mine automation strategy.

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This paper describes recent developments at INCO Ltd., Ontario Division, in the field of information systems for automated mining (FOREMAN Project). A CATV cable network has been combined with a broad spectrum radio antenna system to allow the supply of voice, data, and video services to underground mobile and stationary locations. The system formed the basis of a field experiment at the Copper Cliff North Mine in 1990. In order to test the communications system, telephones and radios were linked together with outside phone lines for voice communication. Stationary data was implemented on a supervisory control and data acquisition (SCADA) system for mine monitoring and control using programmable logic controllers (PLCs), while using personal workstations for the mine planning and engineering functions. Stationary video was installed in the experiment to observe crushing, conveyor transfer points, and skip dumping areas. Mobile data and video were tested by the teleoperation of an LHD. The functions supplied to the vehicle were monitored through a computer, with control being maintained through a standard radio interface and real time video pictures for the operation of the machine. This paper discusses the field testing of the information system and results achieved to date. It concludes by discussing the options considered to be open to provide information systems for future automated mining.

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Automatic Haulage Truck: Design, Development, and Mine Implementation at INCO Ltd.
CIM Bulletin. **85**. 964. *41-46*. October 1992.

An Automatic Haulage Truck (AHT) has been developed for manless tramming of run-of-mine material in an operating mine. The AHT has 70-ton capacity and used electric trolley system in combination with a computer control system to operate the vehicle. The purpose of the AHT was to provide a high capacity, high productivity material transfer system where conveyor belt applications are not immediately practical. The AHT project was started in 1983 at INCO Ltd., Ontario Division as a result of the need for rapid material transport to match increased extraction rates resulting from bulk mining methods. The original concept was to use a continuous loader with the truck. However, in order to minimize development problems, the truck project was considered a stand-alone project. The AHT project consisted of concept development, preliminary and detailed design, manufacture, surface testing and mine implementation. The AHT was manufactured and ready for testing in 1988. At this point the truck was first moved onto the test track for debugging. This proved successful and in 1989 the decision was made to install the AHT at Little Stobie mine on 2000 level. Commissioning of the system was started in 1990 and at present a fully-functional automated haulage system is in place at Little Stobie mine producing 3000 tons a day. This paper describes the project presenting results achieved to date.

[Baiden93a] Baiden, G.R.
A Study of Underground Mine Automation.
Ph.D. Thesis. Department of Mining and Metallurgical Engineering. McGill University. Montreal, Quebec. March 1993.

A review of automation, robotics, and communications technology has established the need for the development of a communications infrastructure capable of supporting future underground hard rock mine automation systems. A series of underground experiments were undertaken at Copper Cliff North Mine to evaluate the design criteria and performance of several communications infrastructures. The work successfully demonstrated the capability of real-time operation of voice, data, and stationary video communication, as well as surface-to-underground teleoperation of a load-haul-dump machine. This was achieved with a communications system consisting of a broadband bus linked to a leaky feeder coaxial cables by means of distributed antenna translators (DATs). The success of the trials permitted a strategy for mine automation to be devised. The economic benefits, evaluated in terms of mining cost reduction, throughput time and quality improvement, were concluded to be significant. As a result of the analysis, future research and development is concluded to be best targeted at improving ore grade, optimizing process productivity and maximizing machine utilization.

[Baiden93b] Baiden, G.R.; Scoble, M.J.; Flewelling, S.
Research into the Design and Implementation of Hardrock Mine Automation.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *357-362.* [Bawden93]

It has only been in the last few years that the underground hardrock mining sector has begun to recognize both the feasibility and the necessity of automation. It is recent advances in information technology that have created the potential for hardrock mine automation. This paper considers what was seen as the priority challenge to the implementation of mine automation, namely: effective infrastructure to support voice, data and video communication for both stationary and mobile locations. It reports on underground studies that have evaluated the design criteria for effective communication infrastructure and the economic potential. In conclusion, the paper reviews a strategy for mine automation and a new initiative in Canada for mine automation research.

[Baiden93c] Baiden, G.R.
Combining Teleoperation with Vehicle Guidance for Improving LHD Productivity at INCO Ltd.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *527-532.* [Bawden93]

This paper discusses the application of load-haul-dump (LHD) machine teleoperation in combination with a guidance system for single operator control of multiple LHDs. A system accomplishing these goals has been tested at Copper Cliff North Mine of INCO Ltd. This development uses a high speed, high capacity production network to teleoperate an LHD during loading by supplying 3D video and teleoperation control. Following loading, the operator dispatches the LHD using an automatic guidance system to traverse the drifts to the orepass. Manual dumping occurs at the orepass and then the machine returns to repeat the procedure. This has significant productivity gains and improvements in safety. Productivity is improved since the operator is only involved in the loading and dumping part of the process. This frees the operators to utilize their time more effectively loading or dumping a particular machine while other machines with guidance systems will be continuing to work traveling and/or automatically dumping ore in the orepasses. Safety is improved as the operator is located on a remote control station and only involved in the material handling process remotely.

[Baiden94a] Baiden, G.R.
Research and Development Plan for Robotic Mining of the 175 Orebody.

INCO Ltd., Mines Research, Automation and Robotics. Copper Cliff, Ontario. Internal Report. 1994.

Remote Control or Robotic Mining will be an absolute necessity if INCO's long term survival in Canada is to be assured. This is due to increasing labor rates, legislated costs, and depth of future mining. This Research and Development proposal is targeted at all the necessary attributes required to use robotics to mine the 175 orebody of the Copper Cliff North Mine complex. This proposal also addresses management concerns about the PRECARN Mining Automation Plan (MAP) project. It specifically discusses the technology and personnel development plan in the MAP project as it relates to the robotic mining and shows the complementary nature of these two projects. It is recommended that the PRECARN MAP project proceed with the minor modifications discussed in this proposal. The R&D plan for the 175 orebody is a long range view of the necessary elements to achieve robotic mining. It is a continuous development program achieving results throughout the five year plan. The project will require major changes to the Mines Research Department in terms of structure and personnel.

[Baiden94b] Baiden, G.R.; Henderson, E.
LHD Teleoperation and Guidance: Proven Productivity Improvement Tools.
96th CIM Annual General Meeting. Toronto, Ontario. May 1-4, 1994.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *77-86.* [Daneshmend94]

An LHD teleoperation and guidance system, developed at the Ontario Division of INCO Ltd., has been demonstrated in operation at Copper Cliff North Mine (CCNM) since late September 1993. The tests performed to date have evaluated the feasibility and production viability of multiple LHD operation, from surface by one operator. The systems technology required to accomplish this consists of: an electronic monitoring and control package mounted on the LHD; a high bandwidth mining computer network capable of providing radio frequency coverage; and an operator control console which provides an operator workstation for multiple LHD operation. This paper discusses the systems required to accomplish the task of LHD teleoperation and guidance, the benefits of multiple machine operation and future research and development directions.

[Baiden95] Baiden, G.R.
Future Robotic Mining: The Next 25 Years.
97th CIM Annual General Meeting. Halifax, Nova Scotia. May 14-18, 1995.
<u>CIM Bulletin.</u> **89.** 996. *36-40.* January 1996.

The next 25 years will see major changes in underground mining equipment and methods through the gradual introduction of robotic mining equipment. The necessary components of this change are already being experimented with and some are in production today. This paper explores the elements required to achieve robotic mining: telecommunication systems, robotic mining equipment, underground positioning systems, and robotic mining software. The economics of moving to robotic mining are discussed.

[Bascur93] Bascur, O.A.
Bridging the Gap Between Plant Management and Process Control.
Emerging Computer Techniques for the Minerals Industry. SME Annual Meeting and Exhibit. Reno, Nevada. February 15-18, 1993. *73-81.* [Scheiner93]

Current competitive demands on the process industries stimulate the need for improved operating efficiencies and compliance to stricter governmental regulations. Emerging information technologies allow narrowing the gap between management business objectives and the process control level. Benefits come from enhanced energy management, operating costs reduction, enhanced scheduling of activities, reduced quality giveaway, enhanced market driven production and enhanced decision making. Plant management systems integrate economic performance monitoring by controlling the business rather than just throughput and product quality. Sound business based decisions about how to operate the plant can be achieved by adequate dynamic performance monitoring at the plant level and the enforcement of the desired targets at the process control level. This paper describes some of the key requirements to implement a process management system to meet stricter process performance standards. Extensions are made to facilitate conforming with regulations established by various governmental and industry monitoring agencies.

[Bawden93] Bawden, W.F.; Archibald, J.F. (Editors)
Innovative Mine Design for the 21st Century.
A.A. Balkema. Rotterdam, Netherlands. Proceedings of the International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993.

[Berard93] Berard, E.V.
Essays on Object-Oriented Software Engineering.
Prentice-Hall. Englewood Cliffs, New Jersey. 1993.

[Beus92] Beus, M.J.; Orr, T.J.
Applications of Real-Time Monitoring to an Underground Mining Environment.
5th Canadian Symposium on Mining Automation. Vancouver, British Columbia. September 27-29, 1992. *68-77.* [Piche92]

U.S. Bureau of Mines researchers are using computerized data acquisition systems and real-time monitoring to visualize underground metal mining operations, including deep shafts, cut-and-fill mining in creeping ground, and drift-and-fill mining. Sensors monitor rock mass deformation and strain, support loads, temperature, SO_2 emissions, and blasting. The system functions through a distributed PC-DOS network and high-speed modems. Results from testing at several mines in South Dakota, Idaho, and Alaska show the system improves confidence in ground control measurements and could improve mine productivity and decrease mining costs. Data scans are triggered by blast sensor alarms, as well as recorded periodically. Results are visualized on a real-time basis within the context of the process being monitored. Research is underway to define and test specific process control functions, such as air doors, ventilation fans, and shaft hoisting, and loading pocket operations using the sensor and processor network. A multi-user, graphical interface is being evaluated for monitoring and control of the underground mine environment.

[Boehm88] Boehm, B.W.
A Spiral Model of Software Development and Enhancement.
IEEE Computer. **21.** 5. *61-72.* May 1988.

The spiral model presented in this article is one candidate for improving the software process model situation. The major distinguishing feature of the spiral model is that it creates a risk-driven approach to the software process rather than a primarly document-driven and code-driven process. It incorporates many of the strengths of other models and resolves many of their difficulties. This article opens with a short description of software process models and the issues they address. Subsequent sections outline the process steps involved in the spiral model; illustrate the application of the spiral model to a software project;

summarize the primary advantages and implications involved in using the spiral model and the primary difficulties in using it at its current incomplete level of elaboration; and present resulting conclusions.

[Booch86] Booch, G.
Object-Oriented Development.
IEEE Transactions on Software Engineering. **SE-12.** 2. *211-221.* February 1986.

[Booch94a] Booch, G.
Object-Oriented Analysis and Design with Applications.
Benjamin/Cummings. Redwood City, California. 2nd ed. 1994.

[Booch94b] Booch, G.
Software Engineering with Ada.
Benjamin/Cummings. Redwood City, California. 3rd ed. 1994.

[Booch94c] Booch, G.
Measures of Goodness.
Report on Object Analysis and Design. **1.** 2. *8-10, 14.* July-August 1994.

[Bostwick93] Bostwick, C.J.; Buchanan, T.L.
Computer-Aided Achievement of Mine Planning and Production Goals at Barrick Goldstrike Mines Inc.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *303-311.* [Bawden93]

Over the past five years American Barrick Resources has implemented an extensive suite of systems designed to assist in achieving an aggressive 415,000 tpd mining program at the Goldstrike operation near Elko, Nevada. Goldstrike employs a mix of software to undertake reserve modeling, long-range planning, equipment evaluation, short-range planning, ore control and daily production optimization and accounting. The key to integrating these functions is utilizing the best off-the-shelf software currently available and developing custom applications to Goldstrike's specifications when software does not exist to meet the requirements.

[Braithwaite88] Braithwaite
Analysis, Design, and Implementation of Data Dictionaries.
McGraw-Hill. New York, New York. 1988.

[Brooks87] Brooks, F.
No Silver Bullet: Essence and Accidents of Software Engineering.
IEEE Computer. **20.** 4. *10-19.* April 1987.

[Burns94] Burns, A.; Wellings, A.J.
HRT-HOOD: A structured Design Method for Hard Real-Time Systems.
Real-Time Systems. **6.** 1. *73-114.* January 1994.

Most structured design methods claim to address the needs of hard real-time systems. However, few contain abstractions which directly relate to common hard real-time activities, such as periodic or sporadic processes. Furthermore, the methods do not constrain the designer to produce systems which can be analyzed for their timing properties. In this article we present a structured design method called HRT-HOOD (Hard Real-Time Hierarchical Object Oriented Design). HRT-HOOD is an extension of HOOD, and includes object types which enable common hard real-time abstractions to be represented. The method is presented in the context of a hard real-time system life cycle, which enables issues of timeliness and dependability to be addressed much earlier on in the development process. We argue that this will enable dependable real-time systems to be engineered in a more cost effective manner than the current practice, which in effect treats these topics as performance issues. To illustrate our approach we present a simple case study of a Mine Drainage Control System, and show how it can be designed using the abstractions presented in the article.

[Bylinsky94] Bylinsky, G.
The Digital Factory.
Fortune, **130.** 10. *92-110.* November 14, 1994.

The new American factory is an Information Age marvel that is enabling U.S. manufacturing, declared dead more often than a lathe turns, to come storming back. In industries as diverse as construction equipment, cars, PCs, and electronic pagers, Japanese and European producers are scrambling to copy American techniques. The new automation paradigm they are looking to involves an ingenious balancing in which software and computer networks have emerged as more important than production machines, in which robots play a mere supporting role, if they are present at all, and in which human workers are back in unexpected force. Call it the *digital factory*, for its dependence on information technology, or the *soft factory*, for its mix of the human and the mechanical. Whatever you call it, it is likely to set the tone of manufacturing for years, even decades, to come.

[Campbell91] Campbell, P.S.; Smith, B.F.
An Integrated Mine Planning System for Geology, Surveying, and Engineering.
Second Canadian Conference on Computer Applications in the Mineral Industry. Vancouver, British Columbia. September 15-18, 1991. *115-126.* [Poulin91]

An integrated mine planning system has been developed on a CAD platform. The CAD system is based on solids modeling, utilizes object-oriented concepts, is programmable in C, and has a user-defined schema for attaching attributes to graphical objects. The mine planning system provides integrated tools for ore reserve estimation, stope design, development lay-out and survey control, all within one database structure. The use of an object-oriented solid modeler has startling implications in geological block modeling, eliminated most engineering drafting and simplifies month-end volumetric calculations.

