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Development of a Mobile Equipment Management System

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by

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THE UNIVERSITY OF CALGARY

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A THESIS

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PREFACE

This is an unaltered version of the author's Master of Engineering thesis of the same title. This thesis was accepted by the Faculty of Graduate Studies in October, 2000.

The faculty supervisor for this work was Dr. Yang Gao of The University of Calgary. Members of the examining committee were Dr. Yang Gao, Dr. Vincent Tao, Dr. Michael Collins and Dr. Andrew MacIver all of The University of Calgary.

ABSTRACT

Development of a Mobile Equipment Management System can result in considerable operational cost savings for many exploration and open-pit mining companies in the energy sector. Such a system requires an open architecture, which is capable of processing data from a variety of databases including data retrieval, manipulation, analyzing, presentation, representation and decision making.

Integrating and customizing tools such as Global Navigation Satellite System (GNSS) and Geographic Information System (GIS) coupled with communication technology can provide industries with a real-time Mobile Equipment Management System solution. In the open-pit mining industries there is a need for these companies to embrace new technologies in order to remain globally competitive. These industries have come to recognize with GNSS and GIS through their usage, only then the possibilities and capabilities are discovered. As with all new emerging technologies a Mobile Equipment Management System can make their jobs more effective and efficient. This thesis describes the concept for using satellite navigation and GIS to provide a modular open architecture for the development of an Equipment Management Solution for the open-pit mining sector. The discussion will revolve around a field-to-finish equipment management application and will show how efficient data management can provide industries with profitable cost saving information.

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Thank you all for turning my fears to courage and my dreams to reality

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LIST OF ABBREVATIONS

ARCS	Automatic Remote Control System
AS	Anti-Spoofing
BPSK	Binary-Phase-Shift-Keying
C/A-code	Coarse acquisition code
CDMA	Code Division Multiple Access
CS	Central Synchronizer
CT	Conventional Terrestrial
CTS	Command Tracking Station
DB	Database
DBMS	Database Management Systems
DD	Double Difference
DGPS	Differential Global Positioning System
DOC	Department of Communications
DoD	Department of Defense
DOP	Dilution of Precision
ECEF	Earth Centered Earth Fixed
EMS	Equipment Management System
FARA	Fast Ambiguity Resolution Approach
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
GIS	Geographic Information System

GLONASS	Global Navigation Satellite System (*Global'naya Navigatsionnaya Sputnikovaya Sistema*)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUI	Graphic User Interface
HCI	Human Computer Interaction
HP	High Precision
I/O	Input / Output
KNITs	Coordination Scientific Information Center (*Koordinatsionnity Nauchno-Informatsionnity Tsentr*)
LADGPS	Local Area DGPS
MCS	Master Control System
MEMS	Mobile Equipment Management System
MHz	Megahertz
MM	Mine Metric
N	Integer ambiguity
NAVSTAR	Navigation Satellite using Timing and Ranging
OCS	Operational Control System
ODBC	Open Database Connectivity
OODB	Object Orientated Database
P-code	Precise code
PDOP	Position Dilution Of Precision
PPS	Precise Position Service

PRN	Pseudorandom Noise
RADGPS	Regional Area DGPS
SA	Selective Availability
SD	Single Difference
SQL	Structured Query Language
SRN	Signal-to-noise ratio
SV	Satellite Vehicle
TM	Transverse Mercator
UERE	User Equivalent Range Error
UHF	Ultra High Frequency
US	United States
UTM	Universal Transverse Mercator
VHF	Very High Frequency
WAAS	Wide Area Augmentation System
WAP	Wireless Application Protocol
WGS84	World Geodetic System, 1984
1NF	First Normal Form
3TM	3° Transverse Mercator

CHAPTER 1

INTRODUCTION

In this thesis, a novel concept for mobile equipment management has been investigated and a prototype system developed and tested with an application to open-pit mining mobile equipment management. Mining operations involve hundreds of support equipment such as mobile lightplants, heaters, welding units, electrical generators, graders, dozers and light pickup trucks. A mobile equipment management system can be used to streamline the equipment management process resulting in efficient equipment utilization, maintenance and scheduling in an open-pit mining environment.

This chapter provides readers with the necessary background knowledge and reasons for investigating the system architecture of a mobile equipment management system and developing a prototype for such a system for mining applications. It then introduces the objectives of this study, which is the development of a Mobile Equipment Management System by integrating Global Navigation Satellite System (GNSS), Geographic Information Systems (GIS) and radio communication technologies.

1.1 Background

In today's world, technology is forever enhancing the way industrial goals are accomplished. Technology has changed the way we think; the way we assess problems and the way we work. It has given us tools to make our jobs more effective and efficient.
In the Geomatics industry, these tools particularly Global Navigation Satellite System (GNSS) and Geographical Information Systems (GIS) have emerged to provide end users with phenomenal capabilities. GNSS and GIS have provided several industries such as Energy, Transportation, Environmental and the Military, with the capabilities of collecting spatial and non-spatial information as well as locating and mapping their vehicles instantaneously.

Exploration industries have realized the vast potentials that exist with the use of GNSS and GIS, for enabling automation in their work areas. There are two commonly used GNSS, 1) The Global Positioning System (GPS), and 2) The Russian Global Navigation Satellite System (Global'naya Navigatsionnaya Sputnikovaya Sistema or GLONASS)

The Global Positioning System (GPS) is a satellite based all-weather radio navigation aid consisting of 24 operational satellites developed by the United States Department of Defense (DoD) for providing different levels of accuracies for positioning and navigation information anywhere on the planet. Over the past ten years, extraordinary achievements have been made in the use of GPS for a wide range of applications in a variety of areas including the energy sector. The United States has made a commitment to continue maintaining GPS and to provide free GPS service to all civilians.

The Russian Global Navigation Satellite System (GLONASS) is based on a constellation of active satellites, which continuously transmit coded signals in two frequency bands [Leick, 1998]. Users anywhere on the Earth's surface can identify their position and velocity in real time based on ranging measurements received from these two frequency bands. The Russian Global Navigation Satellite System (GLONASS) system is a counterpart to the United States Global Positioning System (GPS) and it shares the same principles as GPS in the data transmission and positioning methods. Within the past three years, satellite receiver manufacturers have also made GPS + GLONASS receivers available for a wide range of applications.

Geographic Information System (GIS) technology has provided us with powerful sets of tools for collecting, storing, retrieving, transforming and presenting spatial data to real world applications. In order to perform these functions a GIS must consist of three important components: computer hardware, application software modules and organizational context.

Extraordinary achievements in the use of GNSS and GIS have lead to a wide range of applications in a variety of areas including the Energy and Exploration sectors. GNSS particularly GPS has been used to develop systems for:

- Machine control;

- Vehicle tracking and navigation;
- Dispatch systems;
- Airborne systems, etc.

Satellite navigation systems have been used to support data acquisition of spatial and non-spatial information with a variety of accuracies. However, this amount of information has to be controlled by end users. In some cases, more is not necessarily efficient. After collecting vast amounts of spatial information with satellites one encounters the uncertainty of data storage, retrieval, manipulation analyzing, presentation and representation. With the necessary customization of a GIS these requirements can be fulfilled.

Without the integration of GNSS, GIS and information management, information flow becomes disconnected and unavailable to users making it no more efficient than conventional standalone methods. GNSS and GIS are available tools provided to us. However, by integrating and customizing GNSS, GIS, asynchronous/synchronous communication technology and information management, we can provide real-time solutions in data analysis and decision making.

In the energy sector, particularly the open-pit mining industry there is a need for companies to embrace new technologies in order to remain competitive. One such area for development is in the area of mine maintenance of all large and small equipment such as lightplants, heaters, welding units, electrical generators, etc. The location, maintenance and scheduling of these pieces of equipment on the mine site are very critical to the day–

to-day operations. Each piece of equipment has to be at the right place at the right time preventing any downtime in operations. Downtime to mining industries is very costly to their production and can run into millions of lost revenue yearly [Carter, 1999].

Development of a Mobile Equipment Management System can result in considerable operational cost savings for many exploration and mining companies. Such a system requires an open architecture, which is capable of collecting and storing field information and processing data from a variety of databases for performing data retrieval, manipulation, analyzing, presentation, representation and decision making functions. The integration of these technologies (GNSS, GIS and radio communication) can provide a real-time Mobile Equipment Management System solution.

This thesis investigates the concept for using GNSS and GIS to provide a modular open architecture for development of a Mobile Equipment Management Solution for the open-pit mining sector. The discussion will revolve around a field-to-finish equipment management application and will show how efficient data management can provide industries with profitable cost saving information.

1.2 Objective

The objective of this research was to investigate and develop the system architecture of a Mobile Equipment Management System for mining support equipment. Such a system utilizes GNSS, GIS and wireless communication technologies in a modular open real-time architecture that would lead to a field-to-finish process. Listed below are the specific objectives for this research project:

1. Investigate the theory on satellite navigation and positioning techniques using GNSS to determine the best-suited positioning technique for a Mobile Equipment Management System.

2. Investigate the different applications usage of GIS and database technology for determining the system architecture for a Mobile Equipment Management System.

3. Develop a prototype field system for data acquisition of spatial and non-spatial information using GNSS and wireless communication technology.

4. Develop a prototype database application for data collection, management and maintenance for storing, managing and graphically representing support equipment information.

5. Develop a prototype application with an open architecture comprising of several office components, which is capable of processing data from a variety of databases to perform data retrieval, manipulation, analyzing, presentation, representation and decision-making.

6. Test the developed system in the field.

1.3 Outline

This thesis consists of seven chapters. Brief introductions of the remaining chapters are subsequently given as follows.

Chapter Two reviews both GPS and GLONASS satellite navigation systems. It begins with an overview of GPS and GLONASS technologies. In this chapter satellite signal, errors and techniques would be examined. More focus would be spent on satellite navigation and positioning techniques that are concerned with the data collection part for the Mobile Equipment Management System.

Chapter Three focuses on GIS and databases technologies. It shows how GIS systems can be integrated into the prototype software and also provides an understanding to databases for data storage and retrieval.

Chapter Four focuses on the Mobile Equipment Management System design, methodology and concept. Discussions on the concept for a total management system will also be examined. This chapter shows that integrating technologies such as GPS, GIS and wireless communications can provide for the success of a Mobile Equipment Management System.

Chapter Five focuses on the development of a prototype system for Mobile Mining Management. A prototype is defined as an experimental working model of something to be manufactured and put into operation. The Mobile Equipment Management System prototype is designed for collecting and distributing information along with making important decisions for lightplants, support equipment on open-pit mines. The aim of this prototype is to discover and learn how such a system can increase productivity and reduce loss revenue in a mining environment.

Chapter Six examines Syncrude's field test and results, in an open-pit mining requirement. A comparison was also made with previous mine dispatch systems which were found to be unsophisticated since they provided minimal information to Mine Operations. The field of Geomatics concerned with the management of all aspect of spatially referenced information, from initial data acquisition and pre-processing, through to analysis and representation has the ability of enhancing mobile dispatch systems.

Chapter Seven presents conclusive statements and a summary of recommendations for future research in Mobile Equipment Management.

CHAPTER 2

GLOBAL NAVIGATION SATELLITE SYSTEM

A review of GPS and GLONASS technologies will be the main focus for this chapter. Satellite signals, errors and techniques will be examined. More focus will be placed on satellite navigation and positioning techniques that are concerned with the data collection part for the Mobile Equipment Management System. This will determine the best suited real-time data collection techniques for the purpose of a Mobile Equipment Management System.

2.1 Overview of GPS and GLONASS Systems

GNSS systems have become a common tool for applications in the field of positioning and navigation. The integrated use of the U.S. Global Positioning System (GPS) and the Russian GLONASS System is presently being extended and improved to achieve sub-meter accuracy, availability and integrity. The implementation of local, regional and global monitor/reference station networks provides improved performance in a variety of conventional applications and non-conventional applications. The following sections give an overview of these two satellite-positioning systems GPS and GLONASS.

2.1.1 US Global Positioning System

The Global Positioning System (GPS) grew out of a need to simplify airborne, marine and land navigation. It provides accurate real-time locations for various military applications including enroute navigation, target acquisition, photographic reconnaissance, remotely operated vehicles and command and control. GPS design and development took approximately 20 years and cost billions of United States (US) dollars to implement. The system is maintained and operated by the US Department of Defense (DoD). The entire GPS system consists of three inter-related segments: the space segment, the control segment, and the user segment.

The space segment comprises of a constellation of 21 plus 3 active spares NAVSTAR satellites (also referred to as Space Vehicles or SV) which orbit the earth at an approximate altitude of 20,000 kilometers. The GPS constellation of satellites is unevenly distributed in six orbital planes inclined at 55 degrees with orbital periods of 12 sidereal hours or one-half the earth’ s rotational period. Therefore, the ground tracks of the GPS satellites repeat themselves after two revolutions. This configuration allows for a minimum of four GPS satellites to be visible between 60 degrees north latitude and 60 degrees south latitude, almost anywhere on the earth 24 hours per day.

The control segment refers to ground-based monitoring stations called Operational Control System (OCS) strategically located around the world with a master control station (MCS) located at Colorado Springs, Colorado. The function of the control segment is to monitor the GPS satellites by determining satellite orbits, track the satellite health and the behavior of the on-board atomic clocks. The master control station applies updated data into the satellites' broadcast transmission once per day. This ensures that the satellites are transmitting accurate information about their orbital path back to the user segment.

The user segment is by far the largest segment. It is made up of the military and civilian users equipped with GPS receivers. A user typically uses a GPS antenna and receiver to track the satellite signals and extract from these signals the codes and messages broadcast by the satellites. This process determines the locations of the satellites and also the distances from the satellites to the receiver. The satellite positions and distances are used to compute locations on the earth's surface.

GPS is the first radio-based navigation system to provide timing and positioning services at all times, under all weather conditions, on a worldwide basis free of charge to an unlimited number of users [Wells et al., 1986]. GPS satellites consist of several Cesium and Rubidium atomic clocks on board. These clocks are set to a fundamental frequency, of 10.23 MHz. All GPS satellite transmissions are derived from the fundamental frequency. By multiplying 154 and 120 to the fundamental frequency creates two ultra-high-frequency (UHF) radio frequencies: the L1 1575.42 MHz, and the L2 1227.60 MHz respectively. L1 and L2 signals are generated in the satellites as pure sinusoidal waves, known as the carrier. The carrier is then modulated to alter the identical sinusoidal waves in a certain derivable random like manner in order to carry information for ranging and timing. The binary-phase-shift-keying (BPSK) method is the preferred digital modulation technique used with all GPS signals. Using the BPSK on the carrier frequency creates an instantaneous phase shift of 0 degrees and 180 degrees.

The modulated carrier transmitted by the GPS satellites is called a pseudo-random noise (PRN) code. The L1 signal is modulated by two PRN codes, the P code (precise code) and C/A code (coarse-acquisition) and the navigation messages. A modulo-2 addition technique combines the two binary data streams from the P code and C/A code into the L1 carrier. The C/A code is decoded by all civilian GPS receivers and sometimes used by the military receivers to gain access to the P code. The L2 carrier, on the other hand, only carries the precise code (P code) available for military users or favored civilians given military clearance.

The C/A code is the basis for the Standard Position Service (SPS) and has 1023 binary bits (or chips) and it is repeated every millisecond (ms). This gives a wavelength (or chip-length) of approximately 293 meters. Due to the epoch synchronization of both the C/A code and the P code and frequent repeatability of 1 ms of the C/A-code, a GPS receiver can quickly lock onto the C/A code and begin matching the received code. This also makes rapid acquisition of the P code achievable for the GPS receivers. The C/A code can achieve a resolution of one hundredth of a chip frequency that is equivalent to approximately 3 meters horizontally. Because of this high accuracy and the fact that it was meant for civilian use, the military introduced an intentional degradation of the C/A code positioning capability. This degradation or accuracy denial is commonly known as selective availability (SA) giving location accuracy within 100 meters.

At midnight May 1st 2000 the United States stopped the intentional degradation of the Global Positioning System (GPS) signals available to the public. This means that civilian users of GPS are able to pinpoint locations up to ten times more accurately than they did before. The decision to discontinue SA coupled with the US administration’ s continuing efforts to upgrade the military utility systems concludes that setting SA to zero at this time would have minimal impact on national security. Additionally, the United States have demonstrated the capability to selectively deny GPS signals on a regional basis when their national security is threatened. This regional approach to denying navigation services is consistent with the 1996 plan to discontinue the degradation of civil and commercial GPS service globally through the SA technique [Presidential Press Release, 2000].

The P code is a pseudo-random noise code generated mathematically by mixing two other pseudo-random codes. The length per chip of the P code is 29.3 meters long, one tenth of that of the C/A code. Achieving a chip frequency ten times higher than the C/A code gives rise to a much higher precision measurement in the centimeter range. Since the P code is of such high precision and only for military use, the repeat sequence period of the P code signal is longer compared to the C/A code: 267 days (or 37 weeks) versus 1 millisecond.

The GPS satellites transmit pseudo-random codes in the navigation messages for the GPS receivers to uniquely identify the satellite and the origins of these codes. This is a technique known as the code division multiple access (CDMA). All codes and messages are initialized once per week during Saturday/Sunday midnight, thus effectively creating the GPS week as a major unit of time.

2.1.2 Russian Global' naya Navigatsionnaya Sputnikovaya Sistema

Global' naya Navigatsionnaya Sputnikovaya Sistema (GLONASS) is based on a constellation of active satellites developed and administrated by the Russian military Space Forces. GLONASS satellites continuously transmit coded radio signals in two frequency bands: the standard precision (SP) navigation signal and the high precision (HP) navigation signal. Users anywhere on the Earth' s surface can identify their three-dimensional position and velocity in real time based on ranging measurements from these navigational signals. The GLONASS system is a counterpart to the United States Global Positioning System (GPS) and both systems share the same principles in the data transmission and positioning methods. As with GPS, civilian and military users can utilizes this system free of charge. Civilian users can obtain official information about GLONASS by going to the web site http://www.rssi.ru/. The entire GLONASS system also comprises of three components: the constellation of satellites, the ground-base control facilities and the user equipment.

A full satellite constellation should have consisted of 21 plus 3 active spares. Today 11 operational satellites are currently located on three orbital planes separated by 120 degrees. These orbits are highly circular with eccentricities close to zero. The satellites within these orbital planes are evenly separated by 45 degrees of latitude with an inclination of 64.8 degrees. A higher orbital inclination provides better satellite coverage in the Polar Regions. GLONASS satellites are located at an approximate altitude of 19,100 kilometers and each satellite completes the orbit in approximately 11 hours 15 minutes 44 seconds [KNITs, 1998]. Such spacing of the satellites allows continuous and global coverage.

The ground-based control facilities of GLONASS consists of the system control center (SCC) in Moscow and a network of several command tracking stations (CTS) in the former Soviet Union (SU) territories. GLONASS SCC and CTS have functions similar to that of GPS master control station and GPS monitoring stations. The CTS tracks the satellites in view and accumulates all the ranging and telemetry information from the satellites' signals. This collected information is then processed at the SCC to determines the ephemerides and satellite clock offset with respect to GLONASS time and the Russian National Etalon time scale. The SCC also provides uploads of the navigation data and corrections to the satellites via the CTS. This upload to the satellites occurs twice per day unlike GPS.

The GLONASS user segment is made up of military and civilian users. The difference being, GLONASS receivers were not as popular as GPS receivers and only recently some satellite receiver manufacturers are investing in a combined receiver capable of tracking both GPS and GLONASS signals. To the civilian users having a combined GPS\GLONASS receiver has increased the number of visible navigation space vehicles (SVs) to more than 1.5 times that of GPS. It has already been demonstrated that tracking both GPS and GLONASS signals dramatically increases the users stand alone position accuracy.

GLONASS satellites are equipped with onboard Cesium clocks to provide time and frequency standards. The GLONASS system transmits the signals within two bands: the LI sub-band (from 1602.5-1616 MHz, with frequencies spaced by 0.5626 MHz) and the L2 sub-band (from 1246.4-1256.5 MHz. with frequencies spaced by 0.4375 MHz). This arrangement provides 25 channels at each sub-hand such that each satellite in the full 24-satellite constellation could be assigned a unique frequency. GLONASS uses a technique for characterizing simultaneous multiple access or transmission known as frequency division multiple access (FDMA).

In September 1993 GLONASS L1 sub-band frequency were being shifted to slightly lower frequencies. The band was shifted from 1598.0625 – 1604.25 MHz for L1 and 1242.9375 – 1247.75 MHz for L2. This reassignment of frequency was necessary since some of GLONASS L1 sub-bands were in conflict with radio astronomers. The International Telecommunications Union (ITU) in the 1990 had given radio astronomers primary user status for the frequency bands of 1610.6 – 1613.8 and 1660 – 1670 MHz [Langley, 1997]. Also the ITU allocated frequency bands of 1610 – 1626.5 MHz to operators of low-earth-orbiting mobile satellites. Taking all these frequencies into consideration GLONASS officials are working with the ITU to reduce the number of frequencies used by the satellites [KNITs, 1998].

The current and future GLONASS frequency channels can be formulated by the following [KNITs, 1998]: L1 = 1602 MHz + k * 0.5625 MHz and L2 = 1246 MHz + k * 0.4375 MHz, where k is the channel number. The wavelength of the carrier is useful in many applications since the L1 carrier is different for each GLONASS satellite due to the different frequencies used. GLONASS satellites transmit two types of signals, the standard precision (SP) and the high precision (HP). GLONASS transmits the P code HP signal on both L1 and L2, with the C/A-code SP only on the L1. The C/A code of GLONASS is 511 chip long with a rate of 511,000 chip per second, giving a repetition interval of 1 millisecond with a wavelength of 586.7 meters. The P code is 33,554,432 chip long with a rate of 5,110,000 chips per second, giving a wavelength of 58.7 meters. The code sequence is truncated to give a repetition interval of one second. The wavelengths of the two pseudorandom noise codes of the GLONASS signal are about twice that of GPS giving noisier measurements. Unlike GPS satellites, all GLONASS satellites transmit the identical code pattern. The timing and frequency references of the signals are derived from one of three onboard cesium atomic clocks operating at 5.0 MHz. The signals are right-hand circularly polarized, like GPS signals, and have a comparable signal strength [GLONASS Interface Control Document, 1998].

The Russian Government has been committed on executing work and maintaining the GLONASS satellite system for civilian users. The government would also encourage foreign investments for funding the work on the GLONASS system by granting the system as a base for the creation of an international navigation satellites system [KNITs, 1997]. The accuracy and coverage of GLONASS can be advantageous to worldwide users especially when it complements the GPS system.

2.2 Error Sources in Satellite Navigation and Positioning

Satellite navigation and positioning applications are affected by range errors from the satellite to the receiver. The range errors can be quite sizeable, depending on the hardware and the information used for computing ranges. Error sources are broken down in the following division and error ranges [Cannon, 1995]:

- Satellite Errors:
  - clock bias: 10 m for broadcast corrections
  - orbital bias: 5 m to 10 m for broadcast corrections
  - SA: 5 m to 80 m (removed as of May 1st, 2000)
- Receiver Errors:
  - code multipath: 0.2 m to 3 m
  - code noise: 0.1 m to 3 m
  - carrier multipath: 0.001 m to 0.080 m
  - carrier noise: 0.0002 m to 0.002 m
- Propagation Errors:
  - Ionosphere: 2 m to 50 m
  - Troposphere: 2 m to 30 m

Figure 2.1, shows most of these errors and the characteristics of different error sources are examined in the following.

Satellite errors consist of satellite orbit and clock errors including SA. The orbit error is caused by the imperfect modeling of the physical phenomena governing the dynamics of the satellites. Orbital error can be eliminated or significantly reduced by using differential positioning techniques described in the next section. As to the satellite clock error, it is due to instrumental bias and drift. Using the broadcast satellite clock model, the residual satellite clock errors could be reduced to a level of several metres with SA off. Since the observed satellite clock error is the same for all receivers tracking the satellite at the same instance, the satellite clock error can be completely eliminated by using differential positioning method.

Station related errors consist of the GPS receiver clock error and multipath. The receiver clock error includes the time offset and drift of the receiver clock with respect to GPS time. The receiver clock offset can be estimated along with station unknown coordinates or eliminated by using differential positioning method [Wells et al., 1986]. Multipath is primarily caused by reflective surfaces in the vicinity of the tracking receiver and therefore the most effective countermeasure to multipath is to avoid reflecting surfaces near the receiver via site selection. Recently, various multipath mitigation algorithms have been implemented into GPS receivers by GPS receiver manufactures.

The troposphere is the portion of the atmosphere from the ground extending up to 60 kilometers above the Earth. The error produced by the troposphere refers to a refraction delay of the satellite signal. This occurs when the signal travels through the troposphere entering the Earth from space. The first 10 kilometers of the troposphere is the most difficult to model as it is affected by temperature, pressure, humidity and satellite elevation. Differencing measurements between receivers and the use of a tropospheric model to estimate the tropospheric errors can reduce or remove this error. Errors due to multipath is dependent on site selection, antenna selection, as well as the in-receiver multipath elimination technology.