[Campbell93] Campbell, P.S.; Smith, B.F.
Models and Drawings in CAD-Based Mine Design.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *659-669.* [Bawden93]

In mine design, very much more than geometric information must be considered. Information like tonnes and grade of the orebody by zone, stope, or blast is very important but is typically not included in a CAD-drawing system. In order to be a useful design tool, designers of mines require a complete model of the mine consisting of geometric and non-geometric data. Such a model must contain all information that an engineer might wish to consider in the course of designing a mine. This information might consist of

diamond drill hole data, geological interpretations, ore reserves, structural geology, ground stresses, costs, schedules as well as geometric data from existing and planned excavations. At best, this non-geometric information is very difficult to link with entities in a drawing system.
A CAD-design system must strive to build a complete model of all data in the design process. To be of practical use, non-geometric information must be as accessible as geometric information is. Falconbridge has developed such a model-based mine design system. The system was built on a CAD platform that uses solid modeling. The solid modeller, is object-oriented, uses a hierarchical data structure, has an internal database for storing and retrieving object attributes, and is programmable in C. This paper will focus on Falconbridge's modeling approach versus a more conventional drawing methodology.

[Carter94] Carter, P.
Real-Time Mine Management Systems.
AIC Mining Information Technology Conference. Sydney, Australia. February 16-17, 1994.

The processes that consume expenditure and determine output in a mining operation occur in real time in an environment dominated by unpredictable events and variable conditions. Mining has long been regarded as an inexact science conducted in unpredictable circumstances with many independent variables affecting the output and resultant cost of production. Financial accountants keep track of expenditure and management accountants analyze the cost of production usually on a weekly or monthly basis, but all this effort cannot affect the outcome that was determined by the real-time events and variations of circumstances over a week ago. Such reporting and analysis can result in conclusions being drawn about what improvements can be made and how you might do better next time, but generally, the data is not detailed enough, is distorted by job function bias or misrepresents the real issues.

[Casteel95a] Casteel, K.
Concurrent Engineering: Thinking Fast, Free-Form and Virtual Reality.
World Mining Equipment, **19.** 1. *35-37.* January/February 1995.

Mining has been quick to apply advances in computer graphics to the modeling of deposits and mines. Similarly, equipment manufacturers have made good use of computer aided design and engineering techniques such as finite element analysis. It's also the case that mine project management teams recognized awhile back the value of what is known as concurrent, or simultaneous, engineering, the carrying out of elements of an engineering project in parallel rather than in sequence. Presently in use but also under development, are two techniques which, used in concurrent engineering projects, have potential to make the design and realization of mines and their equipment quicker, more efficient, and safer.

[Casteel95b] Casteel, K.
Masterhaulers of Sudbury.
World Mining Equipment, **19.** 6. *20-24.* July/August 1995.

Technically exciting and cost-effective technologies have been under study and, in some cases, under development by INCO's Mines Research unit at Copper Cliff in collaboration with mine management. In particular, INCO engineers have focused on new systems for automating the drilling and haulage functions in bulk mining methods and on more cost-effective mechanized drilling and hauling for other mining methods. These new technologies are being applied at the largest of the existing Sudbury mines, Stobie, and in the new orebodies presently being developed in the area, at McCreedy East, Craighton Deep, and Victor Deep. This article reports on the haulage aspects, while INCO's work on automated and narrow vein drilling technology will be reported in the October issue of WME.

[Chadwick92] Chadwick, J.

Mount Isa: Mining.
Mining Magazine. **167.** 1. *10-21.* July 1992.

[Champigny91] Champigny, N.; Pearson, W.N.; Gibbs, B.L.
The Need for Data Interchange Standards for Mining Systems.
Second Canadian Conference on Computer Applications in the Mineral Industry. Vancouver, British Columbia. September 15-18, 1991. *925-934.* [Poulin91]

Software has been under continuous development over the last decade and as a result, a number of ore deposit modeling and mine planning systems are availbale to mining practitioners in the 1990s. Even though manu systems offer a full range of capabilities they all suffer from lack of compatibility with other systems. This compatibility problem can only be solved through the adoption of data interchange standards. Implementation of such standards would: i) facilitate data exchanges between mining organizations, consultants, universitites, and other mining systems users; ii) eliminate the nedd for mining systems vendors to develop their own data interchange format and thus allow the vendors to focus their efforts on the development of specialized products rather than data conversion routines; iii) encourage mining organizations to purchase commercial systems that use the standards rather than develop their own in-house systems. The paper discusses the benefits to be gained from the use of data interchange standards and reviews initiatives underway to implement standards in Australia, USA, and Canada.

[Chen76] Chen, P. P.
The Entity-Relationship Model: Toward a Unifying View of Data.
ACM Transactions on Database Systems. **1.** 1. *9-36.* March 1976.

[Clarke93] Clarke, D.; Sharman, K.
Modelling, Planning, and Mining a Geologically Complex Coal Deposit.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *237-246.* [Bawden93]

Quintette Operating Corporation operates a large open pit coal mine located in northeastern British Columbia, Canada. The mine is comprised of 3 main pits (Mesa, Wolverine, and Shikano) which employ truck and shovel mining techniques to produce 4.35 million tonnes of metallurgical coal annually. The geological structure is extremely complex. A high degree of folding and imbricate thrust faulting within the main syncline and anticline features has resulted in coal seams with dips ranging from nearly flat to overturned. Mineable seam thicknesses vary from 0.6 to 10 meters. The complexity of the deposit has made interpreting, planning, and mining a challenge and has necessitated the adaptation of the most up to date three-dimensional modeling and planning technology available to Quintette's unique operation.

[Coad91a] Coad, P.; Yourdon, E.
Object-Oriented Analysis.
Yourdon Press. Englewood Cliffs, New Jersey. 2nd ed. 1991.

[Coad91b] Coad, P.; Yourdon, E.
Object-Oriented Design.
Yourdon Press. Englewood Cliffs, New Jersey. 1991.

[Coleman94] Coleman, D.; Arnold, P.; Bodoff, S.; Dolly, C.; Gilchrist, M.; Hayes, F.; Jaremaes, P.
Object-Oriented Development: The Fusion Method.
Prentice-Hall, Englewood Cliffs, New Jersey. 1994.

[Connell93] Connell, R.E.
Emerging Computer Techniques for the Minerals Industry and Noranda's Commitment to Excellence.
Emerging Computer Techniques for the Minerals Industry. Reno, Nevada. February 15-18, 1993. *173-182.* [Scheiner93]

From a macro business process perspective, the mining industry may be considered a "simple business". If it is so simple, where does information technology fit ? How does it affect our industry ? Is it a strategic tool ? What approach should we be employing to ensure we are utilizing information technology effectively ? How is information technology integrated or tied together with other areas in the organization such as process control ? What kind of people and skill sets are required to support the whole area of information technology ? What effect does information technology and automation have on streamlining and rethinking the way we do business in the 90s ? This paper covers how these areas have been addressed within the Noranda Group of Companies. It reviews how information technology has evolved, the approach and what effect it has had on a diversified natural resources company in the mining and metals, forests products, and oil and gas industries.

[Cownie94] Cownie, J.
Boeing's New 777: "Right-First-Time".
Engineering World. *8-10.* August 1994.

Boeing's 777 incorporates major technological advances than any previous design from the company. Paramount among these is AIMS, the information management system which embraces flight management, control of glass cockpit displays, central maintenance condition monitoring, and digital communications management. The exploitation of an almost paperless "right-first-time" philosophy has been used in the design of Boeing's new 777. Using the Dessault/IBM CATIA (computer-aided three dimensional interactive application) system, engineers were able to optimize the aircraft's conception, manufacture, and service and development life.

[Cox91] Cox, B.J.; Novobilski, A.J.
Object-Oriented Programming: An Evolutionary Approach.
Addison-Wesley. Reading, Massachussetts. 2nd ed. 1991.

[Cummins73] Cummins, A.B. (Editor)
SME Mining Engineering Handbook.
Society of Mining Engineers (SME) of the American Institute of Mining, Metallurgical, and Petroleum Engineers Inc. (AIME). New York, New York. 2 vols. 1973.

[Cutts90] Cutts
Structured Systems Analysis and Design Methodology.
Van Nostrand Reinhold. New York, New York. 1990.

[Dahl73] Dahl, O.-J.; Myrhaug, B.; Nygaard, K.
SIMULA Begin.
Auerbach. Philadelphia, Pennsylvania. 1973.

[Daneshmend94] Daneshmend, L.K. (Editor)
6th Canadian Symposium on Mining Automation.
Canadian Centre for Automation and Robotics in Mining (CCARM). Proceedings of the 6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994.

[Dasys94] Dasys, A.; Drouin, A.; Louis, G.
Teaching an LHD to Muck.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *87-93.* [Daneshmend94]

Mining automation research has put a concentrated effort in the development of mining production vehicles capable of traveling in mine drifts without operator intervention. Vehicle guidance is but one part of the automation puzzle that must be combined in order to implement a manless mucking system within a modern mine. This paper presents the work done in automating the loading cycle of a load-haul-dump (LHD) vehicle. The paper briefly describes HDRK Mining six year research project, the current control hardware and software.

[Desfray92] Desfray, P.
Ingénierie des objets: Approche classe-relation application à C++.
Editions Masson. Paris, France. 1992.

[Dejesus95] Dejusus, E.X.
Big OOP, No Oops.
Byte. **20.** 8. *74-78.* August 1995.

GTE Government Systems is completely rewriting the firmware and software for its new high-capacity ATM (asynchronous transfer mode) switch. The GTE project team adopted the Shlaer-Mellor object-oriented analysis and design methodology to undertake this task, supported by Cadre Technologies' ObjectTeam for Shlaer-Mellor CASE tool running on Sun SPARC Stations. Benefits of using this method, such as reuse, concurrent development, and simplified upgrades, are discussed.

[DeMarco79] DeMarco, T.
Structured Analysis and System Specification.
Prentice-Hall. Englewood Cliffs, New Jersey. 1979.

[Devine94] Devine, M.; Brogden, I.
Information Technology Planning: Critical for Implementing Advanced Manufacturing Automation.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *239-256.* [Daneshmend94]

The successful implementation of flexible automation systems in manufacturing enterprises requires significant investment of resources and executive leadership in the process of information technology planning. Forward-thinking mining companies that understand the value of implementing advanced automation systems to remain competitive can learn from the experiences of manufacturing companies. By recognizing the key role that information technology planning has played in successfully enabling the rapid introduction of new technologies into manufacturing operations, they can achieve similar results in their mining operations. We describe the major components of a business driven information technology plan and discuss the factors critical for successful development and implementation of the plan.

[EDS93] High Level Information Requirements for INCO's Mine Operation.
EDS Canada. Internal Report to INCO Ltd. November 1993.

[EDS94a] EDS Technology Policy.
Electronic Data Systems Corporation. Plano, Texas. Internal Report. March 1994.

[EDS94b] Upper CASE Tool Product Evaluation.
Electronic Data Systems Corporation. Plano, Texas. Internal Report. August 1994.

[EDS94c] Configuration Management for FOREMAN II.
EDS Canada. Internal Report to INCO Ltd. Technical Consulting Program Class XXXIV. August 1994.

[EDS94d] FOREMAN Statement of Technical Direction.
EDS Canada. Internal Report to INCO Ltd. October 1994.

[EDS95a] FOREMAN Technology Business Case.
EDS Canada. Internal Report to INCO Ltd. February 1995.

[EDS95b] FOREMAN Information Technology Architecture.
EDS Canada. Internal Report to INCO Ltd. May 1995.

[Embley92] Embley, D.W.; Kurtz, B.D.; Woodfield, S.N.
Object-Oriented Systems Analysis: A Model-Driven Approach.
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1992.

[Federchuck95] Federchuck, B.; Sas, J.A.
Central Control and Mine Automation at Falconbridge, Kidd Creek Mines.
97th Annual General Meeting. Halifax, Nova Scotia. May 14-18, 1995. Paper 36.2.
CIM Bulletin. **89.** 996. *33-35.* January 1996.

Falconbridge Ltd. Kidd Creek Mine, in Timmins, has decided to install a Central Hoisting facility to control seven hoists from three distinct head frames, two located on surface and one internal shaft on the 4700 foot level. The central hoisting facility will be located in the Administration Building dry area and will be able to operate and trouble shoot the hoists from Central Control or remotely from Montreal. Over the past three years, Kidd Creek and ABB have been working closely together with the installation and upgrading of PLC based hoist controls, ultimate hoist monitors, that replaced the Lilly Controller, and loading pocket controls. With the installation of these high tech products, we are now able to bring all the controls back to a central location to provide a safe, productive, efficient control as well as an information highway for operators, maintenance and management personnel. It will provide the computer infrastructure to build on the future for the integration of other mining functions into the system. This paper describes the reasoning for the Central Control as well as the technology used.

[Firesmith93] Firesmith, D.G.
Object-Oriented Requirements Analysis and Logical Design: A Software Engineering Approach.
John Wiley & Sons. New York, New York. 1993.

[Flye88] Flye, G.S.
A Fully Integrated Production Information System at Newmont Gold.
First Canadian Conference on Computer Applications in the Mineral Industry. Quebec City, Quebec. March 7-9, 1988. *503-509.* [Fytas88]

An essential factor in cost competitiveness for today's mining operations is the efficient use of information to aid in decision making. This paper describes the development of a fully integrated production information system utilizing distributed database and fourth generation language technology. Areas of application include mine production, ore movement, mill production, laboratory automation, warehouse inventory, equipment maintenance, exploration drill hole logging, and finished material accounting. The techniques employed in designing this multi-database system are described with special emphasis upon the integration of each database system with all others. Each component database system is evaluated in terms of realized or anticipated benefits, followed by a concluding evaluation of the entire project.

[Fortney96] Fortney, S.J.
Advanced Minewide Automation in Potash.
CIM Bulletin. 89. 996. *41-46.* January 1996.

This paper covers the minewide automation program at the Potash Corporation of Saskatchewan Inc., Rocanville Division. TH emain focus of the paper is the automation of the five Marietta 780-AW4 rotary miners. Other subsystems of the automation, such as broadband, central control room, communications options, hoist integration, and various maintenance and operating concerns are addressed. The miner automation program focussed on utilizing a system which would not alienate the operator and would be as easy to maintain as possible. The use and application of scintillation, laser guidance, ultrasonics, vision systems, digital videao and remote control, as it applies to the miner, is presented. A discussion of operator acceptance, maintenance training, costs savings and improvements to the operation is included.

[Fytas88] Fytas, K.; Collins, J.-L.; Singhal, R.K. (Editors)
Computer Applications in the Mineral Industry.
A.A. Balkema. Rotterdam, Netherlands. Proceedings of the First Canadian Conference on Computer Applications in the Mineral Industry. Quebec City, Quebec. March 7-9, 1988.

[Gane79] Gane, C.; Sarson, T.
Structured Systems Analysis: Tools and Techniques.

Prentice-Hall. Englewood Cliffs, New Jersey. 1979.

[Gibbs90a] Gibbs, B.L.
Mining Software Trends and Applications.
Mining Engineering. **42.** 8. *974-981.* August 1990.

[Gibbs90b] Gibbs, B.L.
Ore Body Modeling and Mine Planning Software.
Mining Engineering. **42.** 8. *976-979.* August 1990.

[Gibbs90c] Gibbs, B.L.
SME/COGS Computer Bulletin Board is Open for Business.
Mining Engineering. **42.** 8. *982-984.* August 1990.

[Gibbs91a] Gibbs, B.L.
Toward a Mining Data Standard.
Computers & Mining. **6.** 9. *1-4.* May 1991.

More than 15 software vendors offer integrated mining systems which in many respects provide similar capabilities for deposit modeling and mine planning. However, one feature common to all is the lack of compatibility between the systems. The difficulties of transferring data between systems means that the vendor must develop complete systems even if their expertise is stronger in one area than in another.

[Gibbs91b] Gibbs, B.L.; Krajewski, S.A.
Workshop Attendees Compare Ore Modeling and Mine Planning Software Systems.
Mining Engineering. **43.** 7. *732-737.* July 1991.

[Gibbs92] Gibbs, B.L.; Krajewski, S.A.
Surface and Underground Mine Modeling with Computers.
Mining Engineering. **44.** 7. *689-692.* July 1992.

[Gibbs94a] Gibbs, B.L.
Computer Use in the Minerals Industry.
Mining Engineering. **46.** 3. *208-213.* March 1994.

To attain a better understanding of how computers are used by minerals producers in the United States and Canada, Gibbs Associates developed a survey questionnaire and in 1991 sent it to 1800 companies across the full range of company sizes and commodity types. The questionnaire covered hardware and software, users and uses, training and plans for future computer expenditures. 112 responses were received. To update the 1991 survey information, selected respondents were contacted directly in the fall of 1993 and asked about changes that had occurred during the past 2 years.

[Gibbs94b] Gibbs, B.L.
Computers: The Catalyst for Information Accessibility.
Mining Engineering. **46.** 6. *516-517.* June 1994.

A general overview of mining applications for the information age: CAD systems, information sources (the Internet and software directories), mining software packages, GPS, and GIS.

[Glass83] Glass, R.L.
Real-Time Software.
Prentice-Hall. Englewood Cliffs, New Jersey. 1983.

[Goldberg84] Goldberg, A.
Smalltalk-80: The Interactive Programming Environment.
Addison-Wesley. Reading, Massachussetts. 1984.

[Gould88] Gould, G.B.; McConechy, B.; Srajer, V.
Equipment Performance Monitoring.
First Canadian Conference on Computer Applications in the Mineral Industry. Quebec City, Quebec. March 7-9, 1988. 463-470. [Fytas88]

This paper describes Gregg River's evaluation of OBDAS, a real-time equipment performance monitoring system developed by Philippi-Hagenbuch Inc. For the evaluation, OBDAS was installed on two 154 tonne haul trucks and operated for a six month trial period starting January 1987. During this time a series of studies were carried out to test the reliability, accuracy, and repeatability of the system. The presentation will describe the system and its installation, the findings and conclusions of the studies and its potential role as a building block in developing an equipment management system.

[Grady90] Grady, L.; Holm, V.; Mitts, R.; Brumit, P.
Short Term Mine Planning and Grade Control Practice at the Mesquite Mine.
Mining Engineering. **42.** 2. *187-190.* February 1990.

The Mesquite mine is a large, open pit, heap leach gold mine owned and operated by Gold Fileds Operating Company. The mine uses a fully integrated mine planning and reserve modeling software system developed at the mine. The system has recently been extended to include short-term mine planning, grade control, and daily production reporting. The grade control portion of the program uses a multiple indicator krieging approach using the blasthole spacing and exploration assays. The program permits ore control geologists and mine planning engineers to have immediate access to all the information.

[Graham94] Graham, I.
Object-Oriented Methods.
Addison-Wesley. Reading, Massachussetts. 2nd ed. 1994.

[Grant90] Grant, R.W.; Patterson, S.C.; Krause, B.R.
A Borehole Information System Incorporating AutoCad.
Computer Treatment of Exploration and Mining Data Workshop and Exhibition. Toronto, Ontario. March 9-10, 1990.

Bore hole data are crucial to exploration and are valuable corporate assets. IETS has accumulated data for many thousands of boreholes. Approximately 600 new boreholes from 25 projects are added annually. This information must be stored securely and be readiliy accessible. A borehole information system developed to meet these needs utilized PC-compatible and DEC Micro VAX hardware. Software was purchased or

developed as warranted, to create an open, modular system. All programs are open to data exchange allowing unobstructed data flow. Comprehensive commercial systems were not adopted since none were entirely suitable; most did not have sufficient capacity and many suffered from inflexible data formats with no acceptable means of exchanging data with other applications.

[Gray91] Gray, J.; Amon, F.; Peck, J.
Integrated Mine Planning and Production.
5th CIM District 5 Meeting. Fort McMurray, Alberta. September 17-20, 1991.

In order to achieve common objectives in Mine Planning and Operations and optimize unit costs, it is necessary to integrate the different mining functions in both groups. The first step is to measure the condition of the muckpile at the different stages of development. Information on pre- and post-blast conditions necessary for optimization can be acquired in an automated manner using instrumentation on blasthole drills and mining shovels. The paper reviews current available technology in drill and shovel monitoring, mine engineering application systems, data processing and analysis, positioning and locating of equipment, and the integration of performance monitoring data. The management information system at Highland Valley Copper is described.

[Grenier94] Grenier, A.; Chevrette, G.; Coache, C.
Noranda Automatic Guidance System Architecture Overview.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *116-119.* [Daneshmend94]

This paper covers the architectural decisions that were made to identify and select the components of an Automatic Guidance System adapted for LHD vehicles and low profile trucks in an underground mine environment. All the decisions were made on the understanding that the target system will need to exceed the overall performance of current operators in order to get general acceptance. The selection of the components was also based on a list of criteria such as maintainability, robustness, and testability to assure the success of an implementation on a production environment.

[Hackwood93]Hackwood, J.; Poole, R.
Selection of Media for a High Bandwidth Utility to Serve as the Backbone of a Mine Information System.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *891-899.* [Bawden93]

As a result of five years of research and development on its Future Ore Manufacturing (FOREMAN) project, INCO Mines Research and its partners have developed a communications and information system that supports the current and future demands for underground mining automation and control. The system is capable of supporting simultaneously, over a single cable system, mobile and fixed information services for voice, video and data. As the backbone for the system, a high bandwidth broadband coaxial cable system has been selected. This paper discusses the criteria around which this selection was made. Consideration of high bandwidth architecture utilizing fiber optic cable is discussed. Other media types, such as unshielded twisted pair, shielded twisted pair and simple coaxial cable are not discussed because of the relative low bandwidth.

[Hackwood94]Hackwood, J.; Poole, R.
The Evolution of Mine Communications: A Utility for Modern Automation and Related Services.

6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *218-224.* [Daneshmend94]

The latest communications systems used in conjunction with automated equipment and related services represent the single most important opportunity for improving mine productivity and personnel safety. The telecommunications system is the utility on which modern automation technologies and related services are supported. The wired and wireless communications services on the system provide the modern mine with the same benefits as those which automated manufacturing plants have achieved over the last few decades. Overlooked as an essential utility in the underground mine, implementation of modern mine communication systems is often an after-thought. In the past this could easily be seen because the communication systems supported only limited services; therefore the communications infrastructure was considered non-essential. This is not true any longer. The latest generation in communication technology is a system that supports the current underground communication requirements for improved safety, productivity, and reduced costs. The applications supported include data acquisition and control, radio voice communication, computer networks, closed circuit television, and the automation needs for unmanned operation of mobile equipment such as drill jumbos, LHDs, trucks, and production drills.

[Hall93] Hall, B.E.
Development of a Computerized Mine Planning System at Mount Isa Mines.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *385-396.* [Bawden93]

Mount Isa Mines Ltd. (MIM) has been developing its own computerized mine planning system for four years, based on Intergraph workstations and the MicroStation CAD package. Initially, a purchased geology and design package and in-house database facilities were used. Subsequent developments have involved the establishment of an Oracle database for the geology, survey, and mine design functions. Utilities developed enable both regular and occasional users to access the system on both Unix workstations and DOS PCs through a common user interface for operations ranging from simple viewing of portions of the mine to complex geological interpretation and mine design procedures. Use of industry standard CAD and database software as the core of the system, combined with in-house developments and porting and integration of existing stand-alone mainframe facilities, is providing an integrated system which is able to evolve with computing industry developments, yet be tailored precisely to the needs of a variety of users within the company.

[Harel90] Harel, D. et al.
STATEMATE: A Working Environment for the Development of Complex Reactive Systems.
IEEE Transactions on Software Engineering. **16.** 3. *403-414.* April 1990.

[Hares90] Hares
SSADM for the Advanced Practicioner.
John Wiley & Sons. New York, New York. 1990.

[Hartman92] Hartman, H.L. (Editor)
SME Mining Engineering Handbook.
Society for Mining, Metallurgy, and Exploration Inc. Littleton, Colorado. 2 vols. 2nd ed. 1992.

[Hatch94] Market Analysis of Automation Technology Opportunities in the Mining Sector.
Hatch Associates Ltd. Mississauga, Ontario. Condensed Final Report for Industry Canada. April 12, 1994.

The National Research Council of Canada (NRC), Industry Canada (IC), and the Canada Center for Mineral and Energy Technology (CANMET) retained Hatch Associates to carry out a market analysis of automation technology opportunities in the mining sector. The purpose of the study was to determine the technical nature and economic dimensions of future mining automation trends. Four levels of focus have been identified: i) *types and methods of mining*; ii) *mining processes*; iii) *potential applications of automation*; and iv) *enabling technologies*. Technologies have been classified as being *base*, *key*, *pacing*, or *emerging*. Four categories of automation were considered: group 1 - *communications infrastructure*; group 2 - *central information system*; group 3 - *semi-automated equipment*; and group 4 - *centralized control of fully automated equipment*. The ultimate goal of an automated mine is the total integration of elements from all four groups. Automation has the potential to improve the Canadian mining industry competitive position through *improved productivity* and *improved protection of workers and the environment*. Concerns related to the use of automation include *design issues*, *proven reliability*, and *safety of operation*. Factors affecting long-term commitment to mine automation have been identified as such: i) size of mine; ii) remaining life of mine; iii) skills level of personnel; iv) long-term commitment from upper management; v) mine-wide communications infrastructure. The current status of mining automation is analyzed with respect to each one of the mining processes, the limitations of current methods and equipment are discussed, and key potential applications of automation are listed. In conclusion, sixteen high priority applications were identified through in-depth interviews with personnel at a sample of Canadian mining companies. Based on these, six areas of technologies which should be the focus of further R&D were presented. Finally, the Canadian mining industry capability to undertake such research and development was discussed and market potential scenario described.

[Hatley87] Hatley, D.J.; Pirbhai, I.A.
Strategies for Real-Time System Specification.
Dorset House. New York, New York. 1987.

[Henderson-Sellers92]Henderson-Sellers, B.
A Book of Object-Oriented Knowledge.
Prentice-Hall. Englewood Cliffs, New Jersey. 1992.

[Henderson-Sellers94]Henderson-Sellers, B.; Edwards, J.M.
Book Two of Object-Oriented Knowledge: The Working Object.
Prentice-Hall. Englewood Cliffs, New Jersey. 1994.

[Hendricks95] Hendricks, C.; Daneshmend, L.K.; Doucet, R.
Advanced Maintenance Monitoring of Drills and Shovels at the Iron Ore Company of Canada.
97th CIM Annual General Meeting. Halifax, Nova Scotia. May 14-18, 1995. Paper 19.3.

Aquila Mining Systems Ltd. has been working on a drill and shovel monitoring at the Iron Ore Company of Canada (IOC) since early 1994. This effort has culminated in an operational Aquila drill monitoring system at IOC capable of: i) automatically identifying the location of fractures within a blasthole and computing a blastability index for each hole; ii) facilitating determination of bit condition and performance using trend analysis of drilling variables; iii) enhanced maintenance monitoring procedures. In addition, an Aquila

shovel monitoring system is now operational at IOC which is capable of automatically logging and assessing: i) shovel operating practices; ii) muckpile diggability and blast effectiveness; iii) basic shovel production statistics. This previous work by Aquila has indicated the significant potential benefits of combining advanced maintenance monitoring functions, such as condition-based maintenance monitoring, with existing production monitoring technology on drills and shovels. There is significant commonality, in both the hardware and software requirements, between production monitoring and maintenance monitoring in term of: i) data acquisition; ii) data processing and analysis; iii) information transmission and display. IOC is committed to achieving comprehensive, condition-based maintenance monitoring of major production equipment. This paper reports on the maintenance aspects of the existing Aquila monitoring systems at IOC, as well as the on-going work which builds upon these capabilities to achieve various advanced maintenance monitoring functions.

[Hind94] Hind, D.J.
Applications of Radio Frequency Identification Systems in the Mining Industry.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *34-49.* [Daneshmend94]

Radio Frequency Identification (RFID) systems are one of the automatic data capture technologies taking over from bar codes and magnetic swipe cards in many applications involving automatic hands free operation in arduous environments. RFID systems are based on the use of miniature radio transponders carrying encoded electronic data that is used to uniquely identify the identity of transponders. The paper reviews the types of systems available and compares the various techniques involved in the different systems. Applications of RFID systems in the mining industry are described in considerable detail, covering applications both on the surface and underground.

[Hinden83] Hinden, H.J.; Rauch-Hinden, W.B.
Real-Time Systems.
Electronic Design. *288-311.* January 6, 1983.

[Houlding89] Houlding, S.W.; Rychkun, E.A.
Technical Computing: A Corporate Solution for the 1990s.
Mining Magazine. **160.** 5. *401-411.* May 1989.