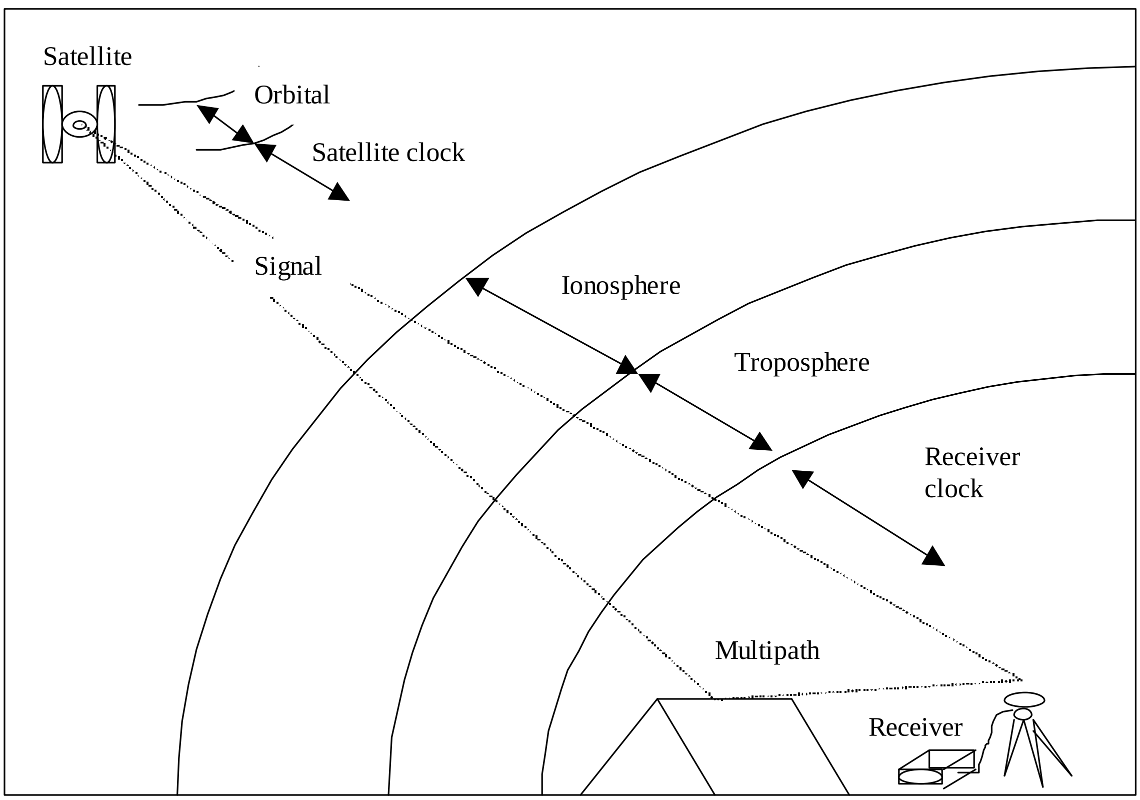


Figure 2.1: Error Sources

The ionosphere is the portion of the atmosphere that extends from 60 kilometers up to 1000 kilometers above the surface of the Earth. This is where free ionized electrons exist causing group delay, carrier phase advance, polarization rotation, angular refraction and amplitude and phase scintillation on radio waves with frequencies greater than 100 MHz [Skone, 1998]. The time of day, time of year, solar cycle and geomagnetic latitude are the most significant factors affecting the ionosphere. There are three ways of handling ionospheric error: differencing of observations can reduce the error depending on the baseline length; using the ionospheric correction broadcast with the almanac data for single frequency receivers; and use of a dual frequency receiver can compute ionospheric free observations [Leick, 1995]. The next two sections will discuss both autonomous and differential GNSS.

2.3 Satellite Navigation and Positioning Techniques

Satellite navigation and positioning techniques have matured into resources far beyond their original design goals. Today surveyors, scientists, dispatchers, miners, fire fighters, farmers, pilots, delivery drivers and other civilians from different walks of life are using satellite navigation and positioning techniques in ways that make their work more productive and safer. Many of these users require accuracies ranging from several meters to less than one meter. Autonomous and differential positioning techniques are concerned with the in-vehicle data collection part of the Mobile Equipment Management System. Also discussions on real-time positioning applications will be the focus.

2.3.1 Autonomous GPS/GLONASS

Autonomous positioning technique requires only one receiver to generate position results, see Figure 2.2. The position of the receiver can be solved by a least squares adjustment based on observation equations. Unknown parameters in this method consist of three coordinate components of the receiver position vector and the receiver clock error. At least four satellites are required at each epoch for a unique or over determined solution since there are four unknown parameters.

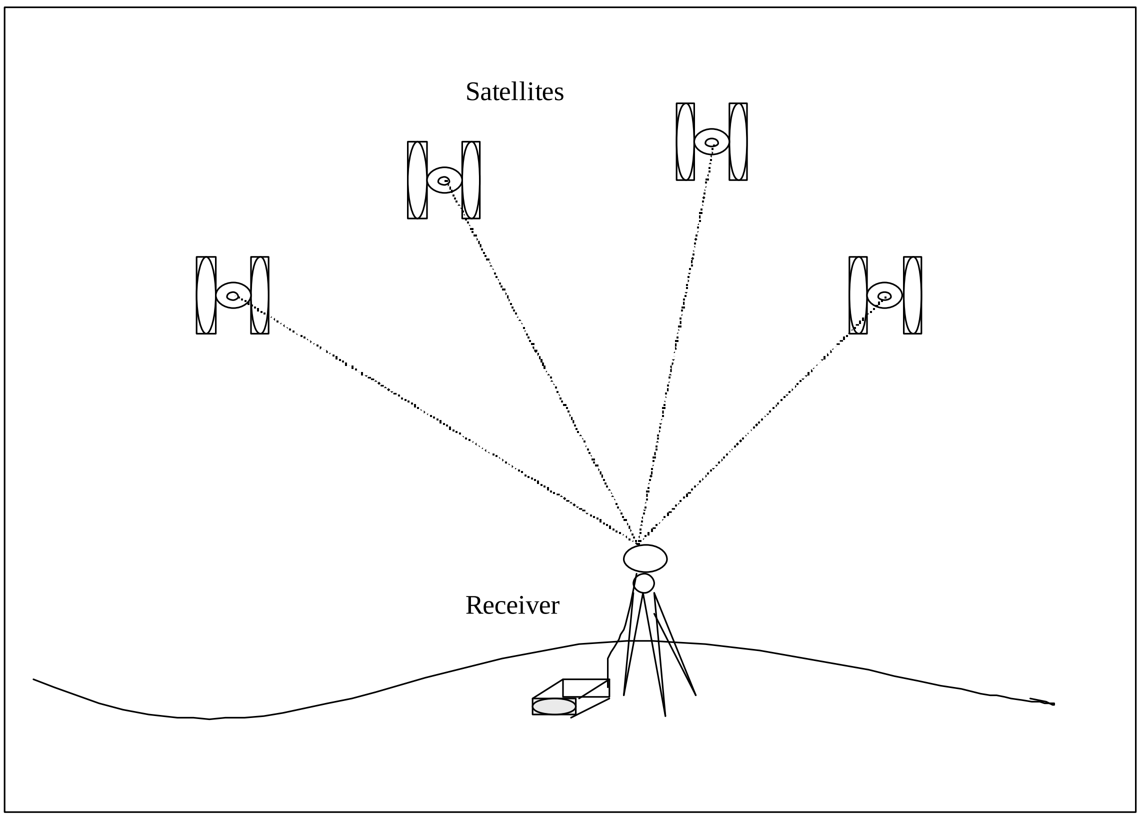


Figure 2.2: Autonomous Positioning

In autonomous positioning all error sources are absorbed by the position except the receiver clock, which is treated as an unknown and resolved [Hofmann-Wellenhof et al., 1994; Wells et al., 1986]. The unresolved error sources discussed in Section 2.2, result in less accurate positions. Prior to May 1st, 2000 when SA was turned on and broadcast ephemerides used the positioning accuracy was over 100 m (2DRMS). Now 2 m to 5 m is achievable with SA removed. To achieve higher accuracies, differential-positioning techniques must be implemented.

2.3.2 Differential GPS/GLONASS

Many applications, including the Mobile Equipment Management System that is presented later in this thesis, require real-time positioning accuracies ranging between one meter to sub-meter levels. These high accuracies are attainable through differential positioning. Differential positioning requires two receivers, a reference and a rover, recording observations from the same satellites simultaneously. Error sources such as: clock offset, ephemeris, orbit, atmospheric, and selective availability can be eliminated or significantly reduced through differential calculations. Differential GPS/GLONASS can eliminate all errors that are common to both the reference receiver and the roving receiver except for multipath and any receiver noise errors. These errors are independent since multipath (see Figure 2.3) occurs right around the receiver, and receiver noise is unique to the receiver.

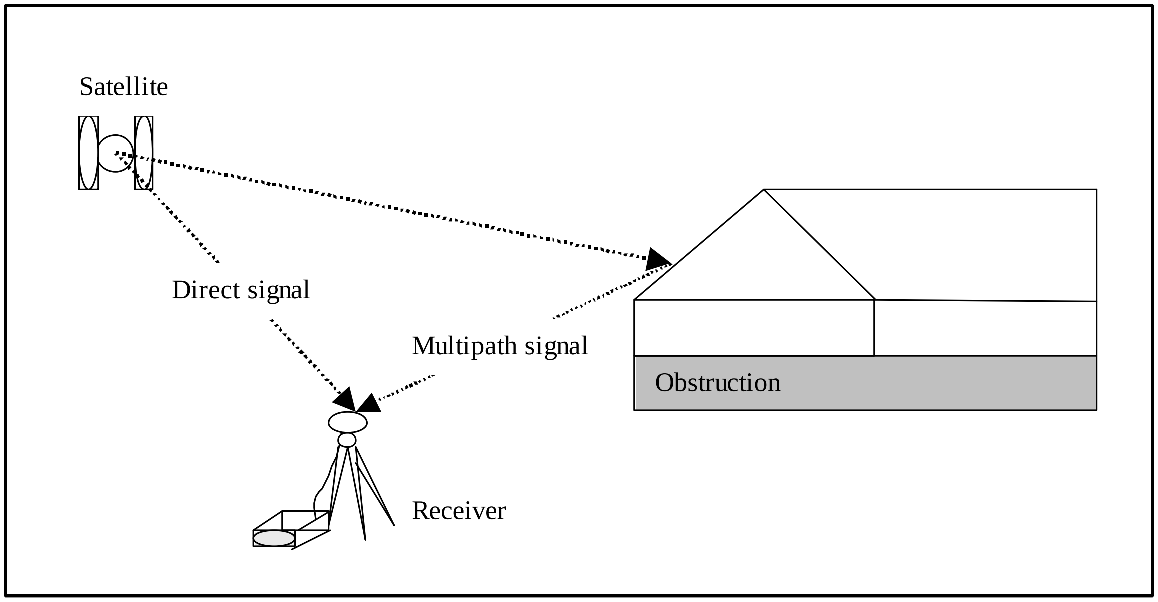


Figure 2.3: Satellite Multipath Error

When performing differential positioning the reference receiver is set on an accurately known point. The degree of accuracy of this known point would affect the position determined by the roving receiver. Figure 2.4 shows a differential positioning method setup.

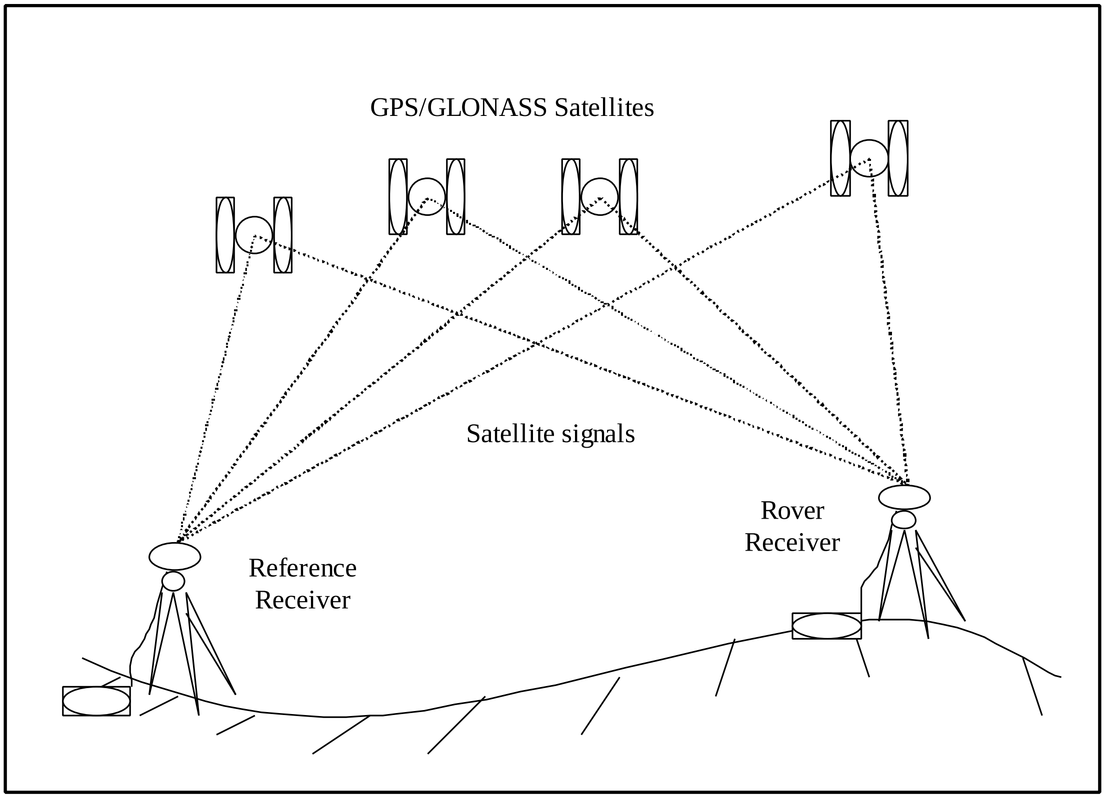


Figure 2.4: Differential Positioning

Differential positioning can be conducted between receivers and between satellites to reduce the error sources mentioned above. The method used between receivers is known as single differencing (SD) therefore, to eliminate the satellite clock. Orbital errors, as well as ionospheric and tropospheric delays are significantly reduced to small values by the differencing process. These values are: 0.1 – 1 ppm for orbital error, 1 – 2 ppm for SA, 0.2 – 0.4 ppm and 0.3 – 3 ppm for ionospheric and tropospheric delays [Abousalem, 1996]. Note, this hold true only if the distance between the reference station and the rover is less that 200 kilometers [Abousalem, 1996]. If SD measurements between receivers are further differenced between two satellites, it will give rise to a technique known as double differencing (DD). With DD technique, the receiver clock offset is eliminated plus a further reduction of orbital, ionospheric and tropospheric errors over short baselines. Double differencing will provide centimeters accuracy, using carrier phase measurements for short distances between the reference and the rover [Lachapelle, 1997].

Data acquisition for the Mobile Equipment Management System requires real-time differential positioning for achieving guaranteed accuracies between 1 – 2 meters and SD methods can fulfil this requirement. In real-time differential positioning, data at the reference station is transmitted to the rover via a data link, shown in Figure 2.5, so as to form the differential observations.

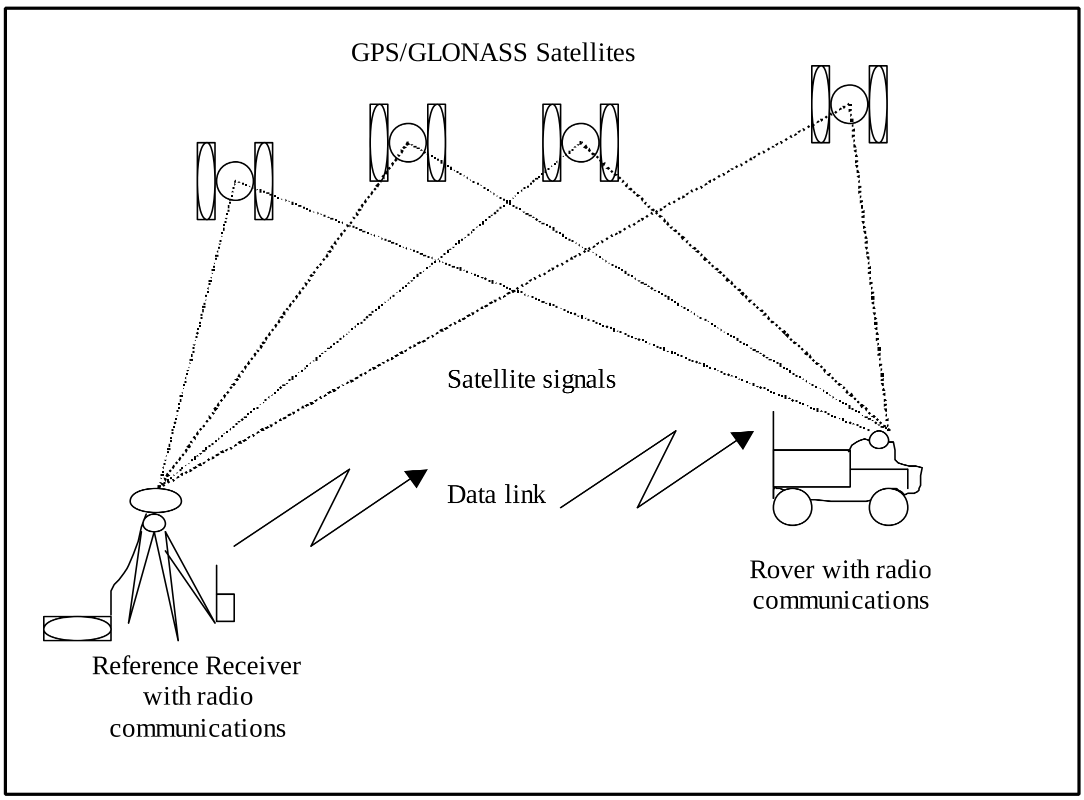


Figure 2.5: Real-Time Differential Positioning

In Figure 2.5, the reference station of known coordinates are used to compute the combined effects of satellite clock error, orbital error, ionospheric and tropospheric delays, and SA on single pseudorange observation. The calculated values for every pseudorange observation are known as the pseudorange corrections. These corrections are then transmitted from the reference station via a data link to the rover. When the rover receives the pseudorange corrections from the reference station, it is applied to the rover pseudorange observations to form single difference observations. Depending on the distances between the reference and the rover sub-meter to meter accuracies can be achieved when using code or code plus carrier phase [Lachapelle, 1997].

Several different types of communication systems can be used to achieve a real-time data link between the reference and rover. Such communication systems are radio transceivers, FM radios, cellular phones and geostationary communication satellites. The data rate transmission for differential pseudorange corrections between the reference and rover should be 50 – 100 bits per second to achieve accuracies of 2 – 5 meters. For accuracies less than 1 meter when using raw carrier phase and pseudorange observations you require 1000 – 2000 bits per second [Lachapelle, 1997]. Data link requirements are a function of the amount of data to be transmitted, reliability, integrity and distance between the reference and rover.

Real-time differential users can also receive pseudorange corrections from different wide area GPS suppliers. These corrections are generated using multiple reference stations in a local area (LADGPS) or a wide area (WADGPS) or a regional area (RADGPS) network. In this method, pseudorange corrections are estimated from several reference stations separated by hundreds or thousands of kilometers and the positioning accuracy, reliability and availability are improved [Abousalem, 1996]. Some suppliers of WADGPS are US Coast Guard, Canadian Active Network, FAA Wide Area Augmentation System (WAAS), Racal Landstar™, Omnistar™, STARLINK Inc. and STARFIX.

CHAPTER 3

INFORMATION MANAGEMENT AND DATABASES

A review of Information Management and Database technologies will be the main focus for this chapter. This chapter will give an understanding towards GIS and will explore the different database models providing an understanding to databases for data storage and retrieval. It will also show how Information Management systems can be integrated into the equipment management prototype software.

3.1 Overview of Geographical Information Systems

A Geographic Information System commonly known as GIS is a computer-base information system that allows for data capture, modeling, manipulation, retrieval, analysis and presentation of geographically referenced information. GIS' s are not just user systems for graphically representing spatial data, these systems can be interfaced, modified, enhanced or adapted to provide better solutions to geo-spatial problems such as in the equipment management prototype system. Since GIS deals with spatial information and allows for human interaction for data analysis, each component of a GIS needs to have a well designed Human Computer Interface (HCI). Every GIS consists of a major component known as the database. The database provides the GIS with context information for informational value and usage. Figure 3.1 shows a typical concept of a GIS system where information is acquired, interpreted and presented to its users.

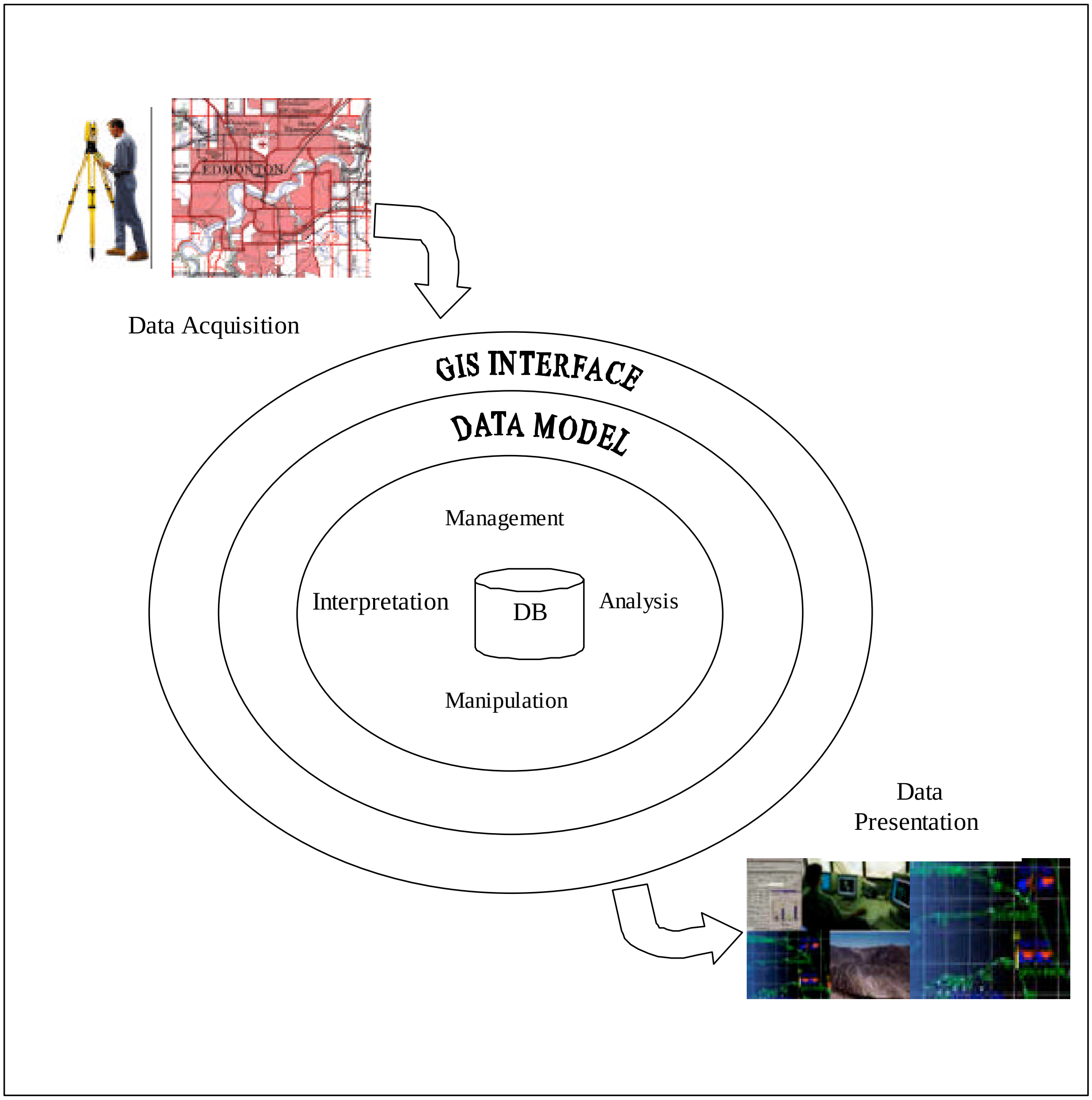


Figure 3.1: A Typical GIS Concept

The operations available in GISs vary from one system to another. However, their fundamental capabilities can be expressed in terms of four types of operations [Tomlin, 1990]:

- Programming operations: They consist of a number of routines in the operating system level such as, supervise and direct the system operations with peripheral devices connected to the computer.
- Data preparation operations: They encompass a variety of methods for capturing data from different sources, processing and storing them appropriately in the database.
- Data presentation operations: They encompass a variety of methods for presentation of data, such as drawing maps and generating reports.
- Data interpretation operations: These operations transform data into information and as such they comprise the heart of any geographic information system.

Operations for data interpretation can be viewed as dealing with a hierarchy of data. At the highest level, there is a library of maps commonly referred to as layers. These layers have to be in registration, meaning they have a common coordinate system. Each layer is partitioned into zones with a common attribute value [Samet and Aref, 1995].

In the past GIS offers very little in terms of semantic control of information processing. This is because application semantics were difficult to map onto the descriptive information available in the input data. Today GISs are being designed to operate with distributed geographic data making information accessible to all users. Distributed GIS provides many incentives compared to monolithic systems, it basically takes advantage of the distributedness in both management and processing of spatial information.