As the 1990s approach, technical computing is being looked at in a new light: major influences are changing the nature of technical computing in the mining industry. The authors examine the growing need for an integrated solution for the application of technical computing, one that faces the corporate challenges rather than the specialized local needs of isolated departmental groups.

[Houlding91] Houlding, S.W.
Computer Modelling Limitations and New Directions.
CIM Bulletin. **84.** 952. *75-78.* August 1991. (Part I)
CIM Bulletin. **84.** 953. *46-49.* September 1991 (Part II)

The objective of Part I of this paper is to identify the limitations of the traditional modeling methods and to illustrate, by example, the potential for error created by their application to complex deposits and mining situations. Part II describes the evolution of new, proven technology which eliminates these deficiencies and provides precise and practical alternatives. These promote the use of realistic geological and mining shapes and eliminate altogether the rectangular approximations of traditional methods.

[Houlding92] Houlding, S.W.
Real-Time Grade Control in Mine Planning and Production.
23rd International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Tucson, Arizona. April 7-11, 1992. *747-755.* [Kim92]

This paper summarizes recent developments in computer modeling and estimation technology. Significant improvements in computational and modeling efficiencies have advanced technical computing to the stage where, for the first time, it can be realistically applied to short-term mine planning and production control. Real-time interactive grade estimation of complex shapes, volumes and grade distributions, based on immediate turn-around of production sample grades, is now possible. An added benefit is the ability to produce complete geostatistical estimates which include confidence limits. These can be incorporated into the decision making and risk assessment processes of production control.

[Jacobson92] Jacobson, I.; Christerson, M.; Jonsson, P.; Overgaard, G.
Object-Oriented Software Engineering: A Use Case Driven Approach.
Addison-Wesley. Reading, Massachussetts. 1992.

[Jedrzejczak9] Jedrzejczak, R.; McDowell, M.
Evolution of a Mine Information System at the Endako Mine.
Mining Engineering. **45.** 4. *355-358.* April 1993.

The present computerized information flow at the Endako Mine site is concentrated into four main and self contained areas: i) milling operations; ii) warehouse-accounting; iii) maintenance; and iv) mine-engineering. These systems are fully autonomous, networked together and integrated within their respective areas. The departmental information flow, however, is by hardcopy output. This is inefficient as far as data transfer and lacks real time analysis and decision making. This article focuses on the existing and developing mine planning and engineering systems, the hardware and software rationalization for the operation and the benefits of these progressive changes.

[Jonkman93] Jonkman, J.; Dagdelen, K.
64-Bit Computing: New Technology That Will Revolutionize Mine Planning and Mine Design.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *595-600.* [Bawden93]

The recent introduction of 64-bit computing is revolutionizing the application of mine planning and design to a much greater extent than was experienced in the late 1970s with the introduction of 32-bit computing. The ability to address 4 billion times more data and achieve computational speeds far greater than similarly configured and priced 32-bit systems will unleash applications previously not imagined and provide answers to problems which lust could not be solved. This paper introduces the new computing architecture as it applies to mine planning and design and discusses 21st century applications being made possible by the 64-bit architecture. Technical details will be provided to assist software developers in optimizing the use of the new architecture.

[Kavouras88] Kavouras, M.; Masry, S.E.; Smart, J.R.; Reeler, E.C.
An Advanced Geo-Information System for Mining Applications.
First Canadian Conference on Computer Applications in the Mineral Industry. Quebec City, Quebec. March 7-9, 1988. *511-515.* [Fytas88]

Resource evaluation and mine design involve large amounts and differing types of spatial information. Efficient integration and handling of such information requires advanced geometric modeling techniques and data organizations. General purpose computer-aided design, and computer graphics systems are not designed to deal with such complexity. This paper present efficient approaches to handle geo-information in order to facilitate mine design and planning. Particular emphasis is given to spatial information. The octree scheme is introduced as it is used to represent highly irregular orebodies. A prototype system, which has been developed as a result of this research, is also introduced. The system facilitates geometric operations, and also spatial and attribute queries which are essential to mine design. An example of the practical utility of the system is also presented.

[Kay94] Kay, R.
Objects in Use.
Byte, 19. 4. *99-104.* April 1994.

A whole new class of object-oriented database management systems (ODBMS) has been added to a wide variety of powerful and relatively inexpensive flat-file database management systems (DBMS) and relational database management systems (RDBMS) products on the market. To find out how these new products are being used in the real world, Byte talked to a number of end users and systems developers about their experiences with object databases.

[Kim92] Kim, Y.C. (Editor)
23rd APCOM: Application of Computers and Operations Research in the Mineral Industry.
Society of Mining, Metallurgy, and Exploration Inc. Littleton, Colorado. Proceedings of the 23rd International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Tucson, Arizona. April 7-11, 1992.

[Knights93] Knights, P.F.
Sensor Selection for Maintenance Fault Detection in ST-8B Load-Haul-Dump Vehicles.
McGill University. Montreal, Quebec. Internal Report to INCO Ltd. December 9, 1993.

[Knights94a] Knights, P.F.; Kairouz, J.; Daneshmend, L.K.; Pathak, J.
Applications of Radio Frequency Identification Systems in Underground Mining..
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *28-33.* [Daneshmend94]

Radio Frequency Identification (RFID) systems operate by exchanging unique identification information between low-cost robust transponder tags and an antenna and controller unit. In many cases, transponder tags are passive and are sufficiently energized by radio signals emitted by the transmitter unit to generate return signals containing unique ID codes. This paper outlines the operating principles of RFID systems and provides a brief coverage of some of the applications of these systems. Existing and potential applications of RFID systems for process control, inventory control, materials handling, access control, security and transportation in underground coal and hardrock mines are discussed. Reference is made to a prototype ore tonnage tracking system which is currently being developed for an LHD vehicle at the CANMET experimental mine in Val d'Or, Quebec.

[Knights94b] Knights, P.F.; Daneshmend, L.K.; Baiden, G.R.
A Methodology for Developing Fault Detection and Diagnosis Systems for Automated Mining Equipment.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *143-155.* [Daneshmend94]

The full productivity benefits of automated mining equipment will not be realized unless attention is directed towards increasing equipment reliability, availability, and maintainability. Fault detection and diagnosis (FDD) systems offer one means of increasing automated equipment availability. This paper examines the suitability of experts systems, case based reasoning (CBR) tools and hypertext systems for machine failure diagnosis, and proposes a hybrid system which employs an expert system skeleton linked to hypertext submodules. The paper also introduces Reliability Centered Maintenance (RCM) concepts which aim to preserve critical machine functions by identifying failure modes which can defeat the functions. RCM has proven to be an indispensable tool in the commercial airline, nuclear powerplant and military sectors. Central to the RCM process is an analysis technique called Failure Mode, Effects and Criticality Analysis (FMECA) which can be used as a structured means of knowledge acquisition during development of FDD systems. Based on the theory outlined, a decision support system architecture is presented and illustrated with reference to a fault detection and diagnosis system currently being developed for an automated LHD vehicle at INCO Limited.

[Knights95] Knights, P.F.; Scoble, M.J.
Integrated Mining Information and Control Systems: Towards the Digital Mine.
SME Annual Meeting. Denver, Colorado. March 6-9, 1995. Paper 95-121.

Integrated mining information and process control systems can reduce information delays, enhance decision making and improve the responsiveness of mining operations to, for example, variations in market conditions, mineral grades, and ground conditions. This paper examines developments in the areas of: monitoring, data analysis and diagnosis, communications systems, integrated mining support systems, and process and machine control. It concludes that the development of a comprehensive information technology plan is fundamental to the phased implementation of these technologies. In addition, hardware and software standards and concurrent digital design and simulation practices in selected manufacturing industries are examined and concluded to have relevance to the mining industry. Integrated information and process control systems will lead to emergence of the "digital mine". Such advances in mining information infrastructure as well as mining equipment will enable mining operations to shift from mass production methods to leaner production techniques. "Lean mining" aims to enhance and accelerate cash flow over the life of a mine by focusing on reduction of: throughput times, stockpiles for volume and quality control, and wastage and rework.

[Kovach89] Kovach, T.S.
Design and Implementation of a Fully Integrated Mine Information Management System.
21st International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Littleton, Colorado. February 27-March 2, 1989. *34-38.* [Weiss89]

This paper describes the cooperative effort between a coal producer and a utility customer to develop and install a fully integrated mine information management system at a 2.5 million tons per year mine in east Texas. A description of each item of the modules is included along with the problems encountered during development and how they were corrected. The system configuration is also described.

[Lalonde94] Lalonde, W.
Discovering Smalltalk.
Benjamin/Cummings. Redwood City, California. 1994.

[Lestage93] Lestage, P.; Mottola, L.; Scherrer, R.; Soumis, F.
Integrated Short Range Production Planning at the Mont Wright Operation.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. *323-330.* [Bawden93]

The short range production planning (SRPP) problem considered in this paper is that of a large open pit truck and shovel iron ore operation. Current computerized methods utilized to perform SRPP display several limitations. In particular, shovel displacements cannot be evaluated by systems based on shoveling capacities. The SRPP process consists in fulfilling the extraction requirements defined by the long range plan, while respecting the operating constraints as well as improving grade control and equipment utilization. The SRPP objective is to suggest an optimal mining sequence given an initial pit configuration. In order to realistically attain this goal, a new software package was developed by Ad Opt in conjunction with the Quebec Cartier Mining Company. Based on dynamic programming techniques, it provides a daily solution over a three month period comprising a precise drilling and blasting sequence, shovel displacements and utilization in time, as well as the type and quantity of material to be mined. The SRPP software package was installed at the Mont Wright operation and is presently being utilized by the mine planning team to obtain suggested planning strategies as well as to evaluate the impact of what-if scenarios. Automated interfacing with the long range planning and truck dispatching systems in place is currently underway.

[Linthicum95] Linthicum, D.S.
The End of Programming.
Byte. **20.** 8. *69-72.* August 1995.

Rapid Application Development (RAD) tools promise two advantages over traditional programming. The first is a shorter, more flexible development cycle, enabling you to leap directly from prototype to finished application. The second is that a reasonably sophisticated end user can develop applications.

[Manaster91] Manaster, C.J.
Interface Considerations in Mine Planning Software.
Second Canadian Conference on Computer Applications in the Mineral Industry. Vancouver, British Columbia. September 15-18, 1991. *167-171.* [Poulin91]

The author is one of a team of people at Cyprus Miami Mining Corp. that recently developed a mine planning package to run on the Macintosh using Object Pascal. Emphasis was placed on user interface to encourage more people to take advantage of computer capabilites.

[Martin67] Martin, J.

Design of Real-Time Computer Systems.
Prentice-Hall. Englewood Cliffs, New Jersey, 1967.

[Martin89] Martin, J.
Information Engineering: Introduction (Book I).
Prentice-Hall. Englewood Cliffs, New Jersey. 1989.

[Martin90a] Martin, J.
Information Engineering: Planning & Analysis (Book II).
Prentice-Hall. Englewood Cliffs, New Jersey. 1990.

[Martin90b] Martin J.
Information Engineering: Design & Construction (Book III).
Prentice-Hall. Englewood Cliffs, New Jersey. 1990.

[Martin92] Martin, J.; Odell, J.
Object-Oriented Analysis and Design.
Prentice Hall. Englewood Cliffs, New Jersey. 1992.

[Martin93] Martin, J.
Principles of Object-Oriented Analysis and Desing.
Prentice Hall. Englewood Cliffs, New Jersey. 1993.

[Mason90] Mason, M.; Pugh, J.
Dataplan.
Mining Magazine. **162.** 2. *128-135.* February 1990.

The authors describe a new way for corporations to do their operating and financial planning, getting information from borehole to boardroom in the shortest possible time. Dataplan does not replace existing mine scheduling systems nor displace Lotus-type spreadsheets, but it does link them through a corporate planning database in such a way that all departments can interchange their data and senior management can produce ad hoc reports from up-to-the-minute data with bare minimum of training. It brings together all aspects of a company, from production scheduling to financial modeling and human resource planning.

[McGregor92] McGregor, J.D.; Sykes, D.A.
Object-Oriented Software Development: Engineering Software for Reuse.
Van Nostrand Reinhold. New York, New York. 1992.

[ME90] *Applying Computers On-Board Surface Mining Equipment.*
Mining Engineering. **42.** 4. *349-350.* April 1990.

Application of microprocessors, programmable logic devices, and other computer-oriented hardware and software on-board large surface mining equipment to optimize availability and productivity, stretch machine life, and protect against catastrophic breakdown has been a goal of heavy equipment manufacturers for several years. Summarized here are the on-board computer-oriented products of three heavy equipment suppliers, P&H Harnischfeger (2800XP mining shovels), Marathon LeTourneau Vital Signs Monitor (Titan trucks and front-end loaders), and Haulpak division of Dresser Metalert Monitoring System (haul trucks, front-end loaders, crawler tractors, continuous miners) not a comprehensive survey, but perhaps indicative of the direction such development is taking.

[Mellish87] Mellish, M.; Preller, A.H.; Tutton, D.A.
Integrated Open-Pit Planning Approach and Systems.
IMM Transactions (Section A: Mining Industry). **96.** *A162-A170.* October 1987.

The Rio Tinto Zinc (RTZ) Corporation PLC operates major open pit mines around the world, all of which have been planned with the use of computerized techniques. The successful project planning and detailed operational planning of many of these have been achieved by the application of an integrated set of computer software that has been constantly improved over the last two decades. Discussion is limited to the consideration of large open pits, but many aspects are also applicable to other types and sizes of operation. The approach is based on teamwork by geological and mining staff in which both geological and mining aspects are considered at all times. The software follows the same philosophy: integrating mining concepts in the reserve calculations and geological aspects in the plan. The software is modular to prevent it becoming unwieldy, but it allows the transformation of borehole information into a reserve model on which mine planning programs can operate. These, in turn, attempt to optimize the shell design of the mine, to consider the best sequence of mining, to examine cut-off grade policy using the concepts of the finite resource and opportunity cost and finally, to produce detailed, scheduled mine plans. The software is practical and is designed as a tool for use by an engineer. Its optimization techniques are partial and directed at costs and time. It functions in the way that an engineer understands and has no "black-box" features. Above all, it speeds up an engineer's work and enables many cases to be considered. It is tested and proven.

[Mellor86] Mellor, S.J.; Ward, P.T.
Structured Development for Real-Time Systems: Implementation Modeling Techniques (Volume III).
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1986.

[Melvin89] Melvin, G.J.; Scherman, D.P.
Some International Experience in the Implementation of a Fully Integrated Mine Management System.
21st International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Littleton, Colorado. February 27-March 2, 1989. *39-44.* [Weiss89]

Mincom's software, known as MIMS (Mincom Information Management Systems) addresses the major functional areas of: i) maintenance management; ii) materials management; iii) cost accounting and budgeting; iv) production statistics; v) financial accounting; in an integrated set of modules. This paper highlights some of Mincom's international implementation experiences.

[Meyer92] Meyer, B.
Eiffel: The Language.
Prentice-Hall. Englewood Cliffs, New Jersey. 1992

[Mill89] Mill, A.J.B.
Second Generation CAD and IT Systems for Mine Planning and Management.

Mining Magazine. **160.** 2. *134-137.* February 1989

The author describes the second generation of mine CAD systems now being developed and shows how they will encompass decision support, database management and 3D interactive graphics, bridging the divide which at present exists between computer graphics and information technology.

[Mitri95] Mitri, H.S. (Editor)
Computer Applications in the Mineral Industry.
McGill Uniersity, Montreal, Quebec. Proceedings of the Third Canadian Conference on Computer Applications in the Mineral Industry. Montreal, Quebec. October 22-25, 1995.

[Morrison95] Morrison, D.M.
Deep Hardrock Mining: The Future.
97th CIM Annual General Meeting. Halifax, Nova Scotia. May 14-18, 1995.

The most important factor in Canadian mining is not the operating cost of current projects, but the availability of capital for future projects. The future of mining at depth will be producing ore from the top of the orebody working downwards with very effective, tightly controlled mining methods, i.e. either selective mining or bulk mining with well controlled dilution and fragmentation. The key characteristics of future mines will be smaller access excavations, more effective ground support, very precise blasting techniques and more efficient and reliable materials handling systems. Equipment will be smaller and designed for high efficiency and low maintenance, reducing both the capital and operating cost. This means there will be fewer scoops, more continuous mucking machines and conveyor belts, both lateral and vertical. Orepass failures have become accepted and the resultant re-development and re-tramming has become common. The capital investment in so-called permanent orepasses and crusher stations becomes questionable, particularly when crushers are only necessary for less than 10% of the ore going through the system. The best way to solve the chronic instability of orepasses is, as with all of the stability problems at depth, by reducing the excavation size rather than increasing ground support. Smaller access drifts would reduce the capital cost and increase the rate of development as well as reduce the amount of waste to be handled, reducing the ground support and the ventilation requirements. Large drifts and orepasses are essential only for the equipment needed large pieces of ore and the productivity of scoops is very expensive when the requirements for ventilation and large access drifts are taken into account. The key issue is the fragmentation generated by primary blasting. The future of mining in Canada will depend on simple and robust technology geared to the environment in which it will have to operate. Its survival will depend on something much more fundamental and difficult to accomplish than a technological advance: it will require dramatic change in the way the mining process is managed, how work is organized, how effort is rewarded and how costs are measured: a complete change in mind-set.

[Moss95] Moss, A.; Scoble, M.J.; Mathews, K.
Rock Mechanics and Production Management.
97th CIM Annual General Meeting. Halifax, Nova Scotia. May 14-18, 1995.

Rock mechanics has evolved from an initial focus on ground control at mine site towards increasing involvement in design and planning. This paper considers the further development of rock mechanics in accessing and analyzing information in support of production management. It relates to recognition of the particular need for knowledge of the orebody and ground conditions. This has been compounded by the reduced access to information experienced by many mines recently in making the transition from cut-and-fill to non-entry bulk mining. Recent advances in underground communications, information technology and sensing will eventually permit the development of the digital mine, to provide improved speed and reliability in accessing all information relating to the mining processes. These advances offer the opportunity to radically improve production management and integrate rock mechanics fully into future supporting information systems. This paper reviews the nature and structure of production management, examining the role of rock mechanics in strategic planning as well as tactical production and ground control. The issues and priorities in designing production management systems are reviewed. It then discusses the potential management rationale that will drive future systems, including *just-in-time mining*, *lean mining*, and *computer-integrated mining* options. It concludes by considering information technology, rock mechanics integration, and sensor development to improve information quality for production management.

[Mottola94a] Mottola, L.
Systems Analysis for Robotic Mining: M.Eng. Thesis Proposal.
INCO Mines Research, Automation and Robotics. Copper Cliff, Ontario. Internal Report. Rev. 4. October 14, 1994.

[Mottola94b] Mottola, L.
CASE Tools: Product Evaluation.
INCO Mines Research, Automation and Robotics. Copper Cliff, Ontario. Internal Report. December 15, 1994.

[Mottola95] Mottola, L.; Scoble, M.J.; Peck, J.P.; Baiden, G.R.
Systems Analysis for Robotic Mining.
Third Canadian Conference on Computer Applications in the Mineral Industry. Montreal, Quebec. October 22-25, 1995. *595-604.* [Mitri95]

Mining automation has incrementally progressed from line-of-sight remote operation to teleoperation and automatic control of mobile machines, mainly due to significant advances in underground communication systems. The present trend points towards a robotic mining environment where mobile machinery and stationary equipment will be integrated with a mine-wide information system overseeing all aspects of mining via a communication network. The successful design and implementation of the software and hardware components necessary to realize this vision depends on the level of seamless integration achieved. The complexity involved in terms of systems functionality and coherence necessitates systems analysis and computer-aided software engineering tools and techniques to actively support this integration effort. These offer both a detailed and global perspective of robotic mining systems. This paper examines the underground hard rock robotic mining environment in terms of mobile machinery, stationary equipment, mine monitoring, and infrastructure. It attempts to relate some fundamental concepts of systems analysis to this environment and illustrates how this discipline and its tools can have a significant impact throughout the life cycle of both hardware and software components. The structure and flow of information which underlies robotic mining is then reviewed and related to the application of software engineering, information engineering , structured analysis and design, and object-oriented analysis and design. The paper concludes by considering how a specific CASE tool, System Architect©, is being used to analyze the information requirements of robotic mining systems.

[Mutmansky73] Mutmansky, J.M.
The Scope of Systems Engineering.
SME Mining Engineering Handbook. Society of Mining Engineers of AIME. New York, New York. Chapter 30.1. *30.2-30.5.* 1973. [Cummins73]

[Nordbotten85] Nordbotten, J.C.
The Analysis and Design of Computer-Based Information Systems.
Houghton Mifflin Company. Boston, Massachussetts. 1985.

[Norton95] Norton, P.
Introduction to Computers.
Glencoe Macmillan/McGraw-Hill. Westerville, Ohio. 1995.

[O'Neil79] O'Neil, T.J. (Editor)
16th APCOM: Applications of Computers and Operations Research in the Mineral Industry.
Society of Mining Engineers of AIME. New York, New York. Proceedings of the 16th International Conference on the Application of Computers and Operations Reserach in the Mineral Industry. Tucson, Arizona. October 17-19, 1979.

[Ozdemir91] Ozdemir, L.; King, R.; Hanna, K. (Editors)
Mine Mechanization and Automation.
Colorado School of Mines. Proceedings of the First International Symposium on Mine Mechanization and Automation. Golden, Colorado. June 10-13, 1991. 2 vols.

[Ozdemir95] Ozdemir, L.; Hanna, K. (Editors)
Mine Mechanization and Automation.
Colorado School of Mines. Proceedings of the Third International Symposium on Mine Mechanization and Automation. Golden, Colorado. June 12-14, 1995. 2 vols.

[Pages-Jones80] Pages-Jones, M.
The Practical Guide to Structured Systems Design.
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1980.

[Pages-Jones89] Pages-Jones, M.; Weiss, S.
Synthesis: An Object-Oriented Analysis and Design Method.
American Programmer. **2.** 7. *64-67.* 1989.

[Peck95a] Peck, J.; Gray, J.
The Total Mining System (TMS™): The Basis for Open Pit Automation.
97th CIM*Annual General Meeting. Halifax, Nova Scotia. May 14-18, 1995.

With the implementation of more advanced monitoring, control and locating systems in surface mines, there is an ever increasing need for their mine-wide integration towards achieving overall optimization. Aquila Mining Systems Ltd., and their strategic partners, are developing the basis for a comprehensive real-time monitoring, control and information system called Total Mining System, or TMS™. The TMS™ system is being designed to address both current and future needs of open pit mines towards improving productivity and minimizing costs, through better two-way information flow between each component in the operation. At a basic level, feedback from the equipment and process monitoring will enable decision-making to be based on quantitative, on-demand information, thus permitting proactive rather than reactive planning. Dynamic planning would be a valuable tool as market conditions fluctuate, equipment fleets age and variations in the grade, quality, geometry, and hardness of the mined material all contribute to either changing production targets or levels of achievable performance. Such capability could be implemented within the next two years. At a higher level, and within five years, TMS™ will allow for the autonomous operation and/or real-time supervisory control of mobile and stationary equipment in open-pit mines. A discussion is provided in regard to the development and implementation of an autonomous blasthole drill, to demonstrate the need for TMS™. This paper will outline Aquila's program for TMS™ design, development and implementation, primarily in relation to the high-level communication system and its role in the future automation of open-pit mobile equipment.

[Peck95b] Peck, J.; Hendricks, C.
The Total Mining System (TMS™): The Future of Open Pit Mining.
Third Canadian Conference on Computer Applications in the Mineral Industry. Montreal, Quebec. October 22-25, 1995. *586-594.* [Mitri95]

[Piche92] Piché, A. (Editor)
Mining Automation.
Proceedings of the 5th Canadian Symposium on Mining Automation. Vancouver, British Columbia. September 27-29, 1992.

[Piche96] Piché, A.; Gaultier, P.
Mining Automation Technology: the First Frontier.
CIM Bulletin. **89.** 996. *51-54.* January 1996.

Beginnings of a revolution are only seen in history books. Today's mining methods are quietly being changed. The advent of the remote control for underground LHDs is but the beginning of the automation revolution. Automated guidance, telepresence/teleoperation and automated loading systems have such a dramatic impact that they can change the way mines are designed in the near future. This article summarizes the work done at the Noranda Technology Centre in developing technologies that will pave the way for the mine of the future.

[Poole96] Poole, R.A.; Golde, P.V.; Baiden, G.R.
Remote Operation from Surface of Tamrock DataSolo Drills at INCO's Stobie Mine.
CIM Bulletin. **89.** 996. *47-50.* January 1996.

This paper presents the results obtained during the past year on a drilling automation project at Stobie mine. This project has successfully demonstrated that the remote operation of the uphole drilling process using Tamrock DataSolo 1000 Sixty drills will bring large rewards in terms of labour and maintenance savings.

[Poulin91] Poulin, R.; Pakalnis, R.C.T.; Mular, A.L. (Editors)
Computer Applications in the Mineral Industry.

University of British Columbia. Proceedings of the Second Canadian Conference on Computer Applications in the Mineral Industry. Vancouver, British Columbia. September 15-18, 1991.

[Pressman92] Pressman, R.S.
Software Engineering: A Practitioner's Approach.
McGraw-Hill. New York, New York. 3rd ed. 1992.

[Richmond94] Richmond, M.R.; Lye, G.N.
The Development of Advanced Mining Systems.
Australian Mining Journal. **89.** 9. *42-46.* February 1994.

Resource-based companies are increasingly aware of the impact that reduced demand and lower metal prices are having on their short term profits and long term viability. Mining cost curves are not static and companies that do not reduce mining, smelting and transportation costs will suffer reduced profitability. As a partial counter to this, CRA Advanced Technical Development (ATD) has formed a vision of an Advanced Mining System for underground and open pit operations. It is ATD's view that the high leverage points in mining operations lie in continuous and automated mining and integrated processes where each process is systematically treated as part of a wider whole. As described in this article, other benefits from the approach include better plant performance, reduced unplanned maintenance, and rationalized routing maintenance. In short, allowing operations to "run close to the edge", in the sense that Hamersley Iron's Marandoo mine is being planned. For convenience, ATD has called this set of interrelated processes Advanced Mining Systems (AMS).

[ROB95] *A Future Denied ?*
Report on Business Magazine. The Globe and Mail. Special Report on Mining in Canada. *73-104.* September 1995.

The importance of Canada's $20-billion-a-year mining industry can't be overstated. Mining supports one million Canadians and 150 communities and accounts for 15 per cent of our exports. Canada's mining industry is a world leader in technological innovation and environmental initiatives. Enormous mineral resources await discovery. Can this potential be realized ? What is the future for mining in Canada ?

[Rumbaugh91] Rumbaugh, J.; Blaha, M.; Premerlani, W.; Eddy, F.; Lorensen, W.
Object-Oriented Modeling and Design.
Prentice-Hall. Englewood Cliffs, New Jersey. 1991.

[Rutt94] Rutt, D.K.
Blasthole Drill Positioning Studies at the Iron Ore Company of Canada.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *120-131.* [Daneshmend94]

Custom Industrial Automation Inc. has demonstrated the feasibility of positioning rotary blasthole drills over target hole locations without the use of survey stakes. The purpose of the demonstration and subsequent studies was to show the potential which the correct application of this technology holds for the mining industry. The requirements for an operational drill positioning system are presented along with a comparison of various position determination technologies. For the first field demonstration, CIA utilized a microwave radio-positioning system capable of providing a position accuracy of 15 cm. A PC-based computer interpreted the position data by providing a continuously updated display depicting the intended target hole and the current position of the drill in real time.

[Sas94] Sas, J. A.
Central Control with Distributed Information in the Mining Industry.
6th Canadian Symposium on Mining Automation. Montreal, Quebec. October 16-19, 1994. *205-208.* [Daneshmend94]

In the mining industry of the 90s, issues like production quality, delivery time, system performance and value added service is the focus of today's marketplace for suppliers as well as end users. To realize these goals, the mining industry is headed more and more towards microprocessor-based automation systems in various processes. To integrate different mediums of mine-wide communications can be done with off-the-shelf components. Radio systems using leaky feeder technology, powerline carrier systems, optic fiber networks and so on can all be interfaced to a central control and information system. As technology advances, automation systems are consisting of many different vendors, integrated into a common system. To achieve this integration, open systems technologies are required.

[Schach93] Schach, S.R.
Software Engineering.
Richard D. Irwin and Asken Associates. Homewood, Illinois. 2nd ed. 1993.

[Schaidle94] Schaidle, C.L.
Earthmoving in the Information Age.
SME Annual Meeting. Albuquerque, New Mexico. February 14-17, 1994. Paper 94-48.
Mining Engineering. **46.** 6. *507-509.* June 1994.