A large number of GISs use the relational model for information management typically adopting a hybrid architecture where attribute data and their spatial references are stored and managed in independent structures. These GISs maintain the attribute data in conventional database management systems (DBMS) but organize and manipulate spatial data using conventional file handling techniques. In doing so, special purpose software is employed for both data management and query processing. This relational architecture allows for data management, data security, and data integrity and can facilitate multiple user access or concurrency management.

If benefits from GIS in data management are to be derived from distributed database technology, then GISs must develop that area of database technology. One must consider the particular complexities of distributed database management without being hindered by an approach that stores some data outside of the DBMS [Worboys, 1994]. This makes the information inaccessible to any distributed functions provided within the GIS. Hence, query optimization is a very complicated issue and has to be broken into spatial and aspatial components. In such GIS systems the query must first partitioned into spatial and aspatial components before any type of optimization and evaluation can be undertaken. Also efficient data retrieval through queries depend on appropriate HCI, well design interfaces and query languages and properly structured data in the database. With recent advancements in communications GISs should take a distributed database approach rather than a centralized database approach. The distributed approach also allows data to be shared globally while controlling data integrity at local sites. To preserve data integrity care must be taken when modification to data is carried out. The approved data modifications have to be propagated throughout the entire system. Since databases are the building blocks of a GIS, the next section deals with the principles of databases.

3.2 Databases

To have an effective Mobile Equipment Management System, information pertaining to each piece of equipment needs to be collected, stored, accessed, manipulated and retrieved. Databases allow for the storage and distribution of such information. Developed databases must be comprehensive, accurate, easily accessible, easy to use, easy to update and expandable. Also in the philosophy of databases, a key element is data sharing or the support of multi-user access. This limits users to different levels of access to the database, which ensures data integrity, and security to the system. Each user or user group may require a particular window to the data that is important to their area. This concept is known as the view, which provides users with their own customizable data model. This provides a subset of the entire data model, and the authorization to access that particular sector of the database.

Databases allow for a wide variety of usage such as:

- Regular, day-to-day routine usage, where the users access are limited to their view.

- Regular, expert usage performed by expert database maintenance personnel for the upkeep and system development.
- Irregular but predictable usage, where the user may query the information of a piece of equipment to determine its size and make that he/she already knows but has to confirm it.
- Irregular, flexible, casual usage, where the user may browse through the information resource section of the database to identify relevant information of a piece of equipment.

In the first three cases where usage patterns can be predicted or is routine by the users, interaction facilities can be set up in advance for these canned transactions. These canned transactions may optimize the performance of the database. Case four (Irregular, flexible, casual usage), is the most challenging because the request becomes flexible. The users in most cases would have to create different queries each time. To provide such database interaction for the user, the interaction language, Structured Query Language known as SQL, can be used to control databases. SQL programming is by far the most popular non-procedural data access language on computers of all sizes.

In the overall structure of a database system there are several models, namely, hierarchical, network, relational, object-oriented, and deductive. Today, hierarchical and network databases have been replaced by relational database technology while object-oriented and deductive are progressively coming on stream. The Mobile Equipment

Management System's main focus would be on the relational model, which is described in the next section.

3.3 Database Models

3.3.1 Concept of a Relational Database

E.F. Codd conceived the relational database model in 1969 working for IBM [Samet and Aref, 1995]. The model is based on mathematical theory or specifically, disciplines of set theory and predicate logic. The reasoning behind the relational model is that a database consists of a series of unordered tables or relations that can be manipulated using nonprocedural operations for returning tables. Hence, no single piece of data provides information on its own, instead it's the relationships with other data sets that provides useful information. Relational databases are collections of tabular relations commonly refer to tables. Table 3.1 shows the structure of a relational table called 'Equip Fuel'. This table contains fuel information attributes of the particular piece of equipment such as Unit 44-28-1.

ID	Unit ID	Fuel Date	Fuel Time	Amount of Fuel	Meter Reading
318	44-28-1	10/25/1999	AM	53.00	8848
319	44-28-1	11/02/1999	PM	46.00	8923
320	44-28-1	11/16/1999	PM	50.00	9000
321	44-28-1	11/30/1999	AM	50.00	9623
322	44-28-10	10/08/1999	AM	52.00	7992
323	44-28-10	10/30/1999	AM	53.00	8800
324	44-28-10	11/15/1999	AM	54.00	8999
325	44-28-10	12/04/1999	AM	55.00	9100

Table 3.1: A Typical Relational Table Called Equip Fuel

The attribute names (Unit ID, Fuel Date, Fuel Time, etc.) are placed in columns. The data in a relation are structured as a set of row or tuple containing a set of values for each attribute. The relational model can be applied to both databases and database management programs. When designing a database for equipment management decisions have to be made regarding how best to take some system in the real world and model it in a database. This process consists of deciding which tables to create and which columns they will contain, as well as relationships between tables. In order for a database to have relational characteristics it must meet the following requirements:

- The ordering of rows is not significant.
- The ordering of columns is not significant.
- Rows in a relation are all distinct from one another.
- Columns are ordered with data items corresponding to the attributes in the relation schema.

However, current relational systems require that the data items are themselves atomic, meaning they cannot be decomposed into list of further data items. Therefore, every row-by-column position or cell cannot contain a set, list or array, only one value exists in each cell of Fuel Date or Meter Reading. This relation is said to be in the first normal form (1NF). First normal form also prohibits the presence of repeating groups of information, even if they are stored in multiple columns.

The benefits of a well-designed relational database model are numerous. Listed below are some of the more important benefits:

- Data entry, updates and deletions are efficient.

- Data retrieval, summarization and reporting are efficient.
- Relational databases follow a well formulated model therefore it behaves predictable.
- Since much of the information is stored in the database rather than in the application the database is somewhat self-documenting.
- Changes to the database schema (the definition of the tables) are easily made.

In the following sections, three fundamental system architectural types will be discussed. They are file-based systems, client/server systems and multi-tiered architectures. It is important to understand the differences between the architectures for a Mobile Equipment Management System. As the application and databases grow in size and in complexity, there may be a need to switch from one type to another.

3.3.2 File-Based Systems

Products like Microsoft Access symbolize the simplest form of relational databases. Access consists of one file with an extension ".mdb". Within this file all the database tables, queries and forms that apply to the database as well as any locking information are housed. This file can reside on a single user's computer or can be located on a network for multi-user access. In file server architecture, shown in Figure 3.2, a centralized server or servers provide access to computing resources. Such architecture has a low-cost entry point and flexible deployment. Flexible since it allows computers to be added or reduced within the architecture. Figure 3.2 also shows an Access database connected to several potential database users on a network. In this Figure the database is placed on a File Server with no active database software. It is up to the application on the individual workstations to run the database. The disadvantage with a file-based architecture is scalability. This architecture is more suitable for a small workgroup because handling more than a dozen users over a network on a file-based system would definitely slow the network down.

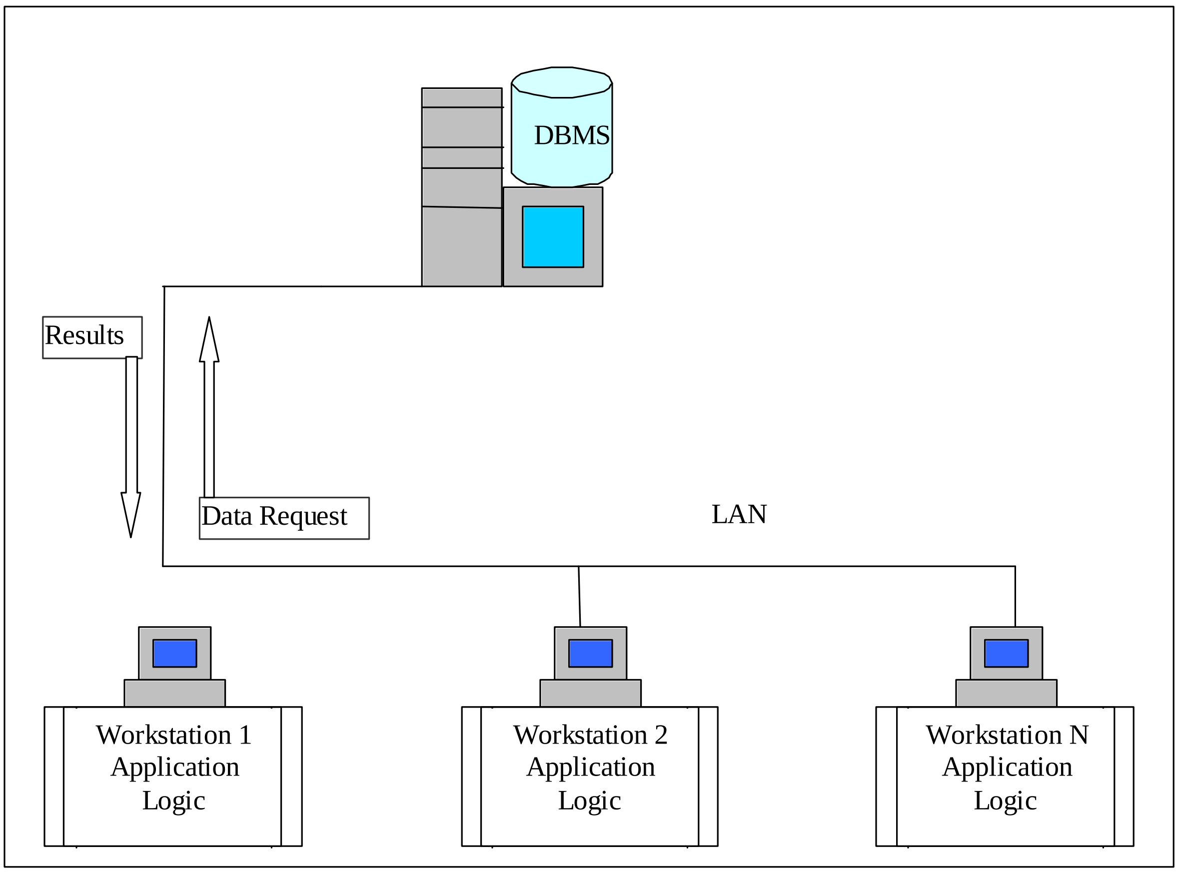


Figure 3.2: Architecture of a File Server

3.3.3 Client/Server Architecture

The client/server application architecture addresses issues of cost and performance. It allows applications to run on both the user workstation and the server. Products such as Oracle and SQL Server can handle this type of application. In a client/server architecture, two separate applications, operating independently, could work together to complete a task. Actual instructions can be communicated to an application running on the server and in turn the server can execute those instructions and send a response back. Figure 3.3 shows client/server architecture. The clients are the individual users running applications

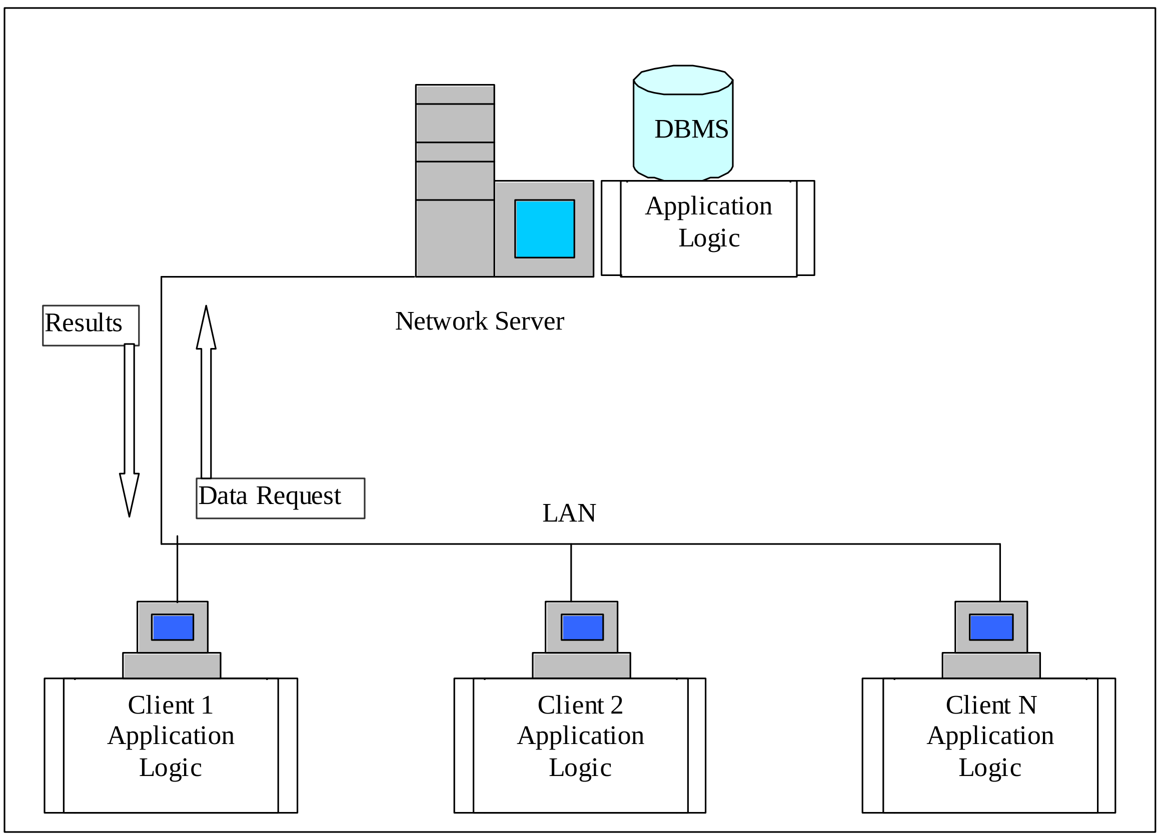


Figure 3.3: Architecture of a Client \ Server

like the Mobile Equipment Management System. The client makes a request of the server, and the server services the request. The request can take the form of an SQL query submitted to an SQL database engine. The database engine in turn processes the request and returns the resulting set. The advantages to having client/server architecture reside with the server and the capabilities it brings to the processing of data. The server no longer has to devote processor cycles for data formatting and report generation; instead it merely ships the data to the client. The network potentially has to transmit less data most of the time.

3.3.4 Multi-tier Architecture

Multi-tier implies that there are various software tiers, each with its own responsibility for a certain task. The tiers are normally divided into three parts shown in Figure 3.4: client or Graphic User Interface (GUI), middle or business and the data tier. The multi-tier software can be installed over a number of client computers, each computer performing a small part of the whole. With this approach, Visual Basic applications can play a role on the client as in a client / server architecture and also in the middle tier using the Active X software components. These active X components can be run on a server under a transaction-processing environment. The multi-tiered approach was designed to solve many of the client/server shortcomings, some of these features are as follows:

- Applications are easier to deploy and keep current, especially when you have to scale applications for use on the Internet.

- Encapsulating all business rules in the middle tier give applications the capability to access the rules by use of shared components rather than coding the same rules into every application.
- The business layer can ensure security of data in a standard manner and also assure applications stability.
- Multi-tier approach leaves room for scalability, since more middle-tier hardware can be included into the architecture.

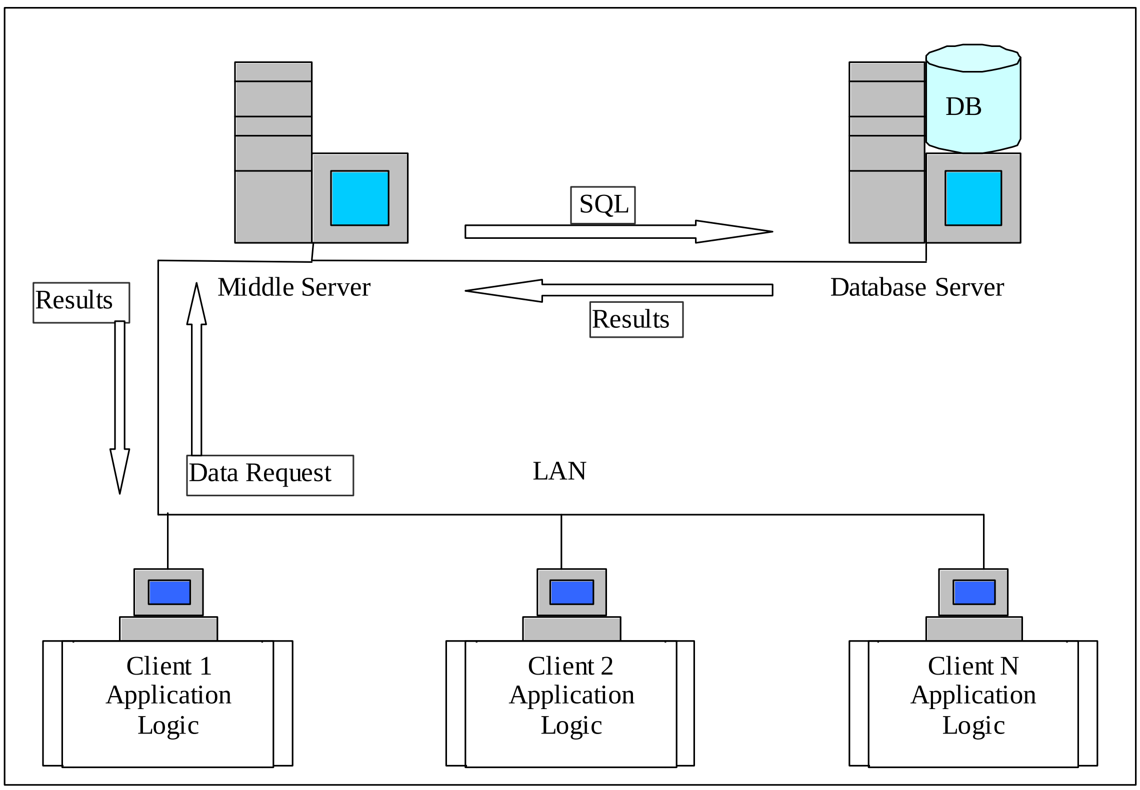


Figure 3.4: Architecture of a Multi-tier System

The benefits of multi-tier architecture are the ability to reuse work, manage large projects, simplify maintenance and improve performance but this architecture is not the answer to every situation. A component-based client / server model can give sufficient return on investment in the Energy and Exploration industry by reducing network traffic.

CHAPTER 4

MOBILE EQUIPMENT MANAGEMENT SYSTEM DESIGN AND METHODOLOGY

System design, methodology and concept of a Mobile Equipment Management System will be the main focus for this chapter. Discussions on the concept for a total management system will also be examined. Integrating technologies such as GPS, GIS and wireless communications can provide for the success in such a concept.

4.1 System Architecture Design

Designing a Mobile Equipment Management System begins with adopting a design methodology. A design methodology is an organized set of procedures that takes a system from initial conception to successful implementation and operation [Brittian, 1980]. The recent explosion of development strategies can be identified as belonging to one of two distinct methodologies. The database methodology and the systems analysis methodologies [Hawryszkiewycz, 1984].

Database methodology is the most traditional design used for information systems. This design concentrates on the data, by defining the elements and structures in the user environment. A model such as relational, hierarchical and network is then selected for representing the essential characteristics of the data. After modeling, the function and process of the system is determined. Database systems are data repositories for serving large numbers of diverse users. Acquisition of data is the most costly component when implementing information systems or GISs. In most instances data will outlast the hardware or software component of such systems. This approach emphasizes computers and computer storage technology first.

System analysis methodologies are becoming the norm for equipment management, vehicle dispatch, and vehicle tracking systems. The design order for these systems is the reverse to database methodologies. Functions and processes requirement models for the users are defined in the beginning stages. An analysis definition for the required processes identifies the data requirements, structure and flow of data through the system. The data models are the last things formed. In this methodology, application requirements are top priority. Technologies and techniques such as GPS, GIS and wireless communication are then tailored to users for providing efficiencies.

The analysis methodology considers the application requirements first and then the technology and techniques are fitted for the user applications. In Figure 4.1 both classes of methodologies are illustrated using the same components.

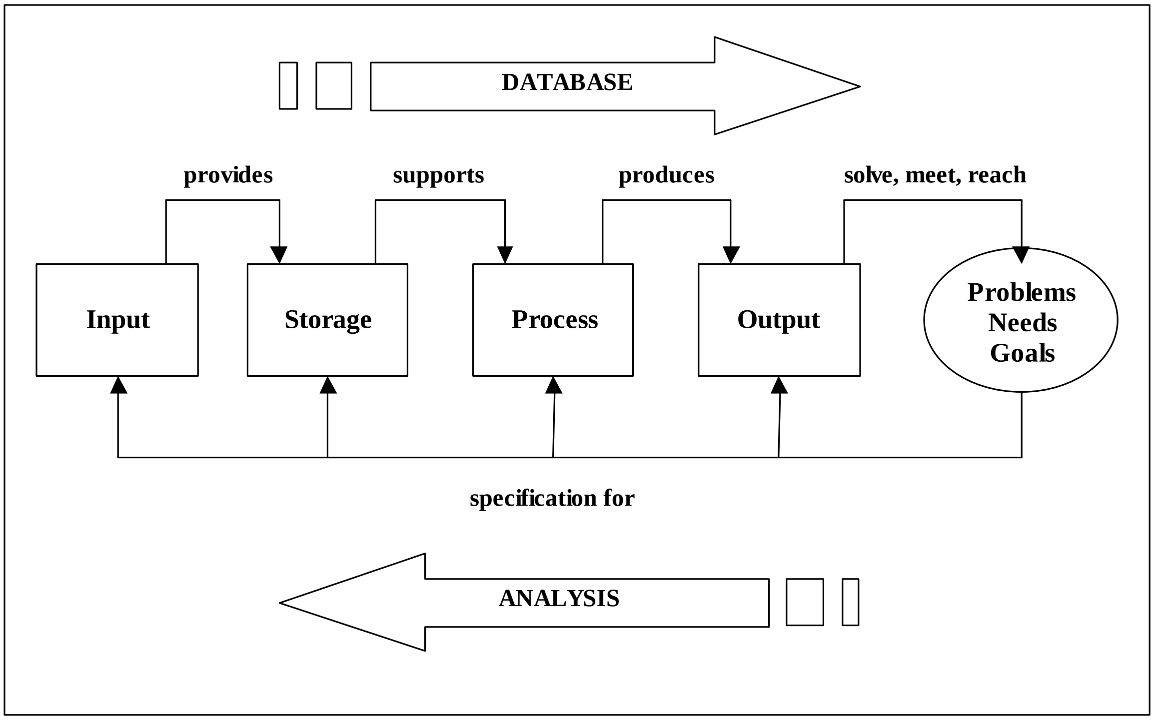


Figure 4.1: Design Methodologies [Montgomery, 1983].

4.2 Mobile Equipment Management System Methodology

The Mobile Equipment Management System (MEMS) uses the analysis methodology. Such a model is more practical given the nature and characteristics of the system. Although data acquisition is part of the MEMS, it is not the major focus. The main requirement of MEMS is to acquire database information from different departments of the Mine to carry out efficient decision making and data management. The design of the system' s data model focuses on the specific functions for achieving user satisfaction and efficiencies, shown in Figure 4.2.

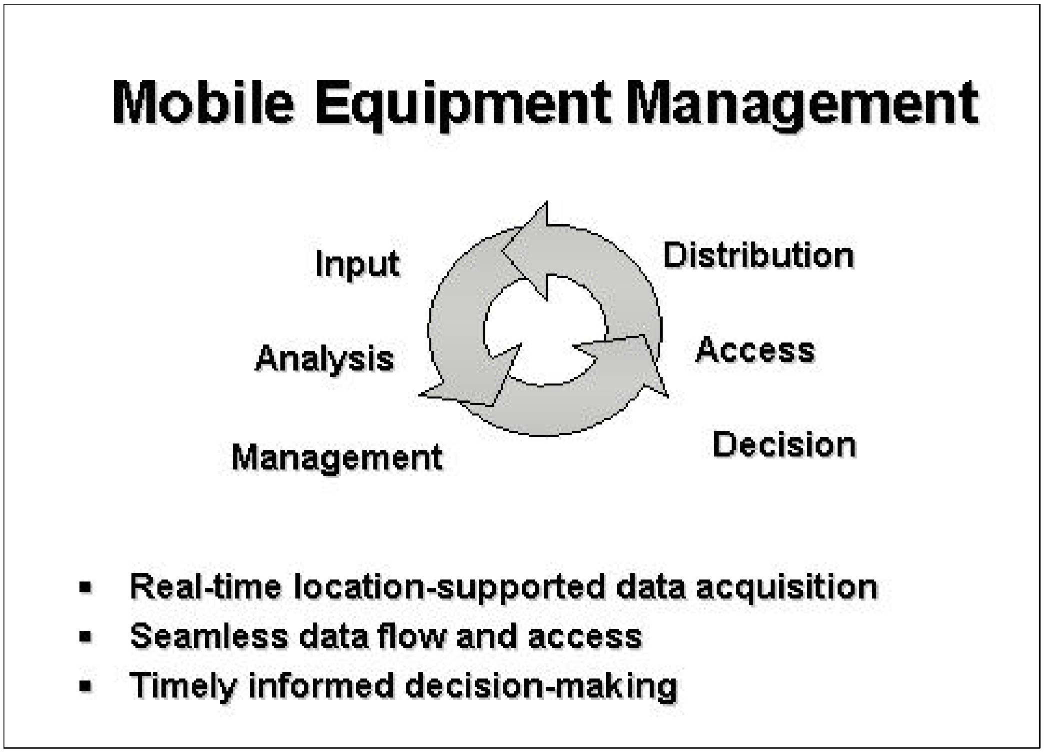


Figure 4.2: System's Model

The adopted systems analysis design for this research is shown in Figure 4.3. This design represents an iterative approach consisting of different stages of development. For the equipment management prototyping system, which will be further discussed in Chapter 5, system analysis problems were defined and constraints identified by the Energy sector. Implementation of the proposed solutions occurred in the development phase. After, implementation of the Mobile Equipment Management System was slated for two testing and evaluation phases, one to be carried out at the University of Calgary and surrounding areas and the second at Syncrude mine site located in Fort McMurray. The results of the evaluation would provide Syncrude with more information that would lead towards enhancing functionality in their present operation. The existing system analysis was modified to reflect these refinements and the design cycle repeated.