Computers and communications technology have revolutionized many industries. In earthmoving, this revolution has just begun. The major changes are still to come, but they are just around the corner. This paper presents a vision of this up-coming revolution in our industry. This vision is comprehensive. It includes basic communication, machine monitoring and diagnostics, job and business management, planning and operations, and machine control. For the industry to realize maximum benefits from the information age, we must have a vision of the future that is shared by technologists, machinery producers, and miners.

[Scheiner93] Scheiner, B.J.; Stanley, D.A.; Karr, C.L. (Editors)
Emerging Computer Techniques for the Minerals Industry.
Society for Mining, Metallurgy, and Exploration, Inc. Littleton, Colorado. Proceedings of a Specialty Symposium on Emerging Computer Techniques for the Minerals Industry. SME Annual Meeting and Exhibit. Reno, Nevada. February 15-18, 1993.

[Schindler90] Schindler
Computer-Aided Software Design.
John Wiley & Sons. New York, New York. 1990.

[Scoble73] Scoble, M.J.

Information in Mines.
University of Nottingham Mining Department Magazine. **25.** *45-51.* 1973.

[Scoble94] Scoble, M.J.
Competitive at Depth: Re-Engineering the Hardrock Mining Process.
First North American Rock Mechanics Symposium. Austin, Texas. 1994.

Canadian hardrock mines recognize the need to radically improve competitiveness in increasingly deeper reserves. The interaction between mining rock mechanics and the new information and automation technologies is examined as a means to re-engineer the mining process at depth. This will be dependent upon advances in mining methods, geosensing, machine intelligence, and intelligent planning and control systems.

[Scoble95a] Scoble, M.J.
Geological Control in the Digital Mine.
MRE 95. University of Leeds. April 1995.

Geological control, in the context of mine design, planning, and control, refers to a sequence of responsibilities: the generation of geological data from exploration and delineation activity, using various sensing sources; the fusion, analysis and interpretation of this data for input into the decision making procedures; and the estimation, modeling, and information management relating to ore estimation, geological and geotechnical modeling. This paper examines the role of geotechnical control in the context of efforts to achieve lean, automated mining and the realization of the digital mine.

[Scoble95b] Scoble, M.J.
Canadian Mining Automation Evolution: From the Digital Mine to Mine-Wide Automation.
97th CIM Annual General Meeting. Halifax, Nova Scotia. May 14-18, 1995.

This paper reviews the evolution of Canadian surface and underground mining automation, principally relating to: advances in communications, initial development of machine teleoperation from line-of-sight remote control, and islands of automation. The eventual role of telerobotics and mine-wide robotic mining remains to be resolved. The progress and approaches adopted have tented to vary within each sector of the mining industry. Recent information technology advances have made possible the Digital Mine, in which information associated with all mining processes, however dispersed, would be integrated with support systems using new communications technology. The Digital Mine will provide the information infrastructure to serve as the foundation for mine-wide automation. The paper concludes by reviewing the issues likely to govern implementation success relating to: mining process design, machine design, machine intelligence, and mine planning and control.

[Scoble96] Scoble, M.J.
Canadian Underground Mine Automation: Progress and Issues.
CIM Bulletin. **89.** 996. *29-32.* January 1996.

The last decade has seen remarkable progress in both surface and underground mining automation, principally relating to advances in communications and machine teleoperation. Underground potash mining appears to be closest to realizing the dream of centralized control of automated continuous mining systems. Advances in surface mine dispatching, machine monitoring , and global positioning systems have also recently reactiated some of the initial R&D enthousiasm developed in the 70s for surface mining automation. How far we are from the adoption of the more advanced telerobotics and mine-wide robotic mining remains to be resolved. Visions of the ultimate automated mine are still developing and are likely to be influenced by the success achieved in the application of new advanced technologies in other industries. This article outlines the progress made int he various mining sectors and discusses what are seen to be important issues. These relate not only to automation technology, but also to mine design, systems, safety, human factors, and economics.

[Seegmiller73]Seegmiller, B.L.
Computers and Operations Research: Mine Usage.
SME Mining Engineering Handbook. Society of Mining Engineers of AIME. New York, New York. Chapter 30.2. *30.5-30.7.* 1973. [Cummins73]

[Selic94] Selic, B.; Gullekson, G.; Ward, P.T.
Real-Time Object-Oriented Modeling.
John Wiley & Sons. New York, New York. 1994.

[Shlaer88] Shlaer, S.; Mellor, S.
Object-Oriented Systems Analysis: Modelling the World in Data.
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1988.

[Shlaer92] Shlaer, S.; Mellor, S.
Object Lifecycles: Modelling the World in States.
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1992.

[Singhal89] Singhal, R.K.
Computerized Mine Planning and Management Information Systems for Surface Mines.
21st International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Littleton, Colorado. February 27-March 2, 1989. *442-460.* [Weiss89]

Three principal activities are involved in planning and developing a surface mine: i) definition of economic and technical feasibility; ii) design, procurement, and construction; iii) mining and reclamation. The last is the only activity which begins in the feasibility study and continues throughout the life of the mine. It is also the activity which depends heavily on the use of computers. This paper deals with a method for selecting mining software and dwells on the recent progress made in this area. Discussed also is the status of computerized equipment management and information systems: a microprocessor-based technology applied to dispatch systems, monitoring of equipment health and performance, wireless data transmission to a centralized data processing unit, and mine-wide information and reporting system. Reference has been made to upcoming developments which offer the potential of transforming the surface mine of the year 2000 into a manless pit.

[Stokes93] Stokes, W.P.C.
Mining Software: The Current Challenge.
Mining Magazine. **168**, 2. *76-77.* February 1993.

The author highlights the problems and diversity in software and data exchange and considers some potential solutions.

[Stroustrup91] Stroustrup, B.
The C++ Programming Language.
Addison-Wesley. Reading, Massachussetts. 2nd ed. 1991.

[Sturgul94] Sturgul, J.R.
Animation Models of Mines to Assist in Mine Planning and Production.
Mining Engineering. **46.** 4. *350-351.* April 1994.

Computer simulation models of working mines can be a great benefit to mining engineers. Such models have been used in mine planning (how many truck-shovels to have, when to add new equipment, etc.) and mine design (should a dispatch system be purchased, where is the optimum location for mine equipment, etc.). A simulation model can be thought of as a dynamic representation of the mine. It can be easily changed to reflect a variety of situations. The results of the simulation are then presented by means of animation.

[Suboleski92] Suboleski, S.C.; Cameron, R.E.; Albert, E.K.
Systems Engineering.
SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration Inc. Littleton, Colorado. Chapter 8.3. *563-597.* 1992. [Hartman92]

[Taylor91] Taylor, R.B.; Paananen, R.T.
The Evolution of Computerized Mine Planning at Falconbridge Ltd., Kidd Creek Division.
Second Canadian Conference on Computer Applications in the Mineral Industry. Vancouver, British Columbia. September 15-18, 1991. *143-153.* [Poulin91]

[TEKES94] Intelligent Mine Technology Program: 1992-1996.
Technology Development Centre (TEKES). Helsinki, Finland. Promotional Brochure. October 1994.

[Thomas91] Thomas, D.R.
Information Technology in the Mining Industry: Planning for Tomorrow.
5th CIM District 5 Meeting. Fort McMurray, Alberta. September 17-20, 1991. Paper Number 67.

The term information technology has come to describe a broad range of products and services focused on computers, telecommunications, and data storage devices. While the boundaries fo IT are not clearly circumscribed, its presence is clearly recognized in evryday life. Some mining companies, because they do not view IT as strategic to their success, have become IT averse. These are not necessarily the companies that spend the least on IT, but their expenditures are usually piecemeal increments and the benefits are temporary. It is the position of this paper that an IT plan can help mining companies gain enduring value from their IT investments.

[Thompson79] Thompson, P.N.; Teale, C.W.; Richardson, R.
A Computer-Based Production Information System.
16th International Conference on Application of Computers and Operations Reserach in the Mineral Industry. Tucson, Arizona. October 17-19, 1979. *3-15.* [O'Neil79]

The past few years have seen the introduction of mini-computers on an increasing scale at collieries in the British coal industry. These are being used for controlling underground transport systems, coal preparation plants, pumps, and for monitoring the mine environment and face operations. A separate mini-computer (termed a primary computer) is dedicated to each of these functions. The information collected by the primary computers, other than that required for immediate control, will be fed to a secondary computer for analysis and processing. This overall concept, called MINOS (MINe Operating System) is being developed by the National Coal Board Mining Research and Development Establishment (MRDE). Eventually most of the data required by the system will be captured automatically, however, it will be some time before these systems are fully developed. In the intervening period, it was thought that useful experience would be gained by using a secondary computer as the basis for an information system with the prime data being fed in manually.

[Topper94] Topper, A.; Ouellette, D.; Jorgensen, P.
Structured Methods: Merging Models, Techniques, and CASE.
McGraw-Hill. New York, New York. 1994.

[Vagenas92] Vagenas, N.; Kumar, U.
Software Reliability: A Prerequisite in Mining Automation.
5th Canadian Symposium on Mining Automation. Vancouver, British Columbia. September 27-29, 1992. *1-11.* [Piche92]

During the last decade, the mining industry has seen a rapid growth in the field of automation and robotization. Highly sophisticated computer-controlled machines are introduced in mining operations. Furthermore, the application of software for decision making, operational control, and monitoring purposes has contributed to a significant improvement in productivity and safety in mining operations all over the world. However, the growth in complexity and importance of modern day computer-controlled mining systems demands more attention to the issues of operational reliability and systems safety. The operational reliability of an automatic system in general depends on both hardware and software. So far in the mining sector, no attention has been paid to analyze and develop methodologies for study and evaluation of the software currently in use. In this paper, an attempt has been made to address the importance of software reliability together with some techniques for evaluation of software reliability.

[Valenzuela93] Valenzuela, I.
Mining into the 21st Century in Latin America.
International Congress on Mine Design. Kingston, Ontario. August 23-26, 1993. Plenary Session Address.

[VanRiper89] Van Riper, T.; Rendu, J.-M.
Information Systems at Newmont Mining Corporation: A Corporate View Point.
21st International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Littleton, Colorado. February 27-March 2, 1989. *26-33.* [Weiss89]

The paper reviews the historical development of Newmont information systems, the data processing philosophy and organization of the company, the information systems architecture, the application development philosophy, as well as future trends.

[Ward85a] Ward, P.T.; Mellor, S.J.
Structured Development for Real-Time Systems: Introduction and Tools (Volume I).
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1985.

[Ward85b] Ward, P.T.; Mellor, S.J.
Structured Development for Real-Time Systems: Essential Modeling Techniques (Volume II).
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1985.

[Ward89] Ward, P.T.
How to Integrate Object-Orientation with Structured Analysis and Design.
IEEE Software. *74-82.* March 1989.

[Wasserman90] Wasserman, A.I.; Pircher, P.A.; Muller, R.J.
The Object-Oriented Structured Design Notation for Software Design Representation.
IEEE Computer. *50-62.* March 1990.

[Weiss89] Weiss, A. (Editor)
21st APCOM: Application of Computers and Operations Research in the Mineral Industry.
Society of Mining Engineers Inc. Proceedings of the 21st International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Littleton, Colorado. February 27-March 2, 1989.

[White87] White, J.Wm.; Zoschke, L.T.
The Development of a Computerized Truck Dispatching System.
Mining Magazine. **157.** 6. December 1987.

For over fifteen years, mining companies have looked for ways to improve their open pit haulage operations by using a computer to dispatch trucks. The idea is simple. Solving the problem looks easy. In actual fact, the solution is complex. This article reviews the installation history of the DISPATCH® system at worldwide operations.

[White89] White, J.Wm.; Johnson, L.V.
Real-Time Monitoring of Heavy Equipment in Open Pit Mines.
Construction Congress. San Francisco, California. March 5-8, 1989. *266-271.*

Monitoring on-board heavy equipment sensors during normal operation in a harsh mining environment is difficult. Here, we report on a system with local intelligence to interpret on-board signals. Existing sensors, pressure switches, warning lights, relays, and on-board monitoring systems provide a mixture of digital and analog signals. The local system transmits alarm conditions and sensor values to the central computer via a UHF/VHF radio link for further decision making and storage. Because the central computer archives such data, the user can reduce, manipulate, and display either current real-time information or historical data over any period of time.

[White92] White, J.Wm.; Olson, J.P.
On Improving Truck-Shovel Productivity in Open Pit Mines.
23rd International Symposium on the Application of Computers and Operations Research in the Mineral Industry. Tucson, Arizona. April 7-11, 1992. *739-746.* [Kim92]

Mine management now recognizes the value of computer-based truck-shovel dispatching in open pit mines. The key tangible benefits are substantial productivity increases with a given fleet of equipment or, alternately, significant reductions in equipment required to meet production quotas. In this work, we review the literature, report on efficient, optimal algorithms for haul-truck dispatching in real-time, and briefly discuss methods used by various mines to evaluate productivity improvements over manual methods. We also present actual results obtained at 13 mining operations around the world.

[White94a] White, J.Wm.; Zoschke, L.T.
Automating Surface Mines.
Mining Engineering. **46.** 6. *510-511.* June 1994.

[White94b] White, J.Wm.; Zoschke, L.T.
Automation of Open Pit Mine Operation Is Long Overdue.
World Mining Equipment. **18.** 7/8. *15-20.* July/August 1994.

A decade and a half ago, Modular Mining Systems Inc. began development and implementation of its DISPATCH® system for haulage optimization in open pit mines and now has over forty systems in operation world-wide. The so-called "top-down" approach deliberately used in system design and implementation now allows addition of features which would otherwise only be feasible after complete system redesign. This paper discusses new devices, systems, and subsystems comprising mining's future. Until recently, truck and shovel operator input provided timing data needed for optimal allocation. Now, addition of high-speed general purpose token ring loop controller and infrared transponders to each piece of mining equipment automates these important functions. Addition of Global Positioning Satellite subsystems provides improved equipment location.

[Whitten89] Whitten, J.L.; Bentley, L.D.; Barlow, V.M.
Systems Analysis and Design Methods.
Richard D. Irwin. Homewood, Illinois. 2nd ed. 1989.

[Winkelmann90] Winkelmann, S.P.
Newmont Gold Outlines Its Mine Planning Procedures.
Mining Engineering. **42.** 4. *333-338.* April 1990.

To increase gold production while minimizing capital requirements and providing for the safe and efficient mining and processing of ores has required a tremendous effort by the mine engineering group at Newmont Gold. Organizational changes were implemented by the company to effectively deal with a full range of engineering problems. Specially developed computer software and its applications will be explained in this article as well as improvements in the techniques used in converting geologic resources into reserves. Scheduling procedures for the mining of multiple pits to feed multiple processing facilities will likewise be presented. Ore control procedures and current mine engineering practices are discussed.

[Wirfs-Brock90] Wirfs-Brock, R.; Wilkerson, B.; Wiener, L.
Designing Object-Oriented Software.
Prentice-Hall. Englewood Cliffs, New Jersey. 1990.

[WME95] *Safety in Microprocessors: TIRIS Tracking.*
World Mining Equipment. **19.** 4. *44.* May 1995.

Texas Instruments Registration and Identification System (TIRIS) radio frequency identification (RFID) tags are being used to detect and control the movement of operator-steered underground vehicles in Chinese coal mines. The newly formed Davis Derby/ DAC consortium was awarded the order by the China National Coal industry Corporation as part of a mine upgrade which includes the introduction of new free-steered underground vehicles to improve flexibility and productivity over fixed rail vehicles. The tracking system is designed to ensure safe, accident free operation and maximum productivity.

[Wraith73] Wraith, W. III
Management Cost Control Systems: A Case Study.
SME Mining Engineering Handbook. Society of Mining Engineers of AIME. New York, New York. Chapter 30.8. *30.54-30.88.* 1973. [Cummins73]

[Wusaty95] Wusaty, E.; Paulhus, L.
Mining's New Frontier: The Fording Coal GPS Experience.
97th CIM Annual General Meeting. Nova Scotia, Halifax. May 14-18, 1995. Paper 43.2.

Early in 1994, Fording Coal realized that advancements in GPS technology made it attractive for mining applications. Fording then entered into several GPS mining related research and development projects. Projects undertaken were the development of a GPS survey system, drill positioning and shovel locating systems. Fording also commissioned a GPS based mine dispatch in December 1994. This paper will discuss the progress of the projects to data, problems encountered, and future directions of GPS mining applications.

[Wykes95] Wykes, E.
Keep Mining in Canada.
CIM Bulletin. **88.** 992. *25.* July-August 1995.

Two years ago, the "Keep Mining in Canada" campaign was launched to raise awareness of mining issues. Year one was devoted to informing and involving people in mining communities whose future is directly linked to the future of mining in Canada. In year two we are reaching beyond the converted to bring city people up-to-date on Canadian mining practices which are the best in the world.

[Yourdon79] Yourdon, E.N.; Constantine, L.L.
Structured Design: Fundamentals of a Discipline of Computer Program and Systems Design.

Prentice-Hall. Englewood Cliffs, New Jersey. 1979.

[Yourdon89] Yourdon, E.N.
Modern Structured Analysis.
Yourdon Press, Prentice-Hall. Englewood Cliffs, New Jersey. 1989.

[Zoschke95] Zoschke, L.T.; White, J.Wm.
Mine Management Systems: The Next Generation.
97th CIM Annual General Meeting. Nova Scotia, Halifax. May 14-18, 1995. Paper 19.2.

In the late 1970s, Modular Mining implemented its first Mine Management System, called DISPATCH®, for haulage optimization in open pit mines. Since that time, this system has been placed in over sixty other mines worldwide. Initially just used for dispatching haul trucks, the system has evolved to provide complete, real-time and historical production and maintenance data. It also allows connection to on-board PLCs supplied by major equipment manufacturers for monitoring machine data and high and low resolution Global Positioning Systems. Here we discuss the latest in automated mine management systems for open pit and underground mines.

8 Appendix A: CASE Tools

Appendix A complements Chapter 4 by providing a list of the vendors contacted for the CASE tool product survey and detailed forms for the top three CASE tools identified.

8.1 Vendor and Product List

The following is a listing of vendors approached and associated products in alphabetical order.

Application Development Workbench [code: ADW]
Maxim [code: MAX]
KnowledgeWare Inc.
55 University Ave., Toronto, Ontario M5J 2H7
tel: (416) 360 2353; fax: (416) 360 7027

Berard Object and Class Specifier [code: BOCS]
Berard Software Engineering Inc.
902 Wind River Lane, Suite 203, Gaithersburg, Maryland 20878
tel: (301) 417 9884; fax: (301) 417 0021

EasyCASE [code: EASY]
Evergreen CASE Tools Inc.
8522 154th Ave., NE, Redmond, WA 98052
tel: (800) 929 5194; tel: (206) 881 5149; fax: (206) 883 7676

ERwin and PBwin (PowerBuilder) [code: ERPB]
Logic Works
1060 Route 206, Princeton, NJ 08540
tel: (800) 783 7946; tel outside US: (609) 252 1177; fax: (609) 252 1175

Excelerator [code: EXCL]
Intersolv
1 Main Street, Cambridge, MA 02142
tel: (800) 777 8858 x520; tel: (617) 494 8200; fax: (617) 577 8945

Information Engineering Facility [code: IEF]
Texas Instruments
tel: (416) 250 5287; fax: (416) 250 6961

Object Maker [code: OMKR]
Mark V Systems
16400 Ventura Boulevard, Suite 303, Encino, CA 91436-2123
tel: (818) 995 7671; fax: (818) 995 4267

Objective Analyst [code: ANAL]
Objective Spectrum
901-C Kildaire Farm Road, Cary, NC 27511
tel: (919) 460 1500; fax: (919) 380 6463

Object Store
Object Design Inc.
25 Mall Road, Burlington, MA 01803-4194
tel: (617) 674 5000; fax: (617) 674 5010; tel: (800) 962 9620

Object Team for Shlaer-Mellor [code: SHML]
Object Team for Rumbaugh [code: RUM]
Teamwork for Structured Methods [code: STM]
Cadre Technologies Inc.
222 Richmond St., Providence, RI 02903
tel: (401) 351 5950 x295; fax: (401) 455 6804

OMTool [code: OMTL]
Martin Marietta Corporation
640 Freedom Business Center, King of Prussia, PA 19406
tel: (800) 438 7246
Advanced Concepts Center
50 O'Connor Street, Suite 1450, Ottawa, Ontario K1P 6L2
tel: (613) 783 4724; fax: (613) 232 4588

Paradigm Plus [code: PAR]
ProtoSoft Inc.
17629 El Camino Real, Suite 202, Houston, TX 77058
tel: (713) 480 3233; fax: (713) 480 6606

PGC CASE Graphics [code: PGC]
Pacific Gold Coast Corp.
15 Glen St., Glen Cove, NY 11542
tel: (800) 732 3002; tel: (516) 759 3011; fax: (516) 759 3014

Rational Rose
Rational Software Corp.
tel: (800) 767 3237

S-Designor [code: SDES]
SDP Technologies Inc.
1 Westbrook Corporate Center, Suite 805, Westchester, IL 60154
tel: (708) 947 4250; fax: (708) 947 4251

Select OMT [code: SOMT]
Select Yourdon [code: SYOU]
Select SSADM [code: SSDM]
Select Software Tools
1526 Brookhollow Dr., Suite 84, Santa Ana, CA 92705
tel: (714) 957 6633; fax: (714) 957 6219

SILVERRUN Application Development Environment [code: SILV]
Computer Systems Adviser Inc.
tel: (800) 361 0528 x245
CSA Research Ltd.
445 Ave. St-Jean-Baptiste, Suite 100, Quebec, Quebec G2E 5N7
tel: (418) 877 1717 x245; fax: (418) 877 2827

System Architect [code: SA]
Popkin Software Systems Inc.
11 Park Place, New York, NY 10007-2801
tel: (800) 732 5227 x155; fax: (212) 571 3436

Systems Engineer [code: SE]
LBMS Inc.
tel: (713) 623 0414
120 Eglinton Avenue East, Toronto, Ontario
tel: (416) 487 5267; fax: (416) 322 5075

Together C++ [code: TOG]
Object International Inc.
8140 N. MoPac Expwy. 4-200, Austin, TX 78759-8864
tel: (512) 795 0202; fax: (512) 795 0332

Visible Analyst Workbench [code: VAW]
Visible Systems Corp.
300 Bear Hill Road, Waltham, MA 02154
tel: (617) 890 2273; fax: (617) 890 8909

Weilan LeCASE [code: WEIL]
Weilan Corp.
24128 S.E. 45th Place, Issaquah, WA 98027
tel: (206) 392 7571; fax: (206) 772 5613

8.2 Detailed Forms

8.2.1 Excellerator II©

CASE Tool Evaluation Criteria	Wts	Excelerator II	Rtg
General	0		0.00
Product Name	0	Excelerator II	0
Company	0	Intersolv	0
Contact	0	Julie Kelly	0
Phone	0	(617) 252 4521	0
Location	0	Cambridge, MA	0
Release	0	Release 2.0	0
Demo Disk(s)	1	N	0
Next Release (when)	0	Release 3.0 January 1995	0
Development Life Cycle	5		4.24
Planning	3	Y	5
Analysis	5	Y	5
Design	5	Y	5
Construction	3	SQL DDL through XL; code through APS or add-ons	3
Testing	1	?	0
Maintenance	1	?	0
Documentation	3	Y	5
Reverse Engineering	0	COBOL through Design Recovery add-on ($1,500)	3
Methodologies	10		4.42
James Martin Information Engineering	3	Y	5.00
Enterprise Modelling	3	Y	5
Process Modelling	5	Y	5
Data Modelling	5	Y	5
Activity Decomposition	5	Y	5
Critical Success Factors	3	Y	5
Structured Analysis and Design	5		4.36
Yourdon/De Marco	5	Y	5
Yourdon/Constantine	1	Y	5
Gane & Sarson	5	Y	5
SSADM	3	Y	5
Ward-Mellor (real-time)	3	Customizer Tool ($15,000)	3
Hatley-Pirbhai (real-time)	3	Customizer Tool	3
Bachman	0	Customizer Tool	3
Chen	1	Y	5
Merise	0	Y	5
IDEF1X	1	Customizer Tool	3
Object-Oriented Analysis and Design	5		4.14
Object Information Model	5	Y	5
Dynamic Model (State Model)	5	Y	5
Functional Model (Process Model)	5	Y	5
Booch	5	Customizer Tool	3
Coad/Yourdon	5	Customizer Tool	3
Rumbaugh (OMT: Object Modelling Technique)	5	Y	5
Wirfs-Brock (RDD: Responsibility Driven Design)	1	Y	5
HP Fusion	3	Customizer Tool	3
Jacobson (Use Cases)	1	Y	5
Berard	0	Customizer Tool	3
Firesmith	1	Customizer Tool	3
Shlaer-Mellor (real-time)	5	Customizer Tool	3
Martin-Odell (OO IE)	3	Y	5
Repository	5		5.00
Central Encyclopedia (specify file structure)	5	RDBMS: Sybase, SQL Server, DB 2/2 (choose one)	5
Completeness and Consistency Checking (real-time or upon request)	5	real-time	5
Balancing	5	Y	5
Redundancy Control	5	Y	5
Access Control (multi-user access)	5	Y	5
Change and Version Control (Audit Trailing, Change History)	5	Y	5

CASE Tool Evaluation Criteria	Wts	Excelerator II	Rtg
Model Maintenance	**5**		**4.00**
Merging of Separate Models	5	Y	5
Integrated Model Views	5	Y	5
Distinct Logical and Physical Models	5	Y	5
Model Verification	5	Y	5
Requirements Traceability	5	?	0
Diagramming	**5**		**3.95**
Data Flow Diagram	5	Y	5
Entity Relationship Diagram	5	Y	5
State Transition Diagram	3	Y	5
Structure Chart	1	Y	5
Matrix Mapping of Components (specify)	5	Interface with Excel	1
Prototyping	**1**		**1.67**
GUI Prototyping	1	Y	5
Animation	1	N	0
Simulation	1	N	0
Construction	**3**		**3.92**
GUI Construction	1	through APS add-on ($7,000-$9,000)	3
Schema Generation (specify language)	3	COBOL through APS; developing C++	3
Data Definition Language (DDL) Generation	3	Sybase, Oracle, DB2, DB 2/2	5
Database Architecture Design	3	Y	5
Code Generation (specify language)	3	COBOL through APS; developing C++	3
Documentation	**3**		**2.78**
Report Generation (text, graphics)	5	Interface with Word (AmiPro in Jan 95)	1
Documentation Building	5	Interface with Word (AmiPro in Jan 95)	1
Data Dictionary	5	Y	5
Process Logic Specification (Pspecs, mini-specs)	3	Y	5
Interfacing	**1**		**3.40**
Import from other CASE tools or 3rd party (specify)	3	CDIF	3
Export to other CASE tools or 3rd party (specify)	3	?	0
Win 3.1 Dynamic Data Exchange (DDE)	5	Y	5
Win 3.1 Object Linking & Embedding (OLE)	3	through add-on	3
File formats	0		0
HPGL (Hewlett Packard Graphics Library)	1	Y	5
EPS (Encapsulated PostScript)	1	Y	5
BMP (Bitmap)	1	Y	5
WPG (Word Perfect Graphics)	1	N	0
CGM	1	Y	5
WMF	1	Y	5

Table 8.1: Excellerator II© Evaluation Form (continued).

CASE Tool Evaluation Criteria	Wts	Excelerator II	Rtg
Hardware and Software Platforms	**3**		**4.17**
Hardware Requirements	*3*		*3.80*
Processor (PC, workstation)	1	80486	5
Clock Speed	1	25-33 MHz	5
RAM	1	32 MB	1
Hard Disk Storage	1	30-100 MB	3
Graphical Display	1	VGA	5
Development Platform	*5*		*4.58*
IBM OS/2 Presentation Manager	5	Y	5
MS-DOS Widows	3	Y	5
Windows under OS/2	3	Y	5
MS-DOS	1	N	0
Unix	0	N	0
Windows NT	0	Y	5
Network Support	*5*		*5.00*
IBM LAN Server	5	Y	5
Novell	1	Y	5
NETBIOS	3	Y	5
TCP/IP	1	Y	5
Database Support	*5*		*3.14*
Oracle	5	Y	5
DB2	1	Y	5
Sybase	1	Y	5
Ingres	1	N	0
Informix	1	N	0
Paradox	1	N	0
dBase	1	N	0
Other (specify)	3	DB 2/2	3
Service & Support	**1**		**3.95**
Company Image	*3*	very good	*4.09*
Product Documentation Quality	5	high	3
Years in Business	3	12 yrs	5
Customer Installed Base for this Product	3	325,000 products licenced @ 14,000 customer locations	5
Professional Services & Support	*3*		*4.75*
On-Site Training	5	Y	5
Public Training	5	Y	5
Consulting	3	Y	5
Hot-Line (hours, toll-free)	5	toll-free M-F 8A-8h30P	5
Newsletter	3	Interlink	5
Electronic Bulletin Board (CompuServe, Internet)	3	available with Support Plus Service	3
Product Cost	*3*		*3.00*
Single User Licence (US$)	0	$5,000 (+ $15,000 for Customizer Tool)	0
Upgrade for Single User Licence (US$)	0	$0	0
Annual Maintenance/Support Fee (US$) per seat	0	$850 (? for Customizer Tool)	0
Total cost for single user with options and support (US$)	3	$5,850 (over $21,000 with Customizer Tool)	3
Overall Weighted Average	***Wavg***		***4.09***

Table 8.1: Excellerator II© Evaluation Form (continued).