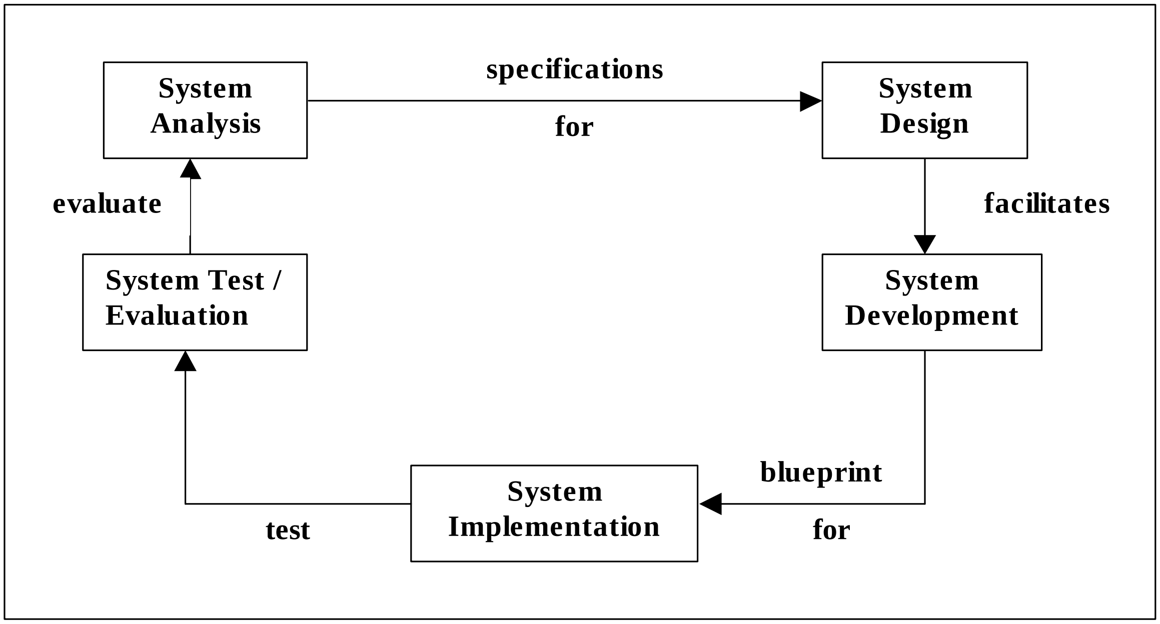


Figure 4.3: MEMS Design Framework

4.3 Mobile Equipment Management Concept

The Mobile Equipment Management System is comprised of primarily three main subsystems shown in Figure 4.4, namely:

1. In-vehicle data acquisition;
2. Communication system and;
3. Main office component.
    - Management and Maintenance; and
    - Scheduling and Decision-Making;

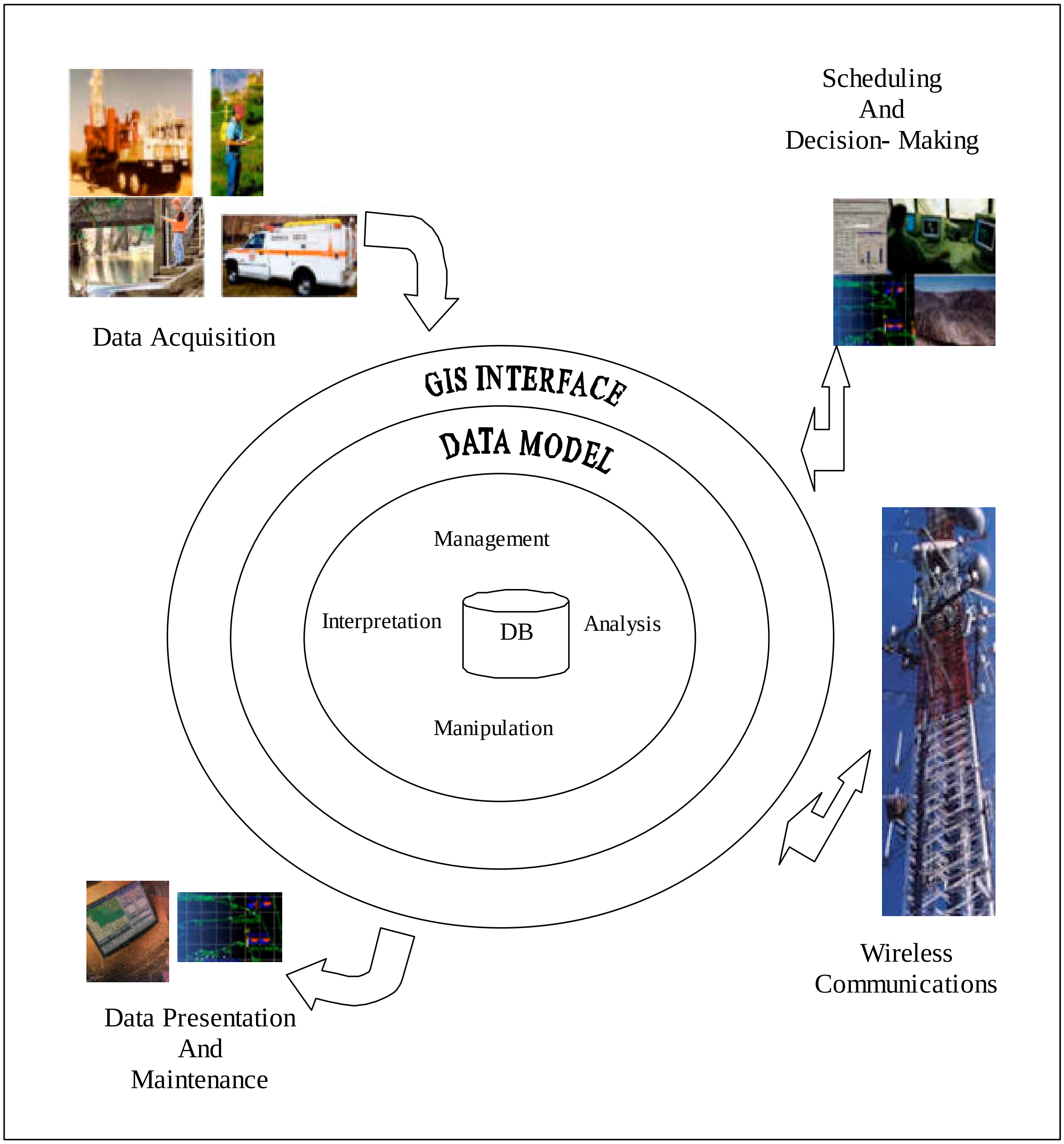


Figure 4.4: MEMS Concept

The main office component is further sub-divided into two components as shown above. The optimal integration of these three subsystems can lead to a Total Mining Solution for the management of equipment and mobile vehicle.

The MEMS concept will allow for new technologies and tools such as, satellite navigation, GIS, information management and wireless communications as shown in Figure 4.4. The framework will provide for existing systems to be integrated and design new guidelines for future development. The potential for this concept will allow for easy integration of stand-alone networks and existing functional modules. This concept will solve occurring problems as the following statement describes in Italics:

"*With increasing technology used in mining, specific information objectives are being met but other problems are being created. Usually the life cycle of technology is small, as current systems are replaced by newer ones creating integration problem and end-user training becomes an on-going issue" [Peck, 1997]*.

4.4 Minimum Critical Specifications for MEMS

During the early stages of development enhance communications between Syncrude and the University of Calgary was carried to establish a common reference point and determine the minimum critical specifications for the MEMS. Some of the minimum critical specifications are as follows:

- On-board computer for the data collection system software;
- On-board GPS with antenna;
- Two-way radio communication;
- 2D location computation in their local grid coordinates;
- 10 m horizontal accuracy;
- Data maintenance and update;

- Provide decision making and reporting;
- Automatic data storage;
- User friendly Windows base software with error checking and,
- Windows NT 4.0 operating system.

Typical hardware components consists of GPS receiver with selectable communication system, Laptop with NT 4.0 operation system consist of two serial ports for receiving information from GPS and to transmit collected information to the main computer via radio modem or cellular technology. Communication systems could include UHF/VHF private radio systems, 800 to 900 MHz trunking, cellular telephone or satellite. In most open-pit mines the preferred method would be cellular telephones or private radio systems. A private radio system was used for system trials and testing with an experimental frequency provided by Eagles Navigation System Inc.

CHAPTER 5

DEVELOPMENT OF A MOBILE EQUIPMENT MANAGEMENT SYSTEM PROTOTYPE

The prototype system will be the main focus of this chapter. A prototype is defined as an experimental working model of something to be manufactured and put into operation. The Mobile Equipment Management System prototype is designed for collecting and distributing information along with making important decisions for lightplants, support equipment on open-pit mines. The aim of this prototype is to discover and learn how such a system can increase productivity and reduce lost revenue in a mining environment.

5.1 In-Vehicle Data Acquisition Component

5.1.1 System Configuration

The Mobile Equipment Management System data acquisition component, see Figure 5.1, consists of a rugged Pentium laptop computer with NT 4.0 operation system, the equipment management data collecting software, GNSS receiver, an active antenna, differential radio and Pacific Crest UHF/VHF radio. The differential radio is used specifically for receiving differential corrections from the base receiver depending on the user-required accuracy. This is optional to the system and for this particular application only absolute positioning was required since it met Syncrude's 3 meter to 5 meter accuracy with SA turned off. However, for positioning stability in obtaining 3 meters consistently, Syncrude is looking at implement real-time differential. The Pacific Crest UHF/VHF radio is used to form a data link between data acquisition and the main office computer for transferring collected data to the office database where data management and maintenance would be performed, Figure 5.2.

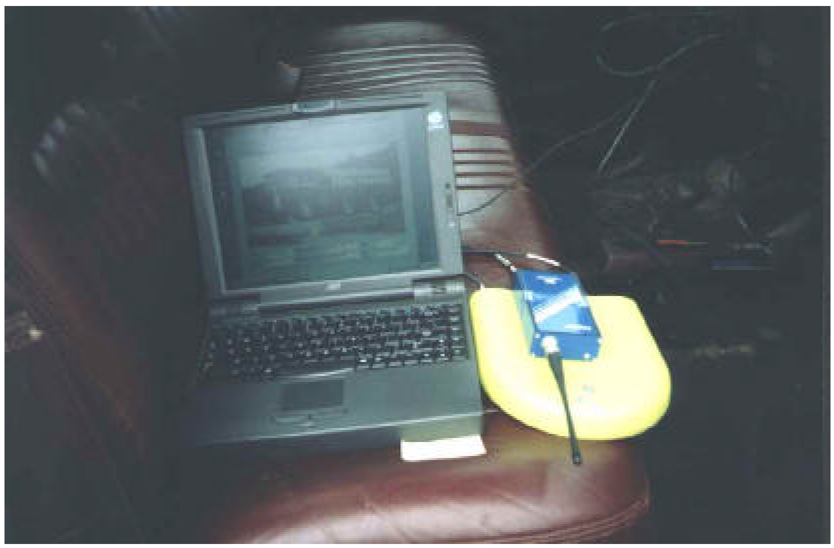


Figure 5.1: In-Vehicle Data Acquisition Hardware Component

GPS/GLONASS receiver was selected to test for better satellite coverage. This particular receiver can track up to 24 satellites at any given time therefore, Syncrude wanted to examine the effects GLONASS would have on absolute positioning. In the northern region around 57° N latitude the number of satellite visible averages between 6 to 8 GPS satellites at any given time. Therefore, by having a receiver that can track both GPS and GLONASS may provide better satellite availability, integrity and accuracy to the system.

The GNSS receiver can also provide its users with differential positioning when needed for different applications.

The equipment management data collecting software is specifically designed to cut down on human errors in the field. The software is designed to collect spatial and non-spatial information. The spatial information is directly recorded from the GPS/GLONASS

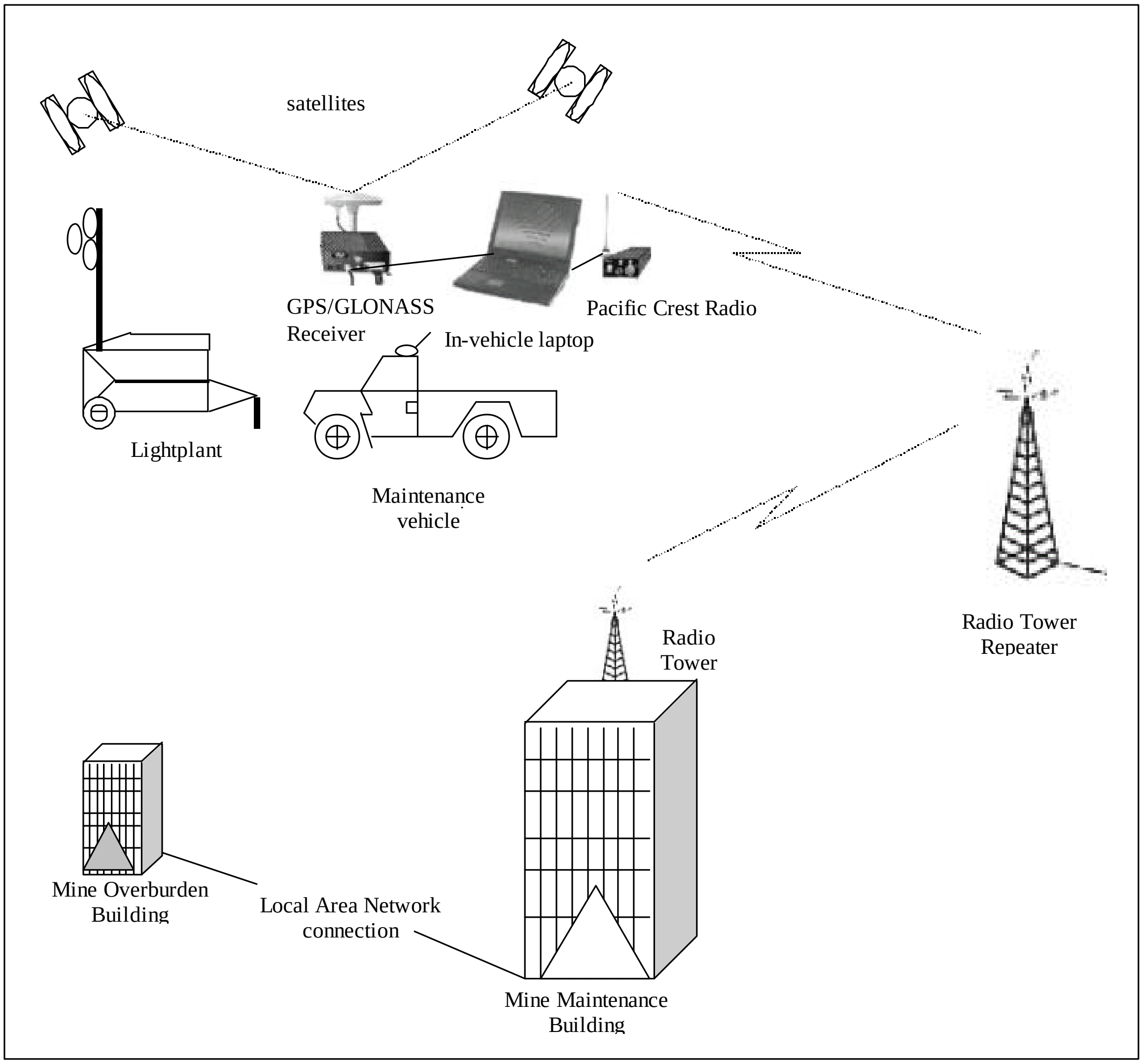


Figure 5.2: Communication Links between In-vehicle Data Acquisition and Office

receiver to the laptop, after recording this information the user can input the non-spatial information into the software. There are several data quality checks to make sure the entered information is of high quality. Pressing the *send* key the user can now transfer his information to the master computer located in the main office via wireless communications. This computer also acts as a server where several other users such as planners, dispatchers, mechanics, etc can retrieve the information.

5.1.2 In-Vehicle Data Acquisition Software

When the data acquisition software is first executed it goes into the configuration screen, Figure 5.3. It allows the user to choose the GPS receiver and the communication mode.

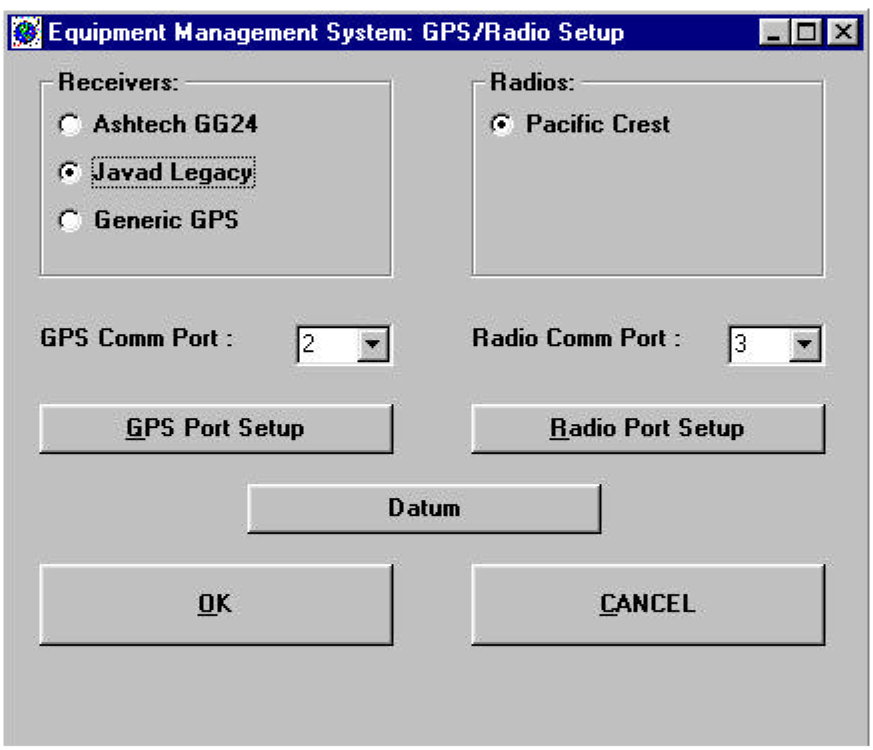


Figure 5.3: Data Acquisition Configuration Screen

The user can choose any of the listed GPS receivers: Ashtech GG24, Javad Legacy or generic receiver. If an Ashtech or Javad receiver is chosen then the software sends the specific receiver configuration command to the receiver to output the standard format NMEA GGA and GSA messages. If the generic receiver option is chosen then the receiver has to be set to output GGA and GSA commands. In this case, the package's receiver software would be used to set those commands before utilizing a generic receiver.

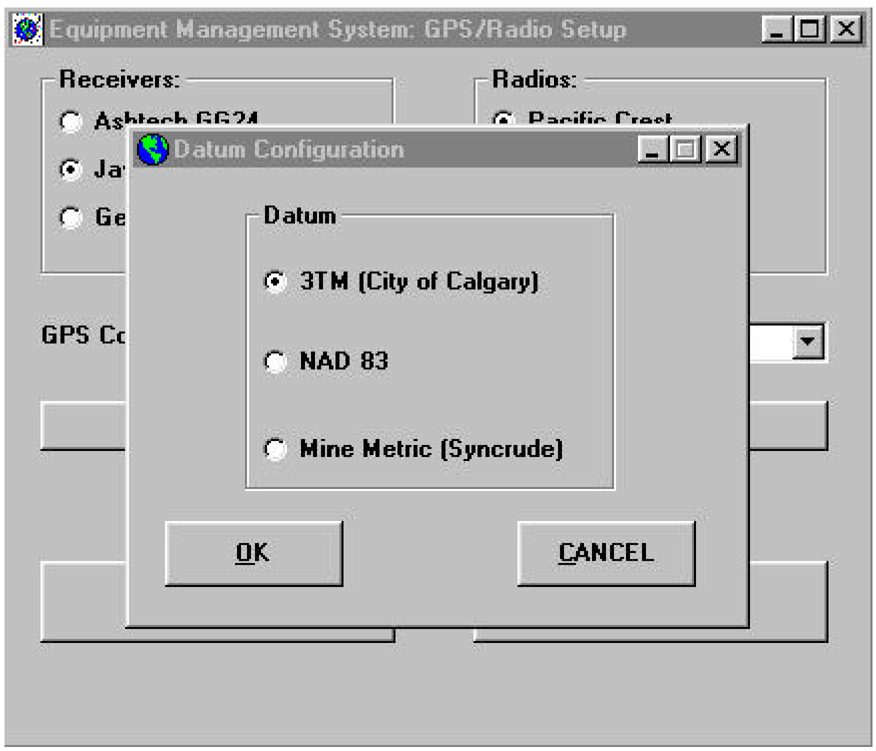


Figure 5.4: MEMS Datum Selection

From the GGA message the software extracts the following information: time, latitude, longitude, differential mode, number of SVs used in position computation and age of the differential correction. The latitude and longitude is then converted into the required coordinate system, Figure 5.4 shows the various datum options to choose from. At Syncrude the required coordinate system is called mine metric and is local only to Syncrude. For the City of Calgary Three Degree Transverse Mercator (3º TM) coordinate system was used for the test. The Mine Metric system is discussed in Chapter 6 and the transformation is shown in Appendix A.

The GSA message provides the system with the dilution of precision, called PDOP. This is used in the software as a flag for determining the average absolute positions. If the PDOP exceeds 4.0 during the averaging process the software automatically restarts the averaging process until the PDOP is consistent throughout the process.

The software also allows the user to set comports and baud rates for communication with the GPS receiver (Figure 5.5) and the radio modem (Figure 5.6). At present the Pacific Crest radios were used for transmitting data from the in-vehicle data acquisition unit to the office software. Further enhancements would allow for communication via cellular telephones or communication satellites eliminating the need for radio modems, which provide limited area coverage. These enhancements can easily be added to the modular design software as an Active-X or a function.

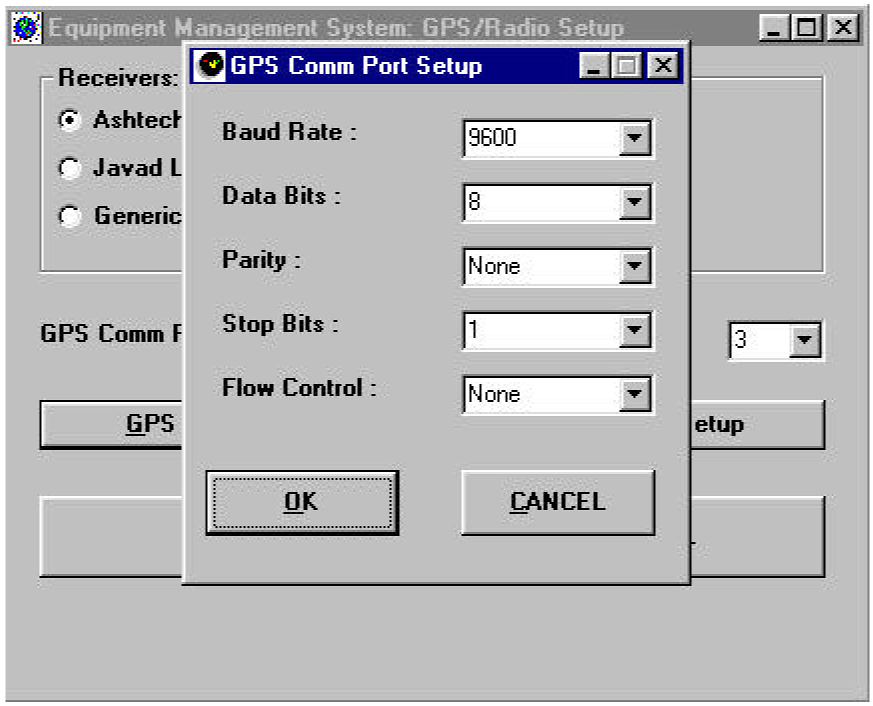


Figure 5.5: GPS Comm Port Configuration

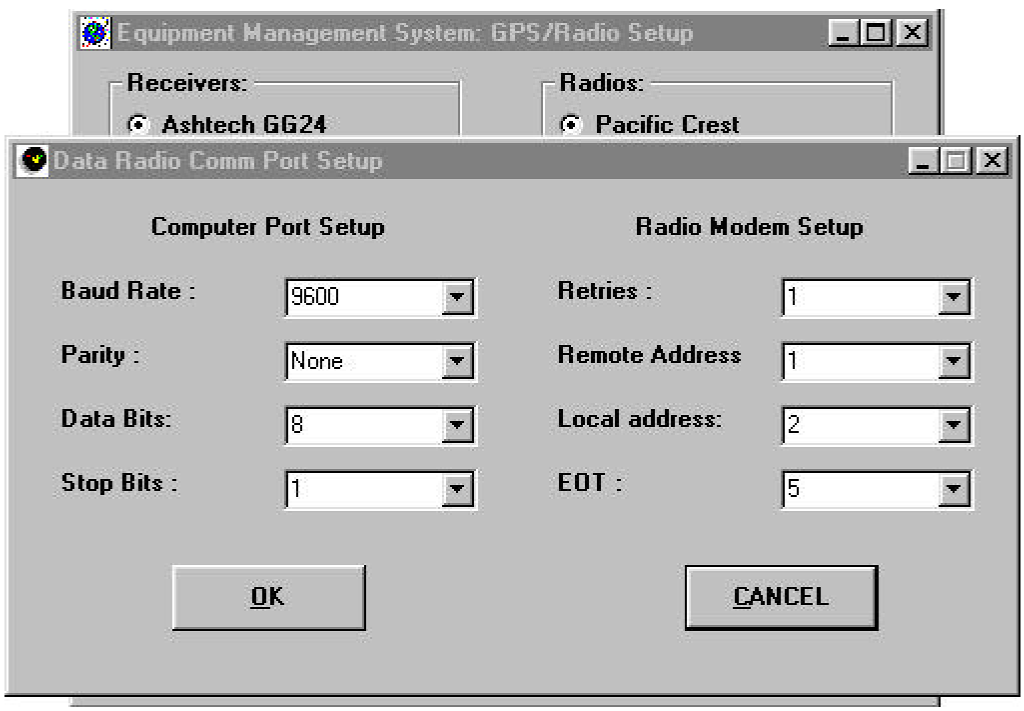


Figure 5.6: Radio Modem Comm Port Configuration

After performing initial configurations for communicating with GPS and the radio modem, the software then goes into tracking mode as shown in Figure 5.7. In this mode, time, PDOP, coordinates, number of satellites and position type are displayed as user information. At Syncrude, the maintenance personnel can optimize this information for navigating to the lightplants. There are four different options for the user: **Configuration, Position, Send and Exit**.

Figure 5.7: Main Tracking Screen

Executing **Configuration** takes the user back to the receiver and radio setup menu as shown in Figure 5.3. On execution of **Position**, it takes the user into another screen shown in Figure 5.8 where the actual recorded position of the lightplant is taken. The user now has the capability of entering the attribute information for that particular lightplant. Here, a series of combination boxes gives the user easy access to the required information. This limits erroneous input entered by users. The positioning results comes

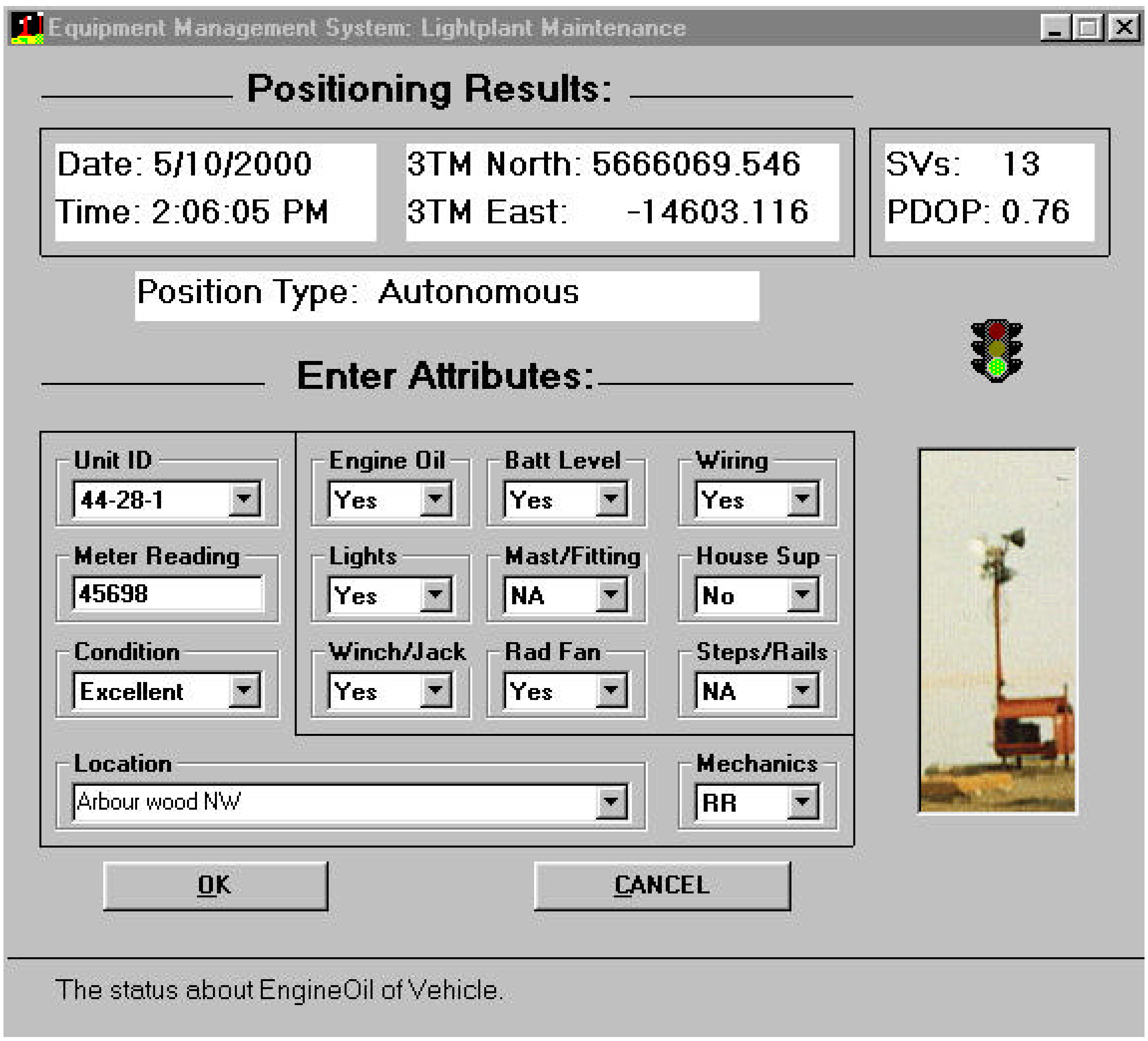


Figure 5.8: Data Acquisition Screen

directly from the GPS receiver. The position type, number of SVs and PDOD defines whether the location is within the required specification, he/she can choose whether to record the position or disregard it. Before **OK** can be executed the user has to fill-in all of the attribute information or else an error message informs the user of the missing fields. Once completed the program goes back to the main tracking screen. The information is now coded into a series of alpha numeric and stored into an ASCII file format. This allows the information to be compressed for fast transmission. More lightplants can be appended to the ASCII file if desired by the user. All the information on the lightplants are also backed-up onto the laptop computer.

Figure 5.9: Screen Showing Send Option

Upon return to the main tracking screen the user can execute **Send** for data transmission a message box shows with the default directory and ASCII file location (Figure 5.9), the user has the option for changing default values. Accepting **OK** transmits the datasend.txt file. Once the file is received at the office computer, a message is sent back to the mobile unit for confirmation as shown in Figure 5.10. This ensures that the message has been received and there is no need for re-sending.

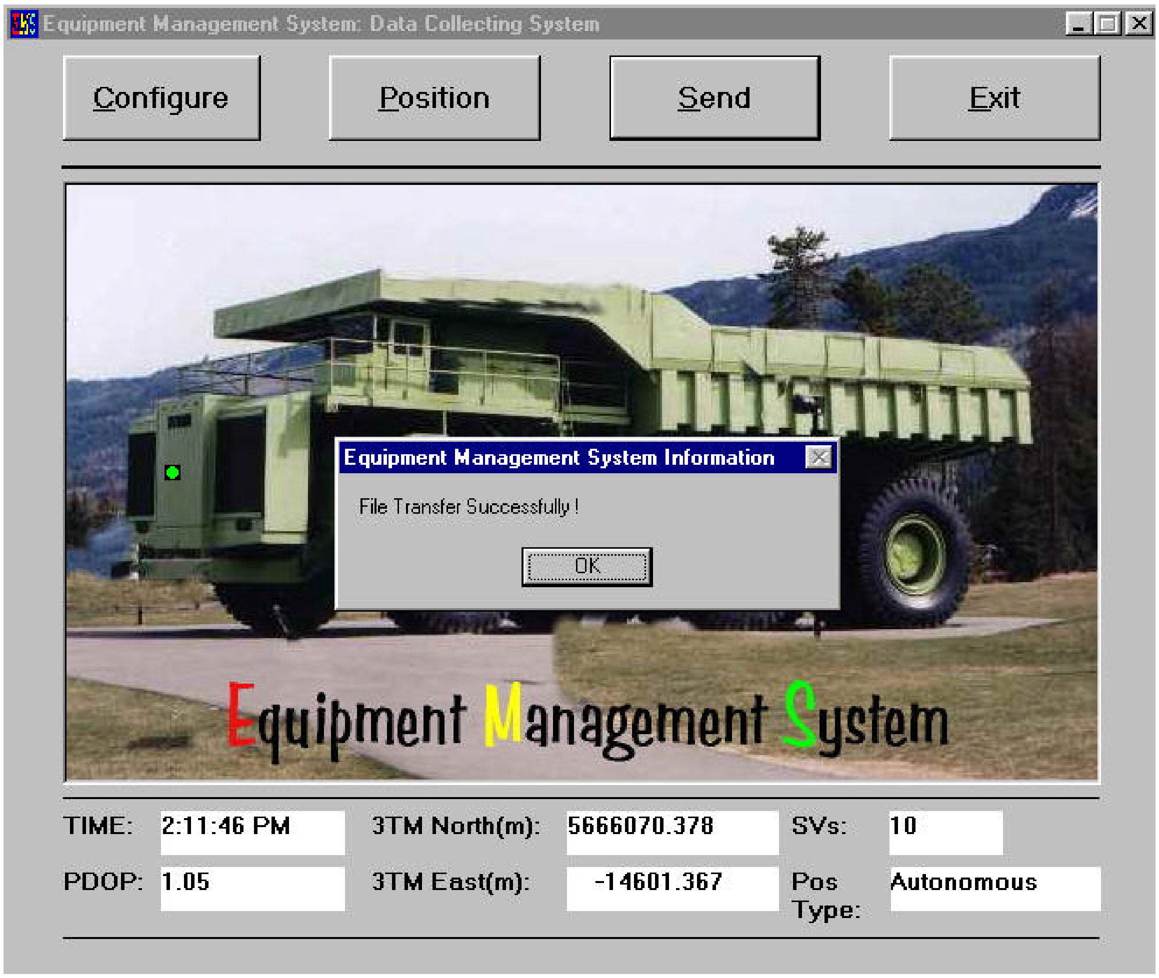


Figure 5.10: Data Transmission was Successful

Exit allows the user to shut down the program and carry on with their regular duties.

5.2 Communication Component

Communication is an integral component in the development of a Mobile Equipment Management System. The communication software enables communication between two systems; that is, the in-vehicle data acquisition system to the main office data management and maintenance system. These two components will be further discussed in the next section. The communication system at its minimum is the transmission of the lightplant location (x, y) along with attribute data on the maintenance of the equipment as shown in Figure 5.8 data acquisition screen. The information here is updated to the main office in either real-time or near real-time as required.

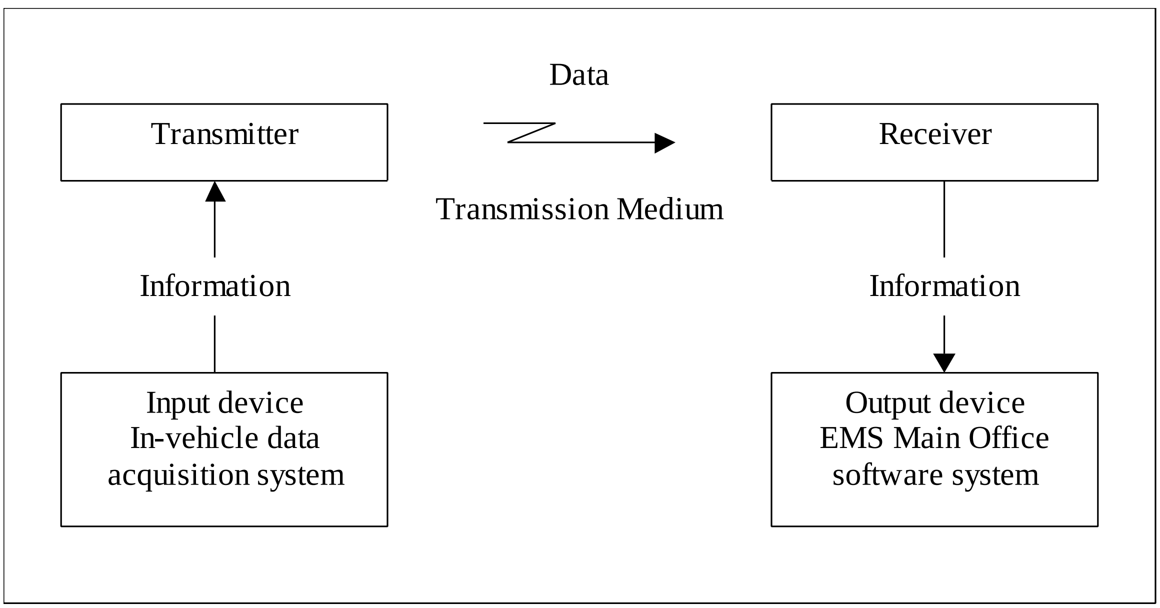


Figure 5.11: MEMS Data Communication Process

The process of data communication requires five elements as shown in Figure 5.11, input device (in-vehicle data acquisition system), transmitter (UHF/VHF radio modem), transmission medium (radio waves), receiver (UHF/VHF radio modem) and output device (MEMS Main office software). The alphanumeric information that makes up the message consists of the lightplant location and maintenance information. This message is transmitted in the form of data, which is a sequence of electrical units or signals. The transmission medium is the path for electrical or electromagnetic transmission between stations. It may consist of a single wire, pairs of wire, fiber-optic cables or the atmosphere.

The Mobile Equipment Management System prototype uses a pair of RFM96 radio modems, which takes digital information from the in-vehicle data acquisition system, transforming it into analog waveform. The signal is then transmitted via radio waves to the Main Office computer software as shown in Figure 5.12. The receiving modem converts the signal back into digital information, which goes to the serial port of the receiving computer. The permissible rate of data transmission is 9600 bits per second as specified by Federal Communications Commission (FCC) standards.

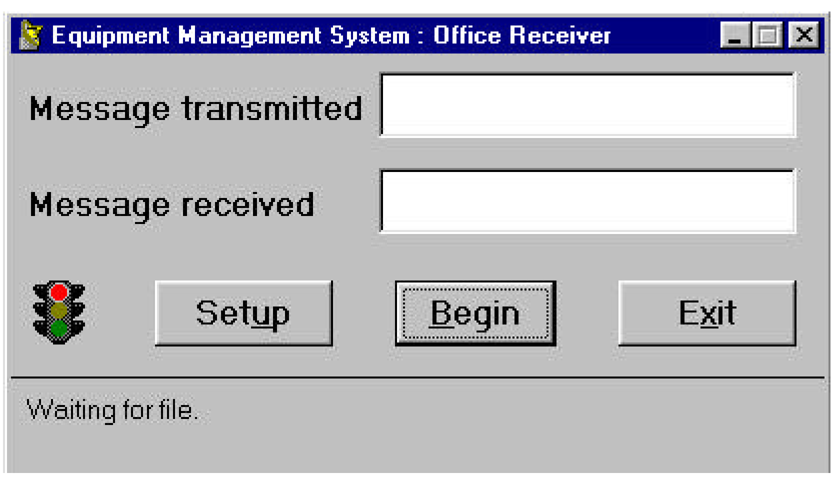


Figure 5.12: Main Office Receiving Software

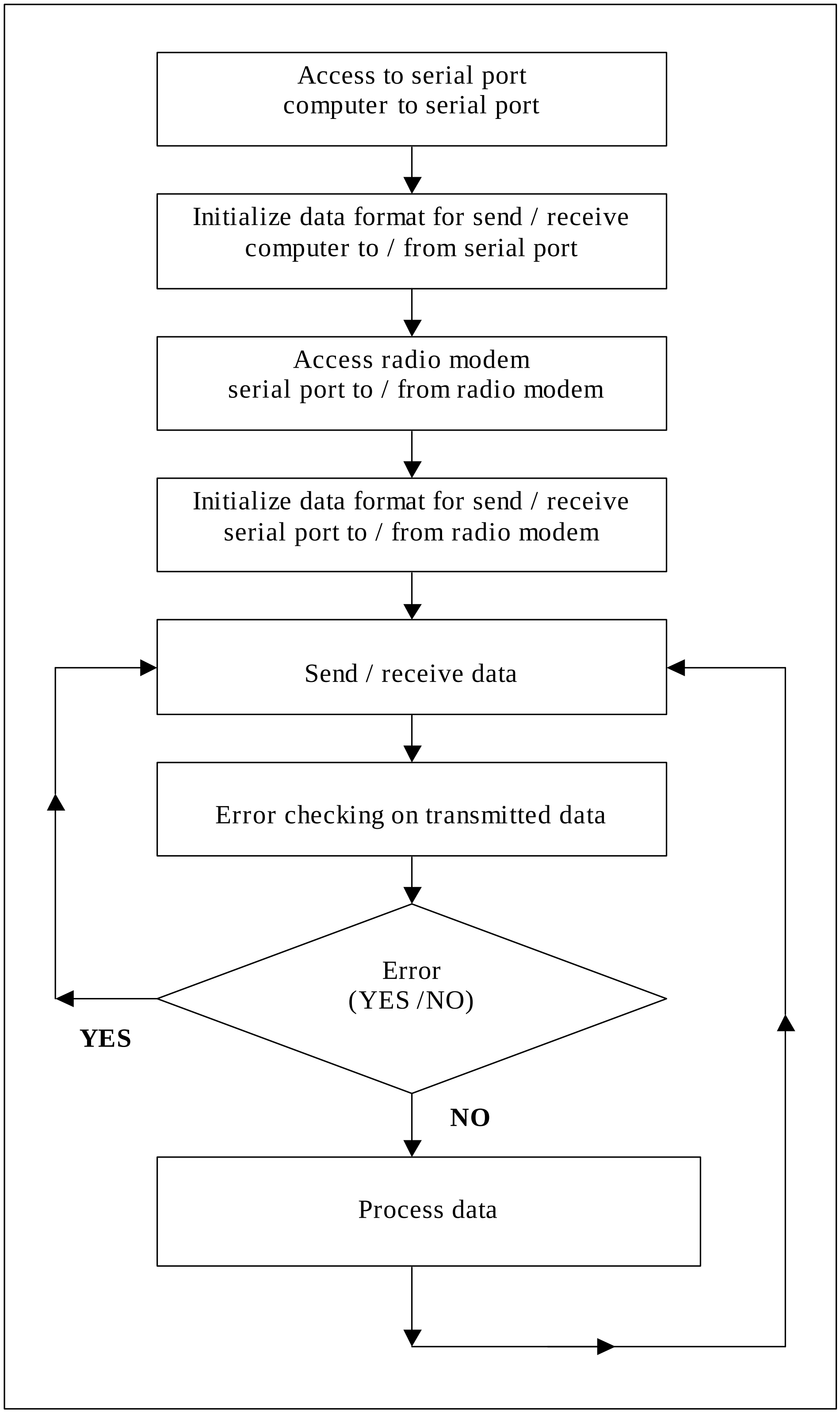


Figure 5.13: MEMS Communication Model

Data communication is technically complicated, since it requires coordination between several processes and independent devices for the transmission of data. Figure 5.13 shows a flowchart of the model for the office receiving and transmitting software. This communication process model was defined by the International Standards Organization (ISO).

The RFM96 radio modem uses a technology call carrier sense multiple access (CSMA) to avoid data collision. Data collision occurs when two transmitters are active at the same time, the messages being transmitted may be corrupted and causes data errors. To prevent data collision the radio modem monitors the frequency and hold off transmission if data is being transmitted by another radio modem with the same frequency. When the frequency is clear, then the radio modem commences the data transmission. The MEMS receiving software receives a signal from the radio modem informing it that data transmission is complete. In doing so, the receiving software transmits back to the in-vehicle data acquisition software to inform the user that the message has been received as shown in Figure 5.10.

The main office receiving software can be configured as shown in Figure 5.14. This allows the user to setup the computer’ s COM port and other settings for the radio modem.

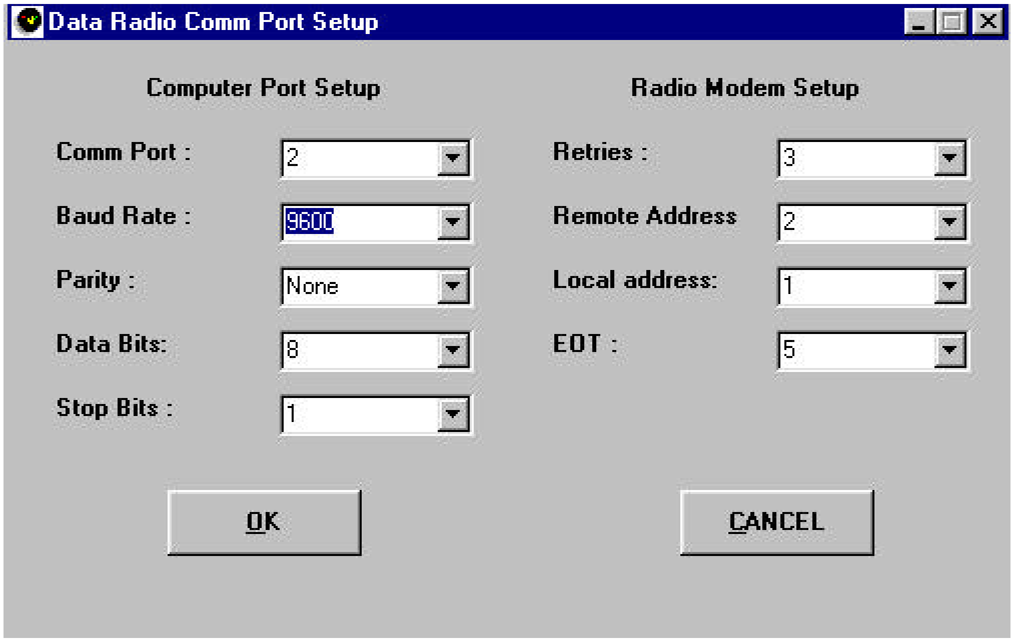


Figure 5.14: Main Office Receiving Software Configuration

Other radio settings that are considered to be important to the user are number of retries, remote address, local address and end of transmission (EOT). The number of retries allows the transmitting radio modem to attempt to communicate with the receiving radio modem if it does not respond. It also retries if the receiving modem sends a negative acknowledgement due to corrupted data packets. The remote and local addresses identifies the receiving and transmitting modems along with which data packets get passed through to the main office computer. EOT defines the context of the operating mode and sends a digital value of either a character or time-out value to signal the end of transmission.

5.3 Main Office Component

The office system consist of a network server and a Pacific Crest UHF/VHF radio used for the data link to retrieve the information from the field. In the development of the Mobile Equipment Management System Office software, defining data structures and choosing the right data access technology has optimized the system architecture for efficient database retrieval. This made the application faster, easily maintained and left room for future enhancements. Figure 5.15 shows the main office component being used out at Syncrude’ s test site Fort McMurray, Alberta.

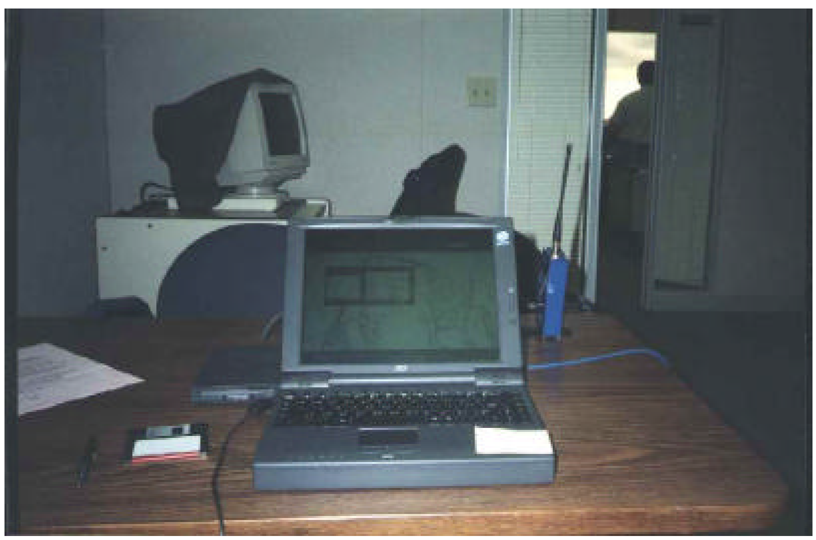


Figure 5.15: Main Office System on Syncrude’ s Test Site

The Office System does not retrieve its information only from a single database. Instead, it uses an extensive set of Component Object Model (COM) to interface with several distributed databases to draw upon diverse information. This employs an open modular system architecture. Since many existing systems are largely incompatible with each other, an open environment allows real-time transactions with a database that can be easily interfaced and integrated with other databases. Figure 5.16 shows the concept for a typical application in an open-pit mining equipment management.