8.2.2 Visible Analyst Workbench©

CASE Tool Evaluation Criteria	Wts	Visible Analyst Workbench	Rtg
General	0		0.00
Product Name	0	Visible Analyst Workbench	0
Company	0	Visible Systems Corp.	0
Contact	0	Stewart Nash	0
Phone	0	(617) 890 2273	0
Location	0	Waltham, MA	0
Release	0	Release 5.4	0
Demo Disk(s)	1	N	0
Next Release (when)	0	Release 5.x, 2nd Q 1995	0
Development Life Cycle	5		4.52
Planning	3	Y	5
Analysis	5	Y	5
Design	5	Y	5
Construction	3	Y	5
Testing	1	?	0
Maintenance	1	?	0
Documentation	3	Y	5
Reverse Engineering	0	Y	5
Methodologies	10		2.10
James Martin Information Engineering	3	Y	3.81
Enterprise Modelling	3	Y	5
Process Modelling	5	Y	5
Data Modelling	5	Y	5
Activity Decomposition	5	N	0
Critical Success Factors	3	Y	5
Structured Analysis and Design	5		3.18
Yourdon/De Marco	5	Y	5
Yourdon/Constantine	1	Y	0
Gane & Sarson	5	Y	5
SSADM	3	Y	5
Ward-Mellor (real-time)	3	Release 5.x	0
Hatley-Pirbhai (real-time)	3	N	0
Bachman	0	Y	5
Chen	1	Y	5
Merise	0	N	0
IDEF1X	1	N	0
Object-Oriented Analysis and Design	5		0.00
Object Information Model	5	N	0
Dynamic Model (State Model)	5	Release 5.x	0
Functional Model (Process Model)	5	N	0
Booch	5	N	0
Coad/Yourdon	5	N	0
Rumbaugh (OMT: Object Modelling Technique)	5	Release 5.x	0
Wirfs-Brock (RDD: Responsibility Driven Design)	1	N	0
HP Fusion	3	N	0
Jacobson (Use Cases)	1	?	0
Berard	0	N	0
Firesmith	1	N	0
Shlaer-Mellor (real-time)	5	Release 5.x	0
Martin-Odell (OO IE)	3	Release 5.x	0
Repository	5		5.00
Central Encyclopedia (specify file structure)	5	Gupta SQLBase or Sybase	5
Completeness and Consistency Checking (real-time or upon request)	5	real-time and upon request	5
Balancing	5	Y	5
Redundancy Control	5	Y	5
Access Control (multi-user access)	5	Y	5
Change and Version Control (Audit Trailing, Change History)	5	Y	5

Table 8.2: Visible Analyst Workbench© Evaluation Form.

CASE Tool Evaluation Criteria	Wts	Visible Analyst Workbench	Rtg
Model Maintenance	**5**		**3.00**
Merging of Separate Models	5	Y	5
Integrated Model Views	5	Y	5
Distinct Logical and Physical Models	5	N	0
Model Verification	5	Y	5
Requirements Traceability	5	?	0
Diagramming	**5**		**5.00**
Data Flow Diagram	5	Y	5
Entity Relationship Diagram	5	Y	5
State Transition Diagram	3	Y	5
Structure Chart	1	Y	5
Matrix Mapping of Components (specify)	5	Y	5
Prototyping	**1**		**1.67**
GUI Prototyping	1	Y	5
Animation	1	N	0
Simulation	1	N	0
Construction	**3**		**4.62**
GUI Construction	1	N	0
Schema Generation (specify language)	3	Y	5
Data Definition Language (DDL) Generation	3	Y	5
Database Architecture Design	3	Y	5
Code Generation (specify language)	3	COBOL, C	5
Documentation	**3**		**5.00**
Report Generation (text, graphics)	5	Y	5
Documentation Building	5	Y	5
Data Dictionary	5	Y	5
Process Logic Specification (Pspecs, mini-specs)	3	Y	5
Interfacing	**1**		**2.65**
Import from other CASE tools or 3rd party (specify)	3	KnowledgeWare, PBwin, Excelerator	3
Export to other CASE tools or 3rd party (specify)	3	KnowledgeWare, PBwin	3
Win 3.1 Dynamic Data Exchange (DDE)	5	Y	5
Win 3.1 Object Linking & Emb~dding (OLE)	3	N	0
File formats	0		0
HPGL (Hewlett Packard Graphics Library)	1	N	0
EPS (Encapsulated PostScript)	1	Y	5
BMP (Bitmap)	1	N	0
WPG (Word Perfect Graphics)	1	N	0
CGM	1	N	0
WMF	1	Y	5

Table 8.2: Visible Analyst Workbench© Evaluation Form (continued).

CASE Tool Evaluation Criteria	Wts	Visible Analyst Workbench	Rtg
Hardware and Software Platforms	**3**		**4.16**
Hardware Requirements	*3*		*5.00*
Processor (PC, workstation)	1	80486	5
Clock Speed	1	25 MHz	5
RAM	1	4 MB	5
Hard Disk Storage	1	5 MB	5
Graphical Display	1	VGA	5
Development Platform	*5*		*2.75*
IBM OS/2 Presentation Manager	5	N	0
MS-DOS Widows	3	Y	5
Windows under OS/2	3	Y	5
MS-DOS	1	Y (MS-DOS 4.3)	3
Unix	0	N	0
Windows NT	0	Y	5
Network Support	*5*		*5.00*
IBM LAN Server	5	Y	5
Novell	1	Y	5
NETBIOS	3	Y	5
TCP/IP	1	Y	5
Database Support	*5*		*4.21*
Oracle	5	Y	5
DB2	1	Y	5
Sybase	1	Y	5
Ingres	1	Y	5
Informix	1	Y	5
Paradox	1	N	0
dBase	1	dBase IV with SQL	5
Other (specify)	3	any ANSI 89 or 92 SQL database	3
Service & Support	**1**		**4.38**
Company Image	*3*	good	*3.55*
Product Documentation Quality	5	high	3
Years in Business	3	13 yrs	5
Customer Installed Base for this Product	3	3,000	3
Professional Services & Support	*3*		*4.58*
On-Site Training	5	Y	5
Public Training	5	Y	5
Consulting	3	Y	5
Hot-Line (hours, toll-free)	5	9A-6P ET	3
Newsletter	3	Y	5
Electronic Bulletin Board (CompuServe, Internet)	3	CompuServe	5
Product Cost	*3*		*5.00*
Single User Licence (US$)	0	$2,795	0
Upgrade for Single User Licence (US$)	0	included in maintenance	0
Annual Maintenance/Support Fee (US$) per seat	0	$505	0
Total cost for single user with options and support (US$)	3	$3,300	5
Overall Weighted Average	***Wavg***		***3.78***

Table 8.2: Visible Analyst Workbench© Evaluation Form (continued).

8.2.3 System Architect©

CASE Tool Evaluation Criteria	Wts	System Architect	Rtg
General	0		0.00
Product Name	0	System Architect	0
Company	0	Popkin Software	0
Contact	0	Katherine McCarthy	0
Phone	0	(212) 571 3434 x205	0
Location	0	New York, NY	0
Release	0	Release 3.0	0
Demo Disk(s)	1	N	0
Next Release (when)	0	?	0
Development Life Cycle	5		3.96
Planning	3	Y	5
Analysis	5	Y	5
Design	5	Y	5
Construction	3	SA Schema Generator ($696 with support)	3
Testing	1		0
Maintenance	1		0
Documentation	3	SA Project Doc Facility ($1,296 with support)	3
Reverse Engineering	0	SA Reverse Data(base) Eng. ($795+$100)	3
Methodologies	10		4.04
James Martin Information Engineering	*3*	Y	*5.00*
Enterprise Modelling	3	Y	5
Process Modelling	5	Y	5
Data Modelling	5	Y	5
Activity Decomposition	5	Y	5
Critical Success Factors	3	Y	5
Structured Analysis and Design	*5*		*4.32*
Yourdon/De Marco	5	Y	5
Yourdon/Constantine	1	Y	5
Gane & Sarson	5	Y	5
SSADM	3	Y	5
Ward-Mellor (real-time)	3	Y	5
Hatley-Pirbhai (real-time)	3	N	0
Bachman	0	Y	5
Chen	1	Y	5
Merise	0	N	0
IDEF1X	1	Y	5
Object-Oriented Analysis and Design	*5*		*3.18*
Object Information Model	5	SA Object ($421 with support)	5
Dynamic Model (State Model)	5	SA Object	5
Functional Model (Process Model)	5	SA [illegible]	5
Booch	5	SA [illegible]	5
Coad/Yourdon	5	[illegible]	5
Rumbaugh (OMT: Object Modelling Technique)	5	available in SA Object 4th Q 1994	0
Wirfs-Brock (RDD: Responsibility Driven Design)	1	N	0
HP Fusion	3	N	0
Jacobson (Use Cases)	1	?	0
Berard	0	N	0
Firesmith	1	N	0
Shlaer-Mellor (real-time)	5	OOA supported in SA Object now; OOD available 1995	3
Martin-Odell (OO IE)	3	N	0
Repository	5		3.83
Central Encyclopedia (specify file structure)	5	Y	5
Completeness and Consistency Checking (real-time or upon request)	5	completeness	3
Balancing	5	Y	5
Redundancy Control	5	N	0
Access Control (multi-user access)	5	Y	5
Change and Version Control (Audit Trailing, Change History)	5	Y	5

Table 8.3: System Architect© Evaluation Form.

CASE Tool Evaluation Criteria	Wts	System Architect	Rtg
Model Maintenance	**5**		**4.00**
Merging of Separate Models	5	Y	5
Integrated Model Views	5	N	0
Distinct Logical and Physical Models	5	Y	5
Model Verification	5	Y	5
Requirements Traceability	5	Y	5
Diagramming	**5**		**4.47**
Data Flow Diagram	5	Y	5
Entity Relationship Diagram	5	Y	5
State Transition Diagram	3	Y	5
Structure Chart	1	Y	5
Matrix Mapping of Components (specify)	5	CRUD	3
Prototyping	**1**		**1.67**
GUI Prototyping	1	Y	5
Animation	1	N	0
Simulation	1	N	0
Construction	**3**		**2.08**
GUI Construction	1	SA Screen Painter ($495+$50)	3
Schema Generation (specify language)	3	SA Schema Gen ($795+$100)	3
Data Definition Language (DDL) Generation	3	Y	5
Database Architecture Design	3	N	0
Code Generation (specify language)	3	C++ (in beta now)	0
Documentation	**3**		**2.72**
Report Generation (text, graphics)	5	N	0
Documentation Building	5	SA Project Doc Facility ($1,296 with support)	3
Data Dictionary	5	Y	5
Process Logic Specification (Pspecs, mini-specs)	3	Minispec in pseudo code	3
Interfacing	**1**		**1.56**
Import from other CASE tools or 3rd party (specify)	3	ASCII, comma delimited value format	1
Export to other CASE tools or 3rd party (specify)	3	ASCII, comma delimited value format	1
Win 3.1 Dynamic Data Exchange (DDE)	5	Y	5
Win 3.1 Object Linking & Embedding (OLE)	3	?	0
File formats	0		0
HPGL (Hewlett Packard Graphics Library)	1	?	0
EPS (Encapsulated PostScript)	1	?	0
BMP (Bitmap)	1	?	0
WPG (Word Perfect Graphics)	1	?	0
CGM	1	?	0
WMF	1	?	0

Table 8.3: System Architect© Evaluation Form (continued).

CASE Tool Evaluation Criteria	Wts	System Architect	Rtg
Hardware and Software Platforms	**3**		**4.65**
Hardware Requirements	*3*		*5.00*
Processor (PC, workstation)	1	80386	5
Clock Speed	1	whatever	5
RAM	1	4-6 MB	5
Hard Disk Storage	1	10-16 MB	5
Graphical Display	1	whatever	5
Development Platform	*5*		*3.75*
IBM OS/2 Presentation Manager	5	Release 3.0 not ready for OS/2 yet	3
MS-DOS Widows	3	Y	5
Windows under OS/2	3	Y	5
MS-DOS	1	N	0
Unix	0	N	0
Windows NT	0	Y	5
Network Support	*5*		*5.00*
IBM LAN Server	5	Y	5
Novell	1	Y	5
NETBIOS	3	Y	5
TCP/IP	1	Y	5
Database Support	*5*		*5.00*
Oracle	5	Y	5
DB2	1	Y	5
Sybase	1	Y	5
Ingres	1	Y	5
Informix	1	Y	5
Paradox	1	Y	5
dBase	1	Y	5
Other (specify)	3	Foxpro, Interbase, Paradox, SQL Server, etc.	5
Service & Support	**1**		**3.96**
Company Image	*3*	very good	*3.55*
Product Documentation Quality	5	high	3
Years in Business	3	8 yrs	3
Customer Installed Base for this Product	3	over 40,000	5
Professional Services & Support	*3*		*3.33*
On-Site Training	5	Y	5
Public Training	5	Y	5
Consulting	3	N	0
Hot-Line (hours, toll-free)	5	8h30A-6h00P	3
Newsletter	3	Y	5
Electronic Bulletin Board (CompuServe, Internet)	3	N	0
Product Cost	*3*		*5.00*
Single User Licence (US$)	0	$1,395 Release 3.0 for Win without options	0
Upgrade for Single User Licence (US$)	0		0
Annual Maintenance/Support Fee (US$) per seat	0	$250 Release 3.0 for Win	0
Total cost for single user with options and support (US$)	3	$2,066 with SA Object	5
Overall Weighted Average	***Wavg***		***3.74***

Table 8.3: System Architect© Evaluation Form (continued).