Having an open modular system architecture prevents costly re-handling of massive amounts of data. Data management technology is utilized in developing the Mobile Equipment Management System, making it capable of transparent access to heterogeneous geospatial data and geo-referencing resources in a network environment. This is essential in linking one system with other systems in the future. Using such an approach can lead in the development of a seamless total solution from data acquisition, data communication to final data management and decision making.

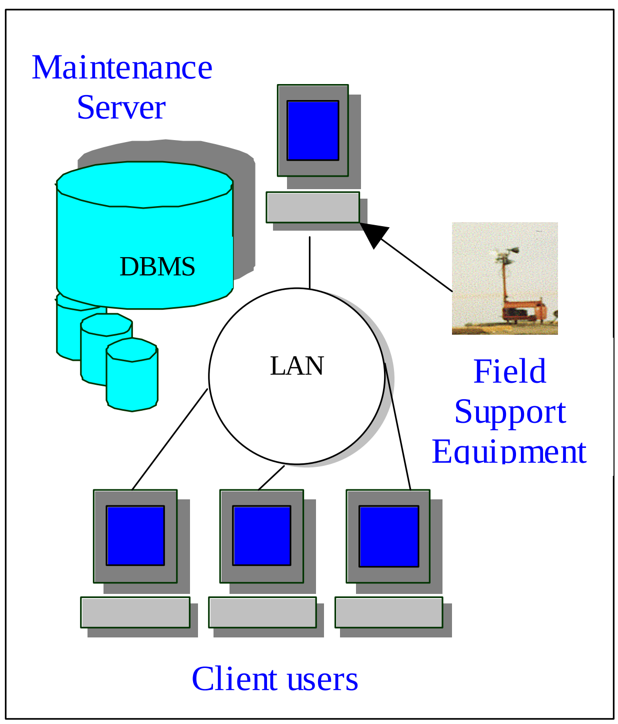


Figure 5.16: MEMS Office System Concept

This entire concept is attained through system integration. The main advantage of an open modular system is that it leaves room for future development within the system rather than replacement of the entire system.

The Office component of the system shown in Figure 5.16 gives internal users in the maintenance area the ability to store, edit, maintain, retrieve, manipulate, analyze, present, represent and make specific decisions using the information collected form different areas. Client users can graphically display their information showing the current or historical location status of their equipment. The graphical user interface provides the clients with information on the particular piece of equipment by pointing and clicking on the object. In Figure 5.16, the field information is being sent from the in-vehicle data acquisition system (Figure 5.1) that located the lightplant in a remote area. In the field, the maintenance person would record its location from the satellite navigation system; the non-spatial information is then recorded into the laptop and sent to the maintenance server via wireless communications.

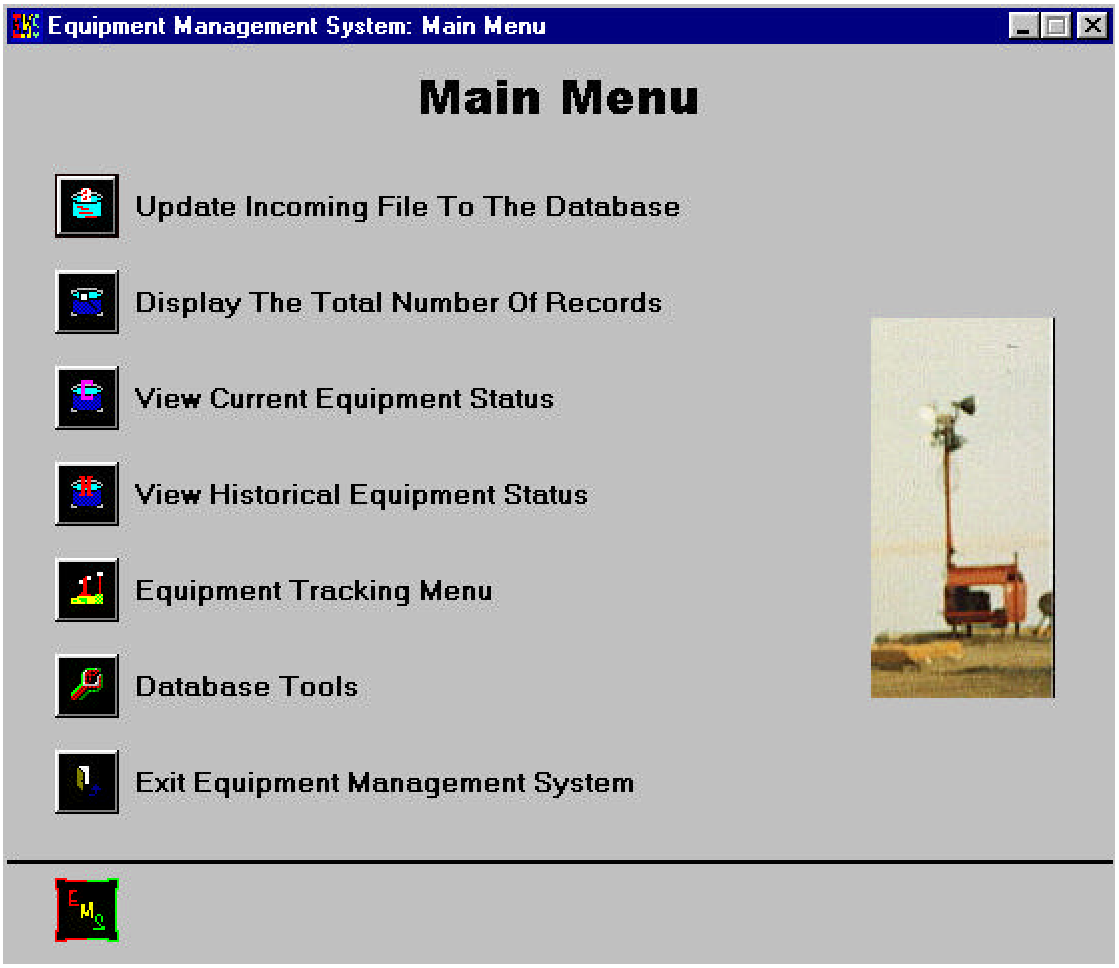


Figure 5.17: Data Management and Maintenance Software

Several clients can now access the information from the server. Figure 5.17 shows the main menu option screen for the Mobile Equipment Management System, this allows maintenance and other users different access privileges. The owner of the information such as maintenance, has administrative permission to all options where as other clients has viewing and non-editing privileges.

The main office component comprises of two areas: the management and maintenance level and the scheduling and decision-making level.

5.3.1 Management and Maintenance Software

The management and maintenance software is one component of the distributed system in which individual components of the Mobile Equipment Management System have specialized functionality as shown in Figure 5.17. Such functionality allows the users to directly combine and manipulate spatial data and non-spatial data in a relational DBMS. All of these operations can be facilitated by the interface shown in Figure 5.17. Direct manipulations allow natural geometrical transformation and overlay operations from the interface. The non-spatial objects used in the database are modeled using types such as integers, character strings, numbers and Boolean. However, the spatial data is more complex and a high-level metaphor is more appropriate since it is stored as point information on the display screen.

The interface allows the database administrator to manually update the incoming information from the field if the wireless interface encounter problems in transmitting information. That is, the field personnel bring the data from the field on a floppy diskette to be loaded onto the office computer. The database administrator can also verify the numbers of records in the database for maintenance and administrative purposes. It' s a good indication to database administrators that the information has been uploaded into the database.

The maintenance personnel can view the current status of all equipment in the field by clicking on the View Current Equipment Status. The information within this table contains no duplicate lightplant identification. It only shows the current locations of all lightplants on the mine site. When new information for lightplants are obtained, it automatically replaces the old lightplants information. Therefore, this table never grows or shrinks; it always provides current lightplant information. Once clicked the software retrieves the information from the database via open database connectivity (ODBC) onto a new form. This form interface is in the format of a spreadsheet as shown in Figure 5.18. It provides the user with direct access to the database for manipulation, querying and editing features. The editing feature has provisions for **commit** and **rollback** transactions.

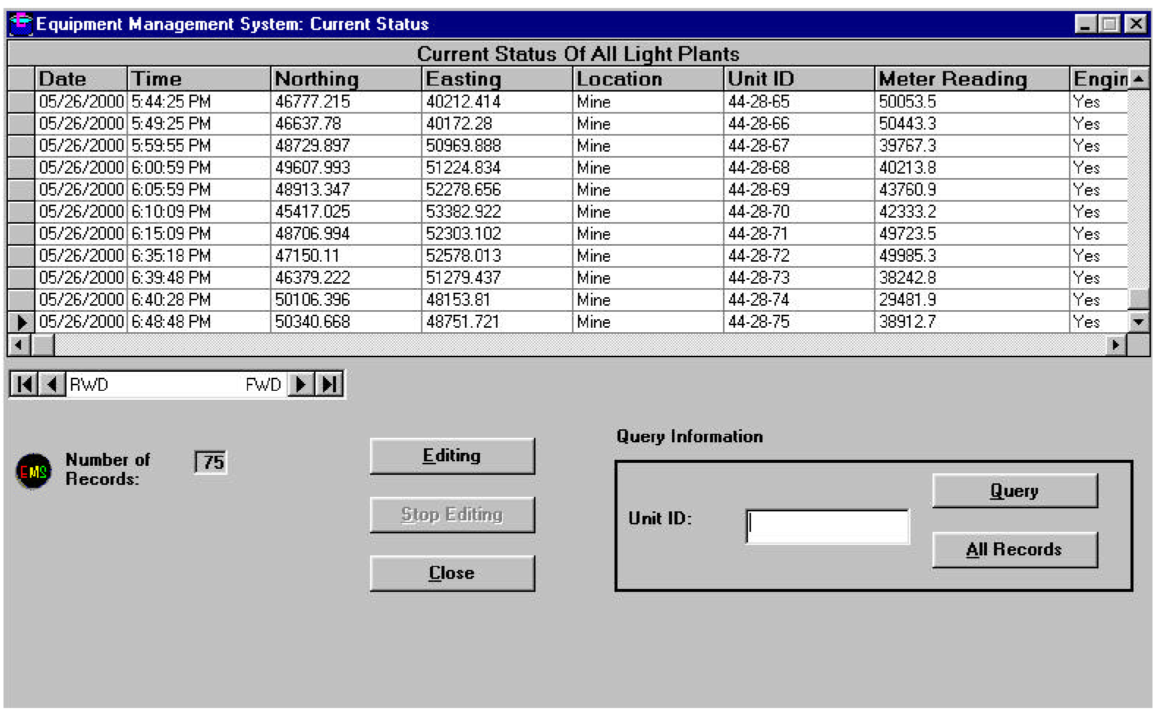


Figure 5.18: View Current Equipment Status Screen

Commit transaction saves all recordset changes and rolls back transactions, or undoes all data changes in the current transaction. When the Editing button is clicked, it gives users editing access to the recordset and the Stop Editing button becomes activated. This allows the user to either accept all changes (commit) or undo all data changes (rollback) to the current recordset during the editing process. Users also have the ability to query lightplants by their unit identification, which makes it easier to track and edit lightplants.

The maintenance personnel also have the ability to track the movement and utilization of lightplants by clicking on the View Historical Equipment Status button. The appearance and functions of this form is similar to that of View Current Equipment Status form, Figure 5.19. The major difference being, all the lightplant information (present and past) is stored within this table.

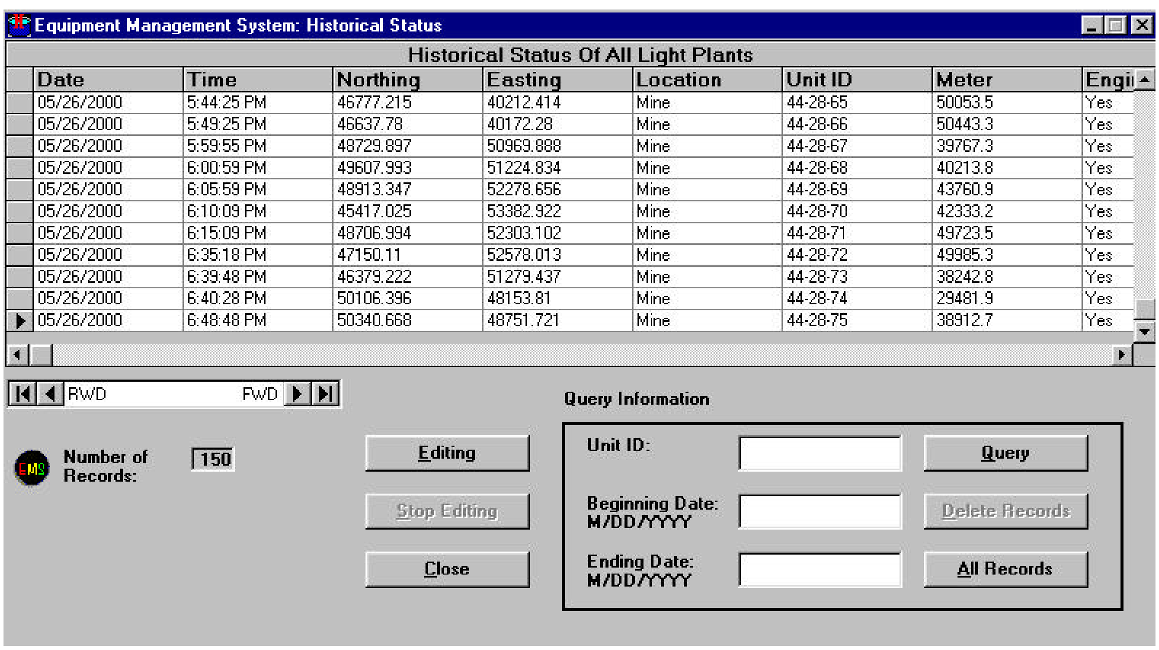


Figure 5.19: View Historical Equipment Status

The Editing and Stop Editing features provide commit and rollback functions as in View Current Equipment Status. The query information consists of Unit ID, Beginning Date, and Ending Date. This gives users the flexibility to track movement of a specific lightplant during a period of time as shown in Figure 5.20. In so doing, utilization studies on efficiencies of lightplants can be carried out. Over a period of time the historical status table would become over populated with information for lightplants, especially if a particular lightplant is being actively moved on a daily basis. The delete feature allows users to clean and maintain the database from this interface.

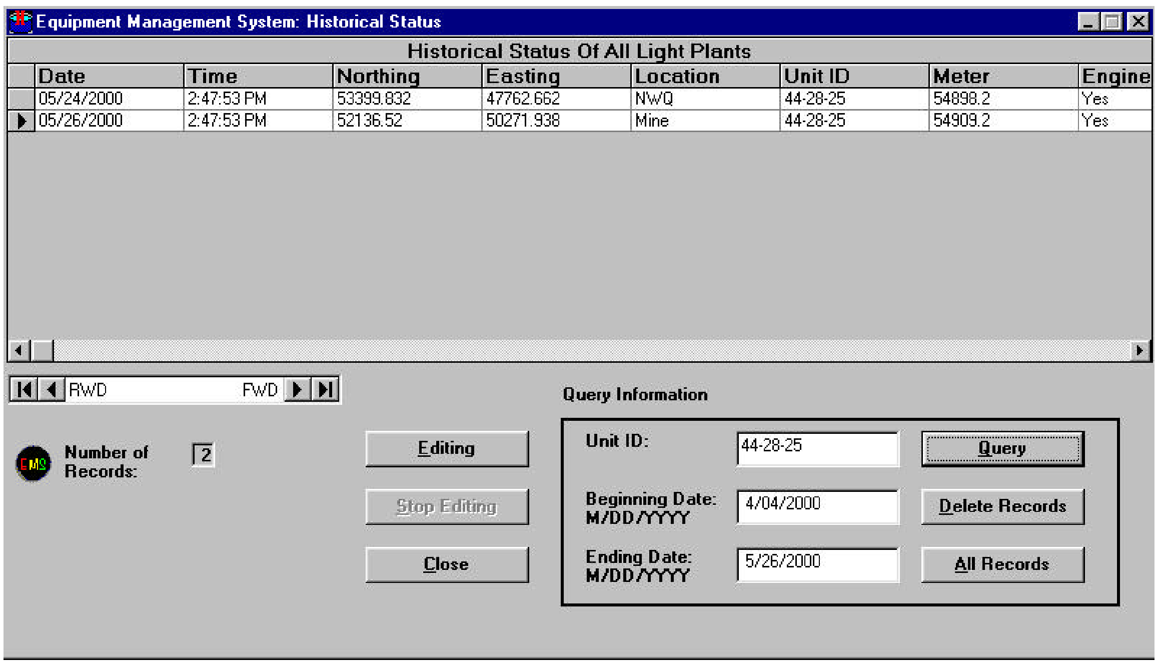


Figure 5.20: Historical Query for Lightplant 44-28-25 Between April 4 and May 26

From the above two lightplant information forms, View Current Equipment Status and View Historical Equipment Status users have quick visual access to the information for determining the equipment usage and also determine the efficiency for scheduling that piece of equipment since one can also map and track its movement graphically. The rate at which data is displayed to the user, especially large amounts of data, is an important factor in developing these interfaces. These interfaces are readily accepted by software designers and makes for a productive end user since the graphical interface of the Windows operating systems (Windows 98 and Windows NT 4.0) provides for a common set of elements that help make an application familiar and user friendly.

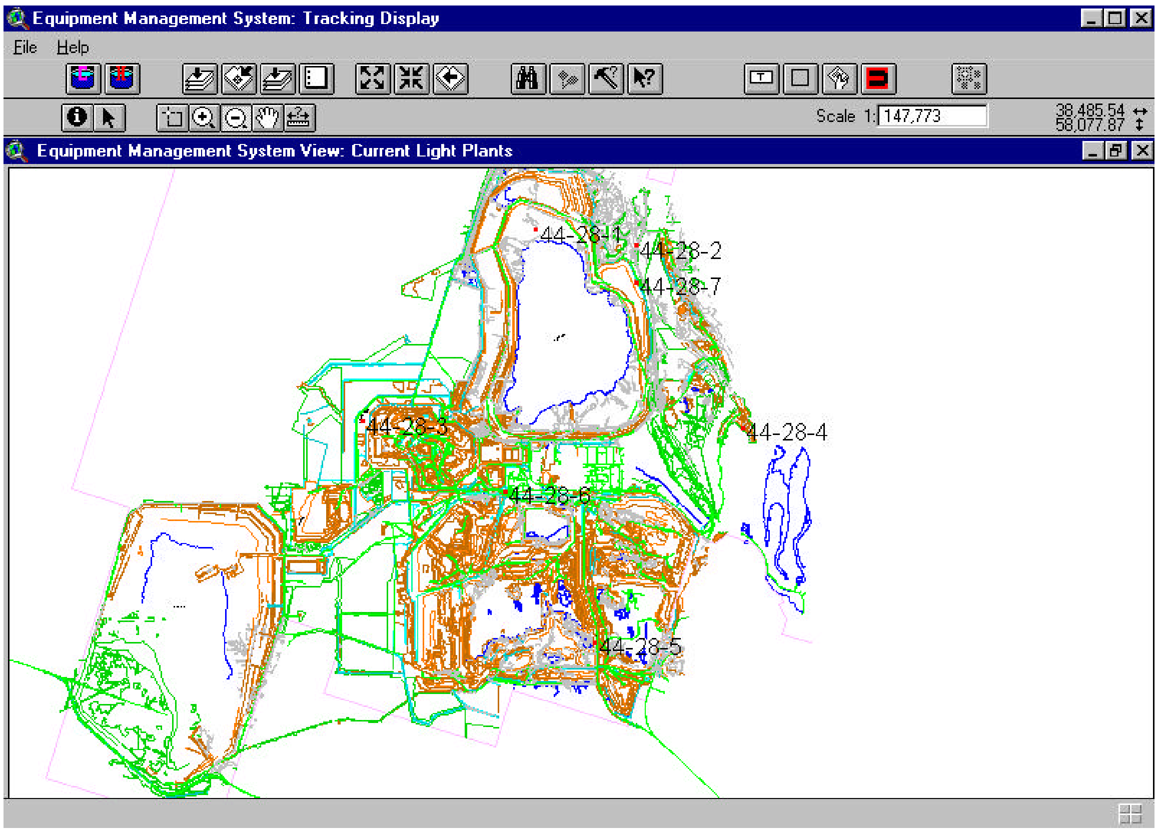
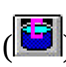


Figure 5.21: MEMS Tracking Display

The Mobile Equipment Management System Management and Maintenance software integrates database functionality for heterogeneous types of data, especially spatial types. It provides a graphical interface to ArcView, which also allows users to effectively select and retrieve relevant spatial data. Users can click on Equipment Tracking Menu button to view the locations of every lightplant both in its current or historical state. Integrating and customizing ArcView through Avenue, ArcView' s programming language, the user can now view the lightplant information on the displayed map as shown in Figure 5.21. The information shown in Figure 5.21 shows a map of Syncrude' s mine site displaying the current location of several lightplants.

ODBC data access technology was used to build the tracking interface to the relational databases for retrieving the information. ODBC was chosen for the importance of code reuse and the ability to implement ArcView interface. This data access technology reduces development time by simplifying code. This still provides high performance while allowing all of the required functionality. It reduces resource requirements in by passing the Microsoft Jet engine and also provides access to server-specific functionality such as specifying parameter values for stored procedures. Since this interface must run asynchronous queries and store procedures against a relational database, ODBC provided these functions. It can also provide batch updating of locally cached recordset changes which makes it very flexible.

When using the tracking interface users have the options of viewing current equipment status or historical equipment status by clicking on buttons **C** () or **H** () on the tool bar. Users can get the attribute information on a single lightplant by using the Identify tool and clicking the lightplant feature as shown in Figure 5.22. The Identify tool is best used for browsing attribute data on the lightplants since they are the active theme. In the graphical interface selection by direct manipulation is accomplish by using a pointing tool such as an arrow on the screen whose position is controlled by the mouse. Pointing is limited to only lightplants in either the current view or historical view depending on the user. Therefore, only the lightplant layering is active so as to avoid other ambiguous features information.

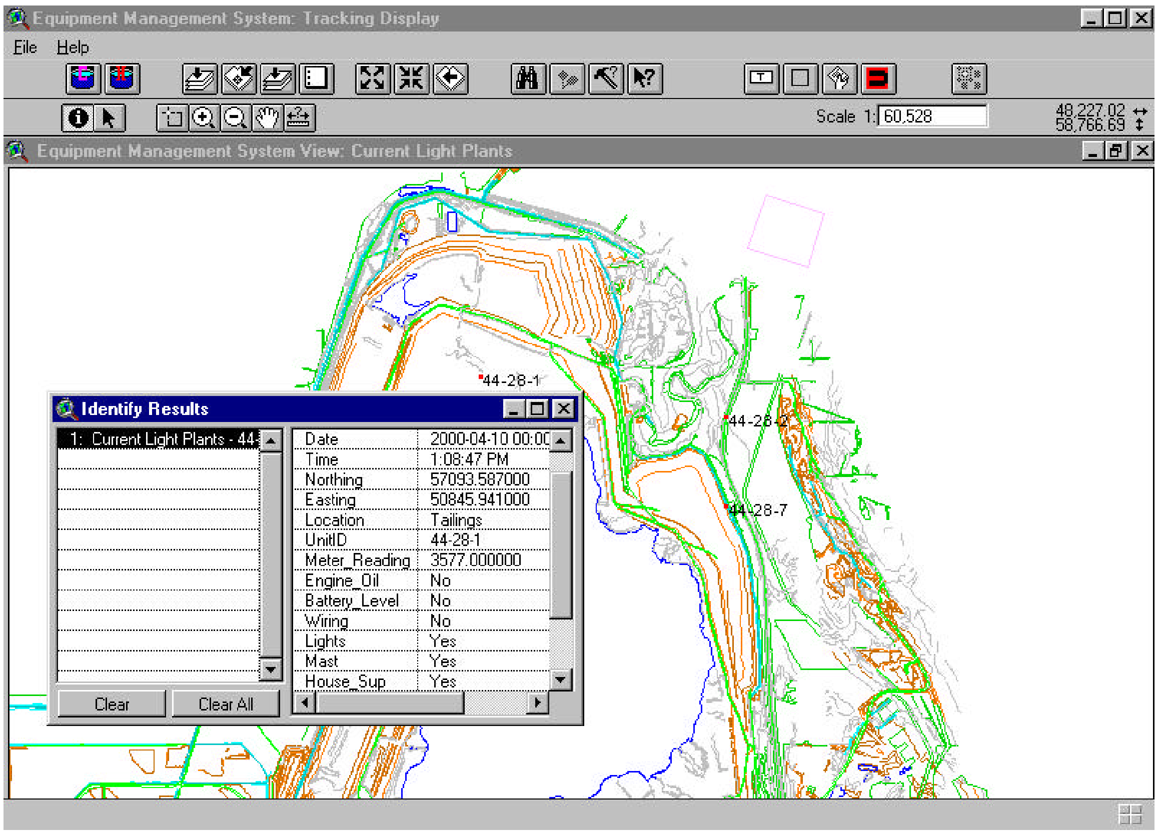


Figure 5.22: Tracking Display Showing Information on Lightplant 44-28-1

Since it is impossible for all the lightplants to be clearly visible on a single screen, the user is provided with extra tools such as, pan, moving the viewing window to a different part of the map, and zoom for providing greater or lesser detail on the map. As shown in Figure 5.22 the area around lightplant 44-28-1 has been zoomed for better viewing.

By integrating a GIS interface into the Mobile Equipment Management System, the Tracking Display allows for the delivery of results from several queries. Users can create their own queries for tracking individual lightplants when in the historical view or develop a query based on the equipment meter reading which shows the number of hours the unit has been working as shown in Figure 5.23. By performing the query based on the meter reading greater or equal **(>=)** to 4600, several units such as 44-28-3, 44-28-4, 44-28-6 and 44-28-4 were highlighted in yellow from its normal red color.

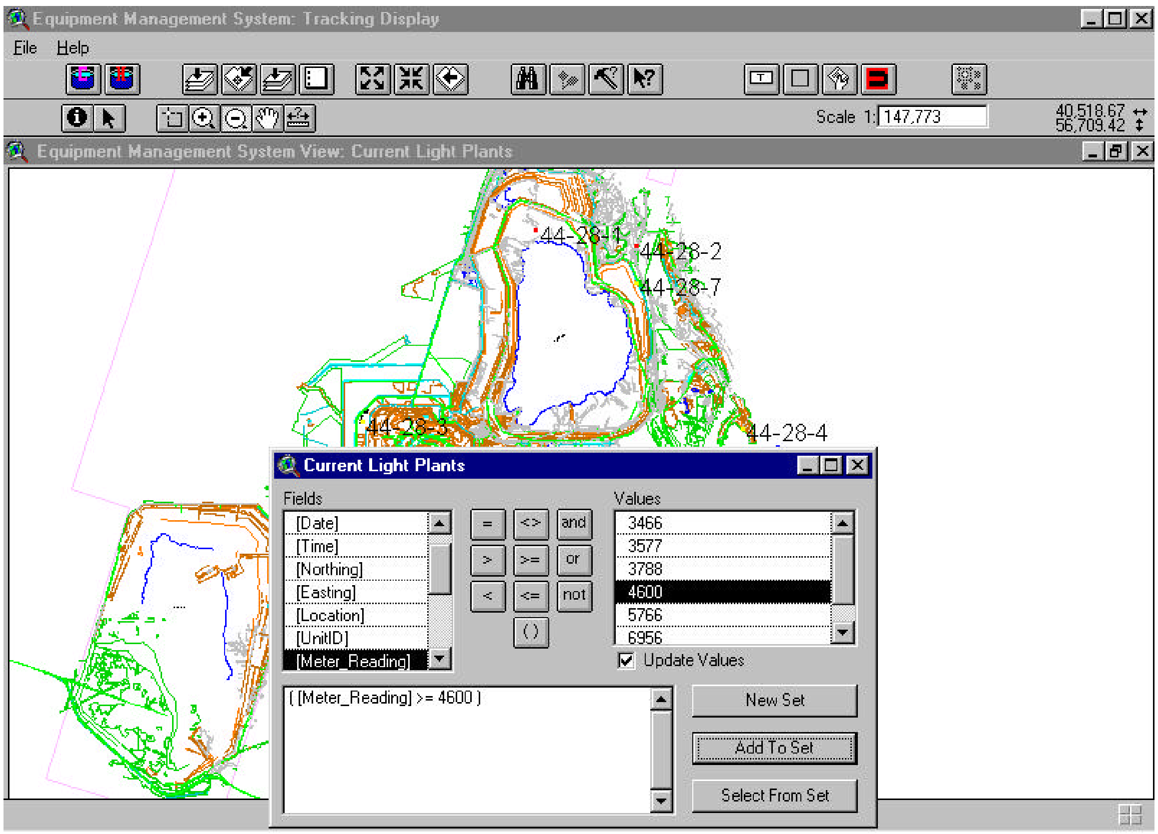


Figure 5.23: Tracking Analysis Query Builder on Meter Readings

As shown in Figure 5.23, queries can be built on any of the database fields shown. This provides an effective medium in which schedulers and maintenance personnel can work by direct manipulation to produce further analysis and results. Therefore, having such an interface data presentation here has more functionality than a standard database. Users can utilize the graphics functionality to present data in several ways. For instance, maintenance personnel can create a query based on date to show lightplant identification numbers, locations and meter readings, this information can be complied into a report form available from the GIS interface for data presentation as shown in Figure 5.24. Direct report generation is useful for relaying fast information to field personnel without having them returning back to the office. In a mining environment such as Syncrude' s where the area coverage is vast, the need for efficient information transfer is critical to the operations.

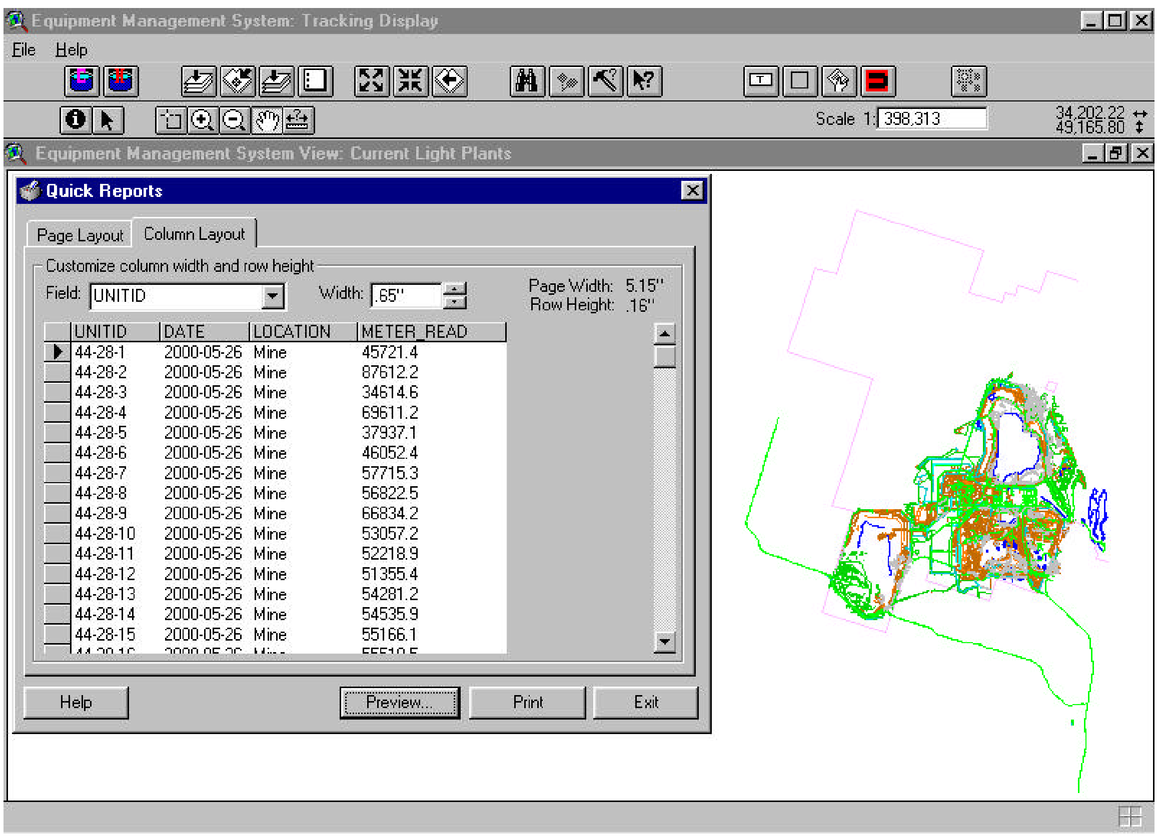


Figure 5.24: MEMS Tracking Display Report

The Mobile Equipment Management System office software also provides back up copies of all incoming files from the field. Database tools shown in Figure 5.25, are also provided for backing up or repairing the database. To maintain a high state of performance the MEMS software defers the removal of discarded pages from the database until database compacting is run. This design keeps the interactive performance of the database high at the expense of recoverable disk space on the server.

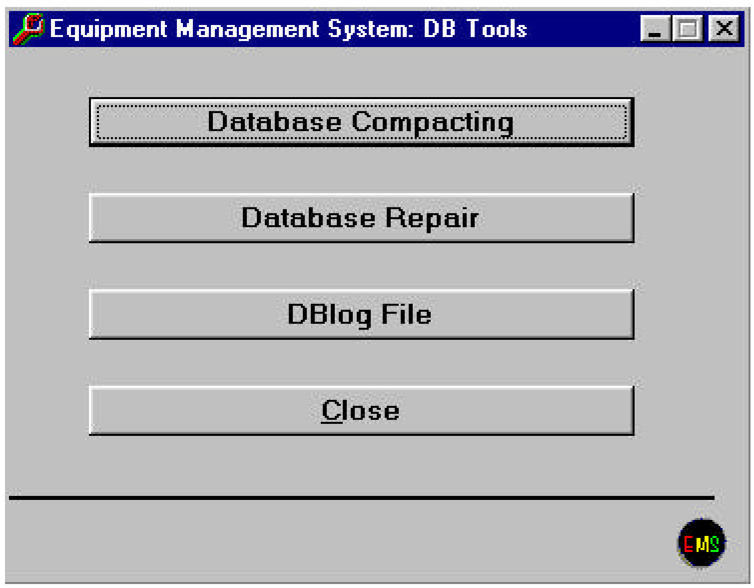


Figure 5.25: MEMS Database Tools

Over time the maintenance database grows substantially therefore, compacting the database is necessary for copying all data from one database into another, removing discarded pages. This process organizes the data in the resulting database contiguously so disk space can be recovered. If the maintenance database becomes damaged, the database repair tool will validate all system tables and all indexes; it will also check all pages in the database for correct linkage. When the database repair tool is used, it may increase the database in size because the process of creating indexes may leave deleted pages within the database. Therefore, it is necessary to run database compacting after database repair to eliminate unnecessary pages. The database administrator can be updated on the status of the database by viewing the database log file shown in Figure 5.26. The log file shows all the important information on status of the database, when it was compacted or repaired and the location of the backed up database. Here the administrator can determine when to back up the database to avoid unrecoverable data loss.

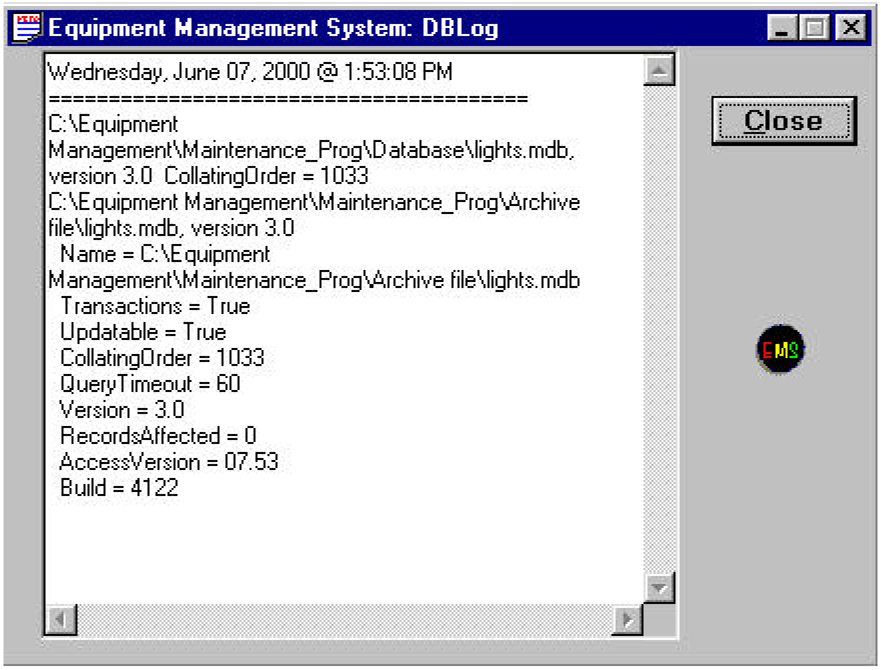


Figure 5.26: Database Log File

The Management and Maintenance software is just one component of a distributed system where spatial data within a GIS and non-spatial data in a relational DBMS is combined for decision-making of the end user. This operation is transparent to users of the system. However, most of the information in a GIS is graphics-based and its analysis and interpretation is often effected by visualization. Visualization is the process of representing information synoptically for the purpose of recognizing, communicating and interpreting pattern and structure. Its domain encompasses the computational, cognitive and mechanical acts of generating, organizing, manipulating and comprehending such representation [Buttenfield, 1991]. Therefore, the next section describes the development of another component of the distributed system for scheduling and decision making.

5.3.2 Decision Making Software

The driving philosophy behind a Total Mobile Equipment Management System for the management of lightplants is shown in a flow diagram format given by Figure 5.27. It is effective for direct information exchange between involved parties.

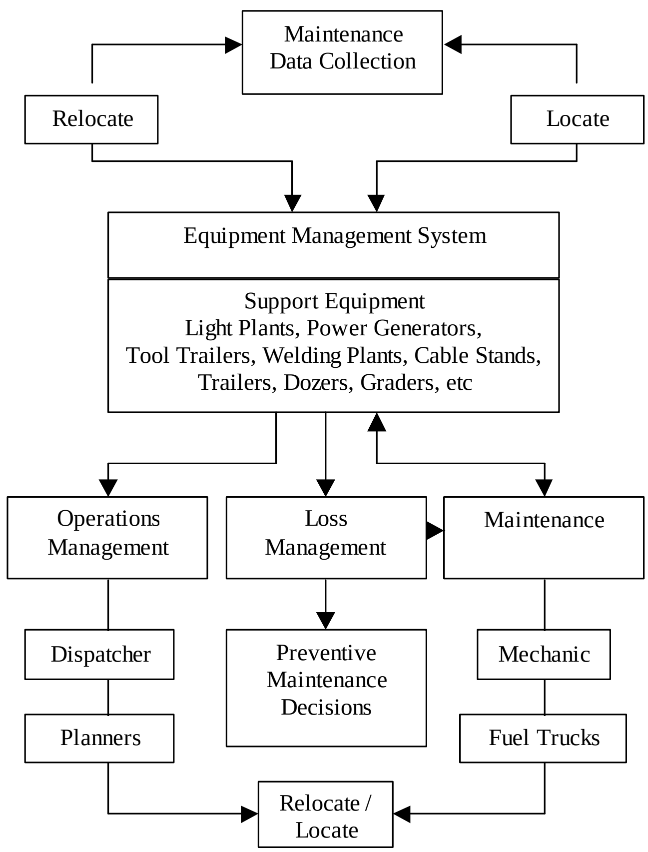


Figure 5.27: Model for the Management of Lightplants

The object for decision making level is to extract new information from data currently being stored or newly collected data on the lightplants. This section of the software system will provide a sequence of events that, when followed, allows the lightplants to be at the right place at the right time in the right working condition. Figure 5.28 shows the main software for making such important decisions. This piece of software provides its users with the functionality for determining fuel, location and maintenance scheduling along with some loss management applications.

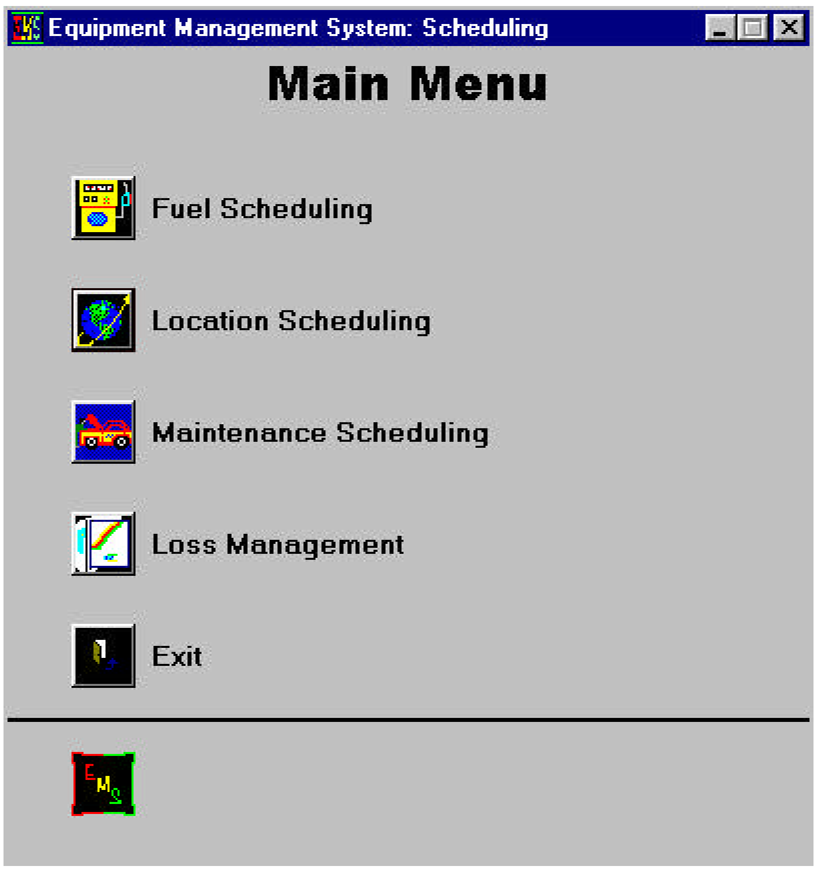


Figure 5.28: Main Menu for the Decision Level Software

The current traditional approach for determining fuel consumption, location, maintenance and equipment performance is much more painstaking for the Maintenance personnel or in some instances not even available to them. Most of these functions can drastically improve decision-making.

Presently, some mines have completed their fleet management, machine guidance, shovel control, planning, surveying and reporting systems. However, these systems all act independent of each other and obtaining real-time information from each individual system for decision-making in planning can be quite challenging. In such a case, an open modular system architecture might not have been employed, a critical factor for the development of a total management system.

The MEMS prototype system created for the tracking of lightplants is capable of integrating Syncrude' s present databases for requesting information. Currently the system retrieves information from two databases with the capability of linking to others. One database supplies the spatial information along with the mechanical information collected from the in-vehicle data acquisition system shown in Figure 5.29, the second database supplies the fuel information shown in Figure 5.30, and repair schedules shown in Figure 5.31 for the lightplants.

Date	Time	Northing	Easting	Location	Unit ID	Meter Reading	Engine
05/26/2000	1:08:47 PM	55705.961	50007.728	Mine	44-28-1	45721.4	No
05/26/2000	1:11:57 PM	56568.481	49678.919	Mine	44-28-2	87612.2	Yes
05/26/2000	1:13:53 PM	54520.291	48122.492	Mine	44-28-3	34614.6	Yes
05/26/2000	1:16:05 PM	53806.575	47900.793	Mine	44-28-4	69611.2	Yes
05/26/2000	1:19:28 PM	49611.915	54420.988	Mine	44-28-5	37937.1	No
05/26/2000	11:43:34 AM	49315.989	54356.017	Mine	44-28-6	46052.4	Yes
05/26/2000	11:57:15 AM	47049.948	54023.026	Mine	44-28-7	57715.3	Yes
05/26/2000	1:27:49 PM	46648.362	53984.648	Mine	44-28-8	56822.5	Yes
05/26/2000	1:34:53 PM	45960.586	54050.494	Mine	44-28-9	66834.2	Yes
05/26/2000	1:35:53 PM	45025.269	53626.985	Mine	44-28-10	53057.2	No
05/26/2000	1:39:53 PM	48618.89	50341.319	Mine	44-28-11	52218.9	Yes
05/26/2000	1:44:53 PM	48089.501	51268.14	Mine	44-28-12	51355.4	Yes
05/26/2000	1:46:54 PM	47572.321	52224.94	Mine	44-28-13	54281.2	Yes
05/26/2000	1:48:59 PM	46819.93	54087.22	Mine	44-28-14	54535.9	No
05/26/2000	1:54:22 PM	43922.71	53338.06	Mine	44-28-15	55166.1	Yes
05/26/2000	1:58:11 PM	45601.31	50439.79	Mine	44-28-16	55519.5	Yes
05/26/2000	2:00:45 PM	47623.02	42402.53	Mine	44-28-17	56124.2	Yes
05/26/2000	2:01:23 PM	50569.03	47997.44	Mine	44-28-18	56539.4	Yes
05/26/2000	2:05:44 PM	44984.301	48606.5	Mine	44-28-19	47352.1	No
05/26/2000	2:09:22 PM	49531.301	48280.898	Mine	44-28-20	54606.8	Yes
05/26/2000	2:12:12 PM	48565.164	48127.617	Mine	44-28-21	47212.8	Yes
05/26/2000	2:24:00 PM	47150.38	48501.41	Mine	44-28-22	48734.9	Yes
05/26/2000	2:28:45 PM	53433.34	47796.83	Mine	44-28-23	53885.1	No
05/26/2000	2:46:53 PM	57695.7	49321.81	Mine	44-28-24	54290.9	Yes
05/26/2000	2:48:30 PM	34417.76	56788.74	Mine	44-28-26	51692.8	Yes

Figure 5.29: Database Table Showing Spatial information

EquipFuel : Table

Unit ID	Fuel Date	Fuel Time	Amount of Fuel	Meter Reading
44-28-22	05/10/2000	PM	48.0	48524
44-28-23	05/10/2000	PM	53.0	53674
44-28-24	05/10/2000	PM	56.0	54080
44-28-26	05/10/2000	PM	60.0	51482
44-28-27	05/10/2000	PM	46.0	55042
44-28-28	05/10/2000	PM	45.0	53513
44-28-29	05/10/2000	PM	42.0	47166
44-28-30	05/10/2000	PM	60.0	50238
44-28-31	05/10/2000	PM	53.0	50421
44-28-33	05/10/2000	PM	60.0	52598
44-28-34	05/10/2000	PM	60.0	51014
44-28-35	05/10/2000	AM	55.0	47968
44-28-36	05/10/2000	AM	60.0	44901
44-28-37	05/10/2000	AM	49.0	43746
44-28-38	05/10/2000	PM	43.0	43728
44-28-39	05/10/2000	PM	54.0	43289
44-28-40	05/10/2000	PM	60.0	41187
44-28-41	05/10/2000	PM	60.0	42840
44-28-42	05/10/2000	PM	60.0	43608
44-28-43	05/10/2000	PM	60.0	45203
44-28-44	05/10/2000	PM	60.0	46706
44-28-45	05/10/2000	PM	54.0	51174

Figure 5.30: Database Table Showing Fuel Information

Database tables for spatial information and fuel information were newly created to provide Syncrude' s maintenance section with the capabilities to make decisions based on several factors that can be created for the information. Collecting and organizing the information requires no more effort than what is currently being carried out. In fact, the fuel and spatial information can now be collected by the same field personnel and sent to the main computer via wireless communication for placing the information directly into the database.

Given a combination of information relating to specific light units, location and availability schedules can now be understood by incorporating mechanical, service and downtime information.

Unit ID	Scheduled Maintenance	Scheduled M	Unit Actual Date In	Completion Date	Down Time	Repair Histor
44-28-1	01/06/1999	AM	01/06/1999	01/10/1999	5	4
44-28-2	01/24/1999	PM	01/24/1999	01/24/1999	1	1
44-28-3	01/28/1999	AM	01/28/1999	01/30/1999	2	2
44-28-4	01/12/1999	PM	01/12/1999	01/15/1999	3	2
44-28-5	01/18/1999	PM	01/18/1999	01/20/1999	2	1
44-28-6	01/22/1999	AM	01/22/1999	01/26/1999	4	3
44-28-7	01/01/1999	PM	01/01/1999	01/10/1999	9	3
44-28-8	01/03/1999	AM	01/03/1999	01/04/1999	1	1
44-28-9	01/10/1999	AM	01/10/1999	01/12/1999	3	1
44-28-10	01/05/1999	AM	01/05/1999	01/15/1999	11	4
44-28-1	03/06/1999	AM	03/06/1999	03/09/1999	4	4
44-28-1	05/06/1999	AM	05/06/1999	05/08/1999	3	4
44-28-1	07/06/1999	AM	07/06/1999	07/10/1999	5	4
44-28-1	09/06/1999	AM	09/06/1999	09/10/1999	5	4
44-28-1	11/06/1999	AM	11/06/1999	11/11/1999	6	4
44-28-1	01/06/2000	AM				
44-28-1	03/06/2000	AM				
44-28-1	05/06/2000	AM				
44-28-2	03/24/1999	PM	03/24/1999	03/24/1999	1	1
44-28-2	05/24/1999	PM	05/24/1999	05/24/1999	1	1
44-28-2	07/24/1999	PM	07/24/1999	07/24/1999	1	1
44-28-2	09/24/1999	PM	09/24/1999	09/24/1999	1	1
44-28-2	11/24/1999	PM	11/25/1999	11/27/1999	2	1
44-28-2	01/24/2000	PM				
44-28-2	03/24/2000	PM				

Figure 5.31: Database Table Showing Repair information

Personnel from the maintenance shop can now create efficient schedules for fuelling the lightplants to ensure they are usable for the long duration. The maintenance personnel can operate the software by choosing one of the two instances (Figure 5.32): a) query based on the fuel efficiency and the number of days lapsed; and b) query based on the number of days lapsed between last fuel date. Having done so, the operator’ s daily routes are now effectively generated and planned eliminating unnecessary driving within the perimeter of the mine. This system also helps by giving the exact up-to-date location for that unit therefore, the operator does not have to rely on where last the unit was seen or left.

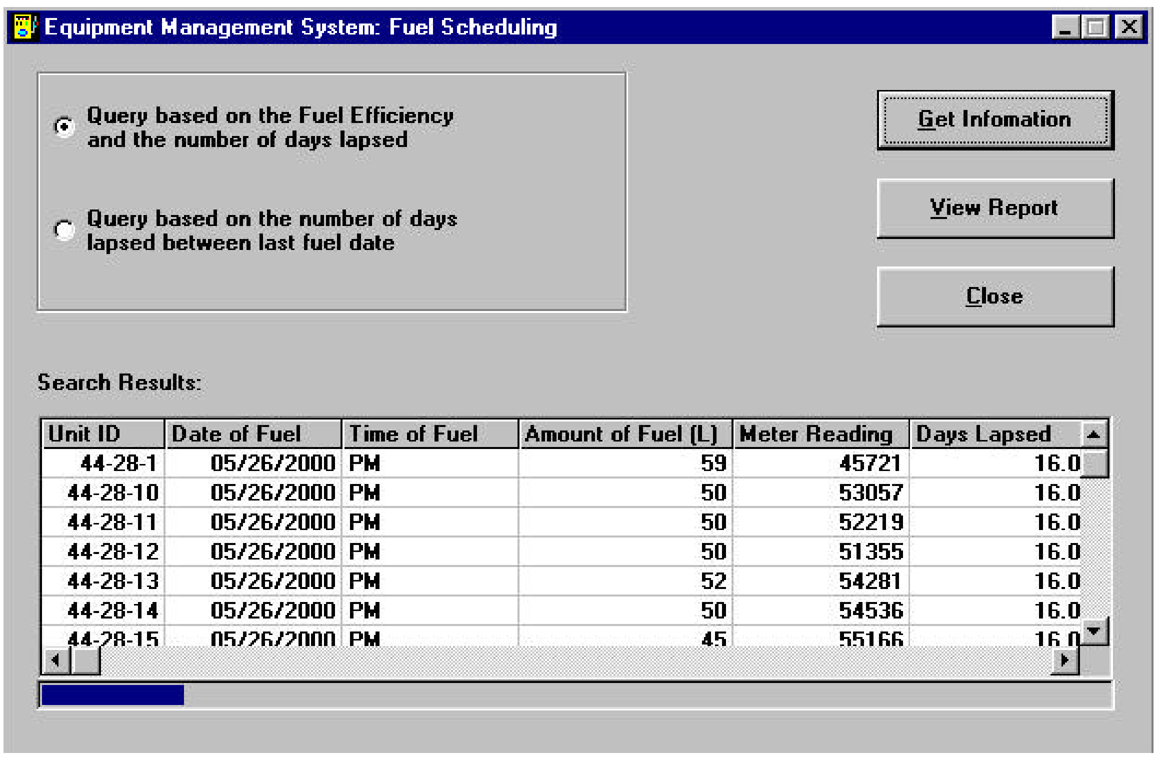


Figure 5.32: Fuel Scheduling

Planners can now locate a unit by several different instances: a) entering northing, easting and a specified search radius b) graphically picking a location on the map with a search radius c) entering a descriptive location name and d) search by unit identification. It is guaranteed that the unit of choice is not scheduled for service nor has a history of breakdowns after working for a number of hours, see Figure 5.33. Initial parameters are set causing the software to guard against repetitive breakdowns or unavailability due to service and other misfortunes. Hence, ensuring that the equipment is operating at peak efficiency for the ongoing project.

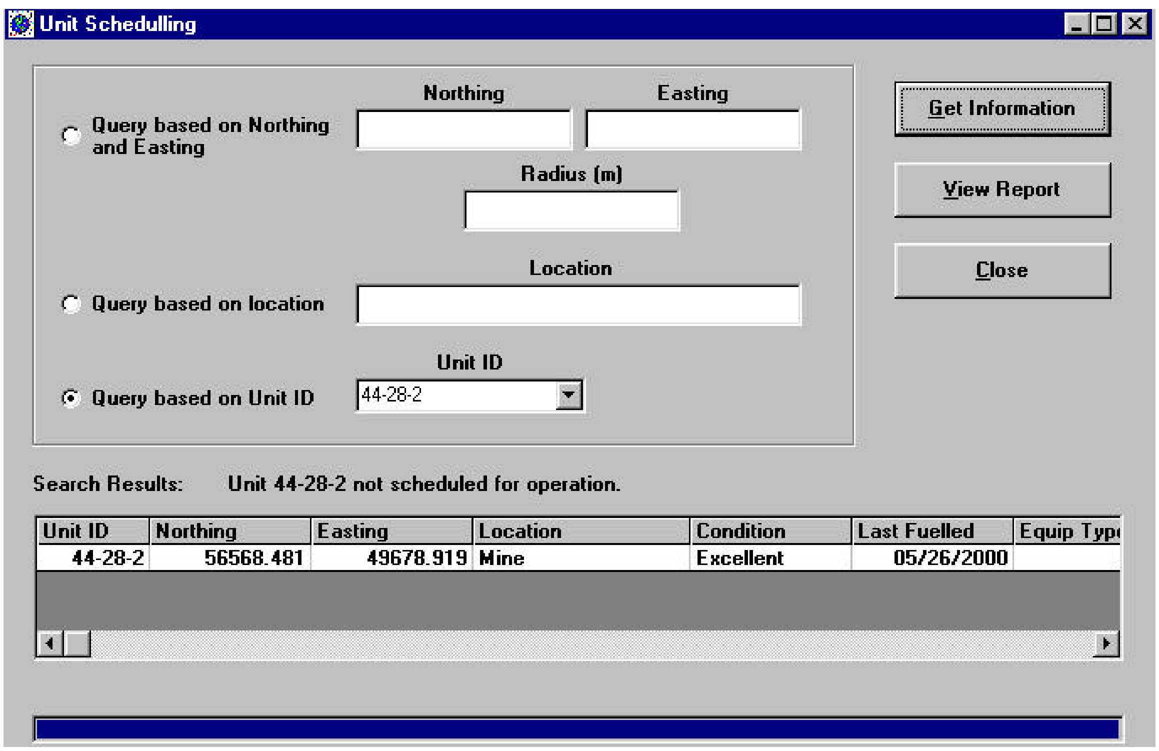


Figure 5.33: Location Scheduling

The equipment management software also assists in providing service history for the lightplants. For this instance the maintenance personnel would set the criteria for the number of hours lapsed between meter readings. Shown in Figure 5.34, the criterion is set to 10 hours. This ensures that the units are properly maintained and serviced. Very expensive engines run these lightplants and constant monitoring of these engines are necessary since they are in operation for long continuous hours. Also during shift change of personnel, people are misinformed or even the information is incorrectly filed or not recorded at all. This creates mishaps and many times some pieces of equipment are overlooked creating downtime or expensive repairs. Having the flexibility this software provides will ensure the proper maintenance schedule is followed. All work carried out to any lightplant will be stored in the database.

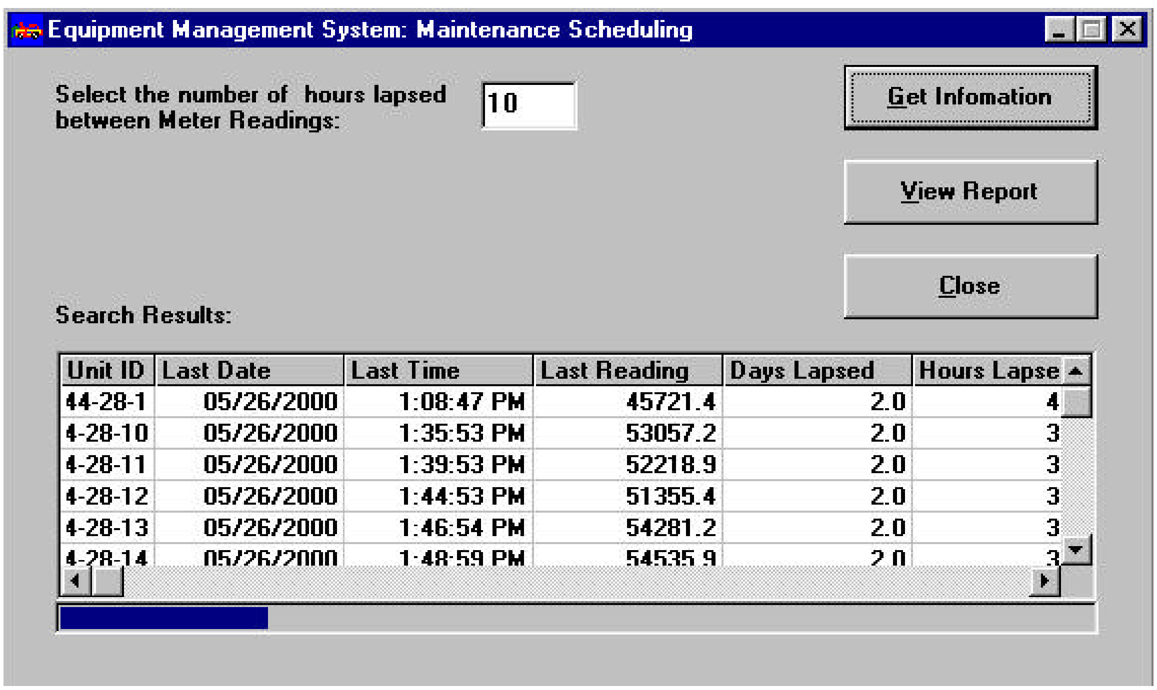


Figure 5.34: Maintenance Scheduling

Preventative maintenance is always an issue with large organizations who own millions of dollars worth of fleet and support equipment. Ensuring that these assets are well maintained is not an easy task. Hundreds of person hours are being spent keeping track of every piece of equipment to ensure that there are no costly repairs or maintenance. Some mining companies have instituted the Loss Management program to help employees manage themselves and company equipment. In prototyping the equipment management software it was necessary to incorporate preventative maintenance for the lightplants, this fell under the loss management section of the program. Using fuel consumption specification and determining downtime, utilization time and not-in-use time for the lightplants gave the opportunity for determining fuel efficiency during equipment utilization. The results shown in Figure 5.35 help in the decision-making process about the optimization for that piece of equipment. It also determines the operation cost and whether it' s in the best interest of the maintenance shop to replace it or perform upgrade on that piece of equipment. Figure 5.35 shows that equipment 44-28-9 has been utilized more during the winter months where daylight is limited. It also shows that the fuel efficiency has decreased during those months of inclement weather conditions. In the overall picture unit 44-28-9 has been maintained and utilized efficiently. Therefore, the software would not flag this unit hence the blank area in the top left corner of Figure 5.35.

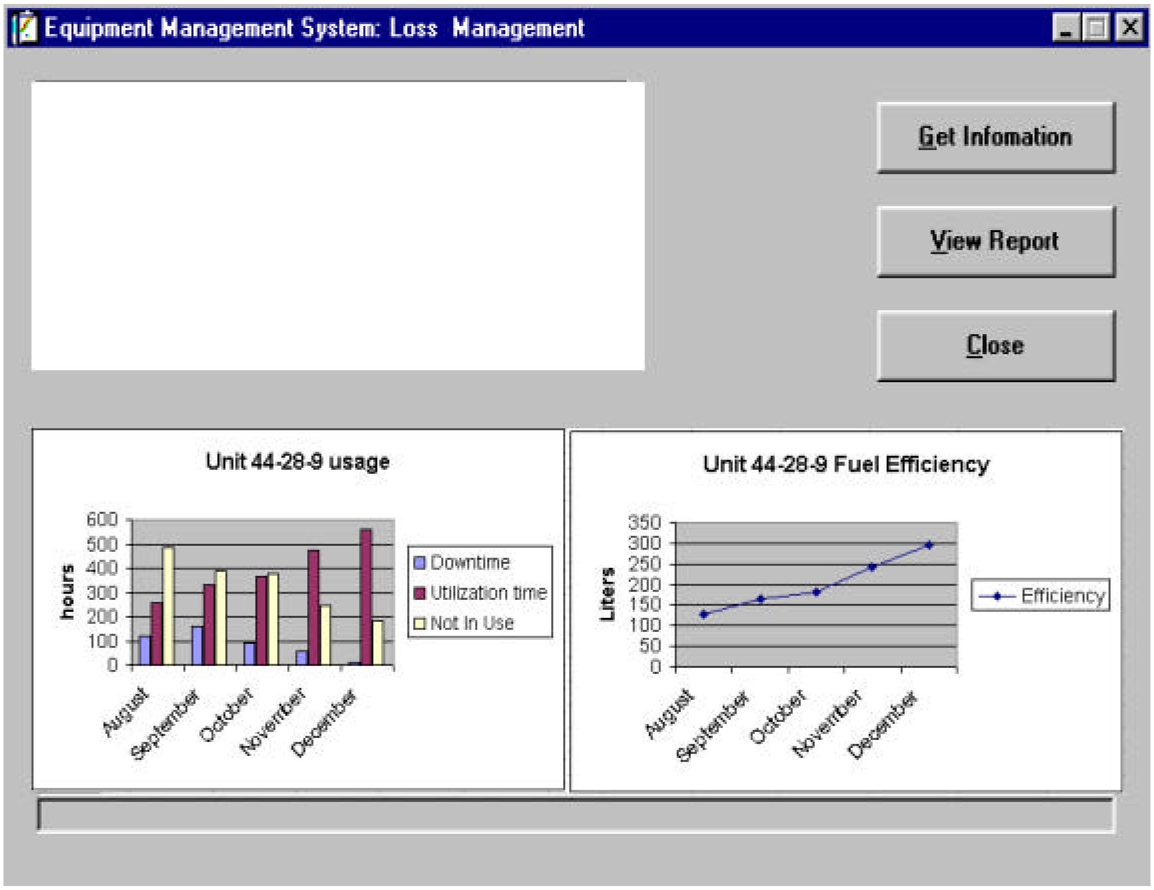


Figure 5.35: Preventative Maintenance for Unit 44-28-9

The next chapter will discuss the results and efficiencies of such a system.

CHAPTER 6

FIELD TEST AND RESULTS

Mine dispatch systems have been around for two decades. Early systems were unsophisticated since they provided minimal information to Mine Operations. The field of Geomatics concerned with the management of all aspect of spatially referenced information, from initial data acquisition and pre-processing, through to analysis and representation has enhanced dispatching systems. Many tools are available and utilized to accomplish these diverse tasks. Tools such as GPS, GIS and wireless communications has been gaining momentum over the years in the mining industry. This chapter will discuss field test and results of the MEMS prototype system developed from this research in an open-pit mining industry in particular Syncrude Canada Ltd.

6.1 GPS and GIS Roles In Mining

In areas of open-pit mining low-cost GPS coupled with real-time communications have made it viable for mines to invest in GPS for their truck dispatch systems, surveying applications, emergency response and grade control. These innovations have proven to be more cost effective than conventional methods. GPS and GIS are currently helping the mining industry to effectively manage their mining operation as a whole. It has allowed dispatchers to monitor the movement of their trucks ensuring that trucks are removing ore from the correct regions and dumping overburden at the correct locations. GPS/GIS dispatch applications have also provided solutions to one of open-pit mining's antagonizing problem, which is determining the efficiencies of the operation during a twelve-hour shift.

Emergency response crews can now reach their destinations quickly without any surprises such as washed-out ramps or changes to haul roads since ground topography is very dynamic in mining. Road closures and detours can be updated instantly to their mobile map in the emergency vehicle. When accidents do take place a quick response time is always necessary to prevent further damage and most important to prevent loss of life. In any industry where the work environment is subjected to hazards or dangers, efficient emergency response is always needed.

Most mining industries have either purchased or developed in-house GPS/GIS-based systems for most of their heavy equipment tracking and surveying applications. Such systems are usually disjointed or closed and only provide information to a specific area. Because of this limitation information is not properly shared among different departments. These systems do not provide total solutions as open modular systems do.

In open-pit mining there is different support equipment from lightplants such as: compressors, welding rigs, etc that requires a Mobile Equipment Management System with the same requirements as the lightplants. These pieces of equipment are always neglected from any mine software applications. MEMS is much needed for reducing the amount of person-hours it take to locate pieces of support equipment in the field;

automating maintenance data downloading retrieved from the field personnel; and finding better ways of managing and sharing this information among the mining division in a more cost-effective manner. These much needed areas will be the focus in the problem definition section.

6.2 Syncrude Canada Ltd.

Syncrude Canada Ltd. is an integrated large-scale oil operation that accounts for approximately twelve percent of Canada's oil production. It is located forty-two kilometers north of Fort McMurray, Alberta. See Figure 6.1. Syncrude's main operation consists of mining oilsands from an open pit mine, extracting the bitumen from oilsands and upgrading bitumen to produce synthetic crude oil.

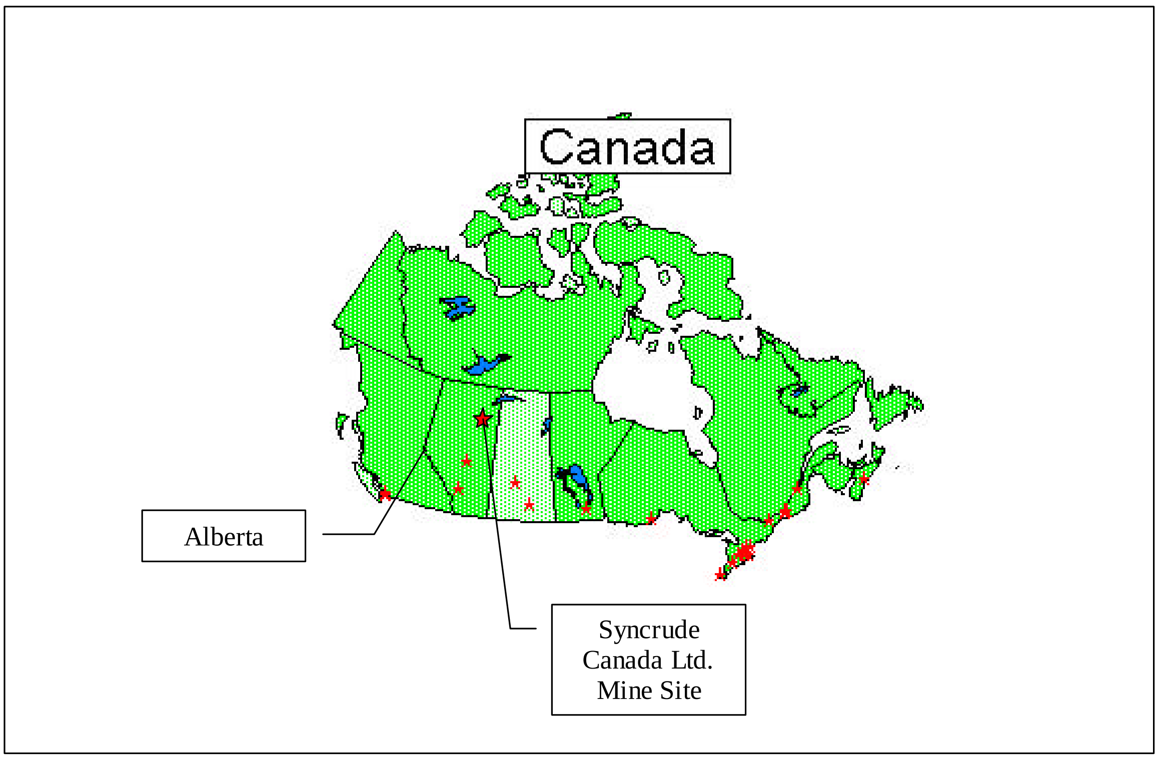


Figure 6.1: Syncrude's Mine Site Location at Fort McMurray, Alberta

Figure 6.2: Plan view of Syncrude' s Mine Site

Syncrude site is divided into five major zones: Base Mine, North Mine, Tailings, maintenance shops and plant facilities and Southwest Sand Storage area, see Figure 6.2. The main mine is divided into four quadrants. Each quadrant has a dragline, a bucketwheel and a system of conveyors. Each dragline is situated at the edge of the pit wall to mine the tarsand vertically. The pit face, known as the highwall, is forty to fifty metres deep with slope angles of forty to fifty degrees. The dragline places the extracted ore onto a windrow. A bucketwheel reclaimer reclaims the ore that places the ore on the conveyor. The conveyor then carries the ore to the extraction plant where it is processed. Figure 6.3 shows a typical cross-section of the east-west quadrant.

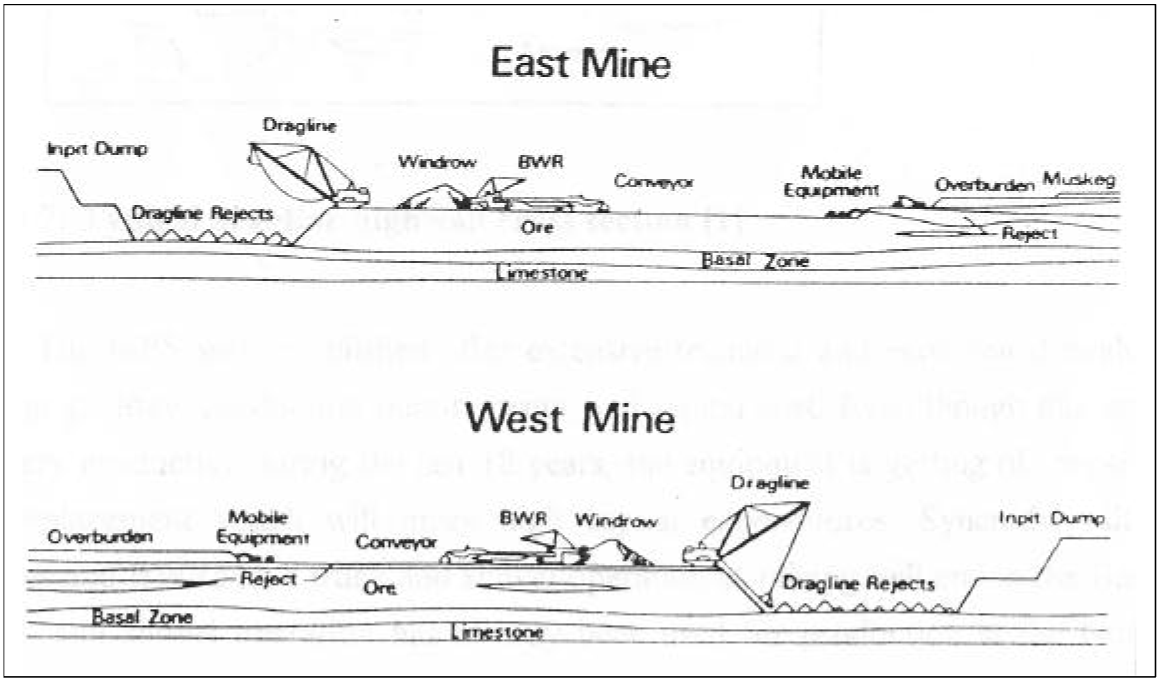


Figure 6.3, Typical East-West Cross Section of Syncrude's Base Mine

The extent of Syncrude's lease covers approximately thirty kilometers by forty kilometers including their new expansion lease. With this in mind, there is a large amount support equipment activities, from scheduling to equipment maintenance. Presently the Maintenance shop uses conventional methods for tracking these pieces of equipment.

Syncrude is divided into four major industrial departments:

- Mining;

- Extraction;
- Upgrading and;
- Utilities

Each of these departments are divided into divisions and for this study the focus will be placed on the Mining area which is divided into seven divisions:

- Mine Electrical: electrical maintenance and power supply for draglines, bucket wheel reclaimers (BWR) and conveyor belts.
- Mine Maintenance: mechanical maintenance of draglines, BWRs, conveyors, and some support equipment (lightplants, welding units, compressors, etc.).
- Mine Mobile: maintenance of trucks and shovels both electrical and mechanical and other support equipment such as dozers, graders and loaders.
- Mine Overburden: road maintenance, overburden removal and extraction of oil sands by trucks and shovels. Also light, medium and heavy-duty equipment and operators.
- Mine Production: oilsands removal by draglines, BWRs, dozers and loaders.
- Mine Reliability: consistency and efficiencies in the mining operations.
- Mine Technical: engineering, geology, geomatics and mine administration.

Syncrude has realized that conventional methods of equipment tracking and use of independent databases cannot meet the growing needs of the mine, especially trying to keep up with all the information gathered from the above seven divisions in Mining. This makes it extremely difficult for the maintenance crews and schedulers to keep up with equipment locations, tracking, maintenance and scheduling. One major necessity in this environment is the need to have a total management system that is accessible to all users of the seven divisions, such as auto mechanics, mine planners, maintenance personnel and mine schedulers. Therefore, a need for implementing the Mobile Equipment Management System.

The expansions of Syncrude' s mining operation and the high cost of producing a barrel of oil have made the company seek more efficient, effective and viable ways of running the daily operation. One of several projects that led to this goal was the introduction of GPS for surveying, truck dispatch and a pilot project for grade control. In order to use GPS for Syncrude' s requirements in the mobile equipment management system, there is a need for datum transformation since their coordinate system is local to the mine site.

6.3 Problem Definition

At present mining industries utilize a variety of standalone systems for planning and managing their operations. Most mines are using a combination of manual and computer-based systems for their planning and engineering, maintenance, scheduling and accounting requirements. Most of these systems are not open-systems by nature and have short life spans where upgrades or system change-out are needed to keep up with production growth of the mine.

One such area is the mine maintenance operation at Syncrude, the Syncrude mine site has the largest maintenance shop west of Thunder Bay [Flakstad, 2000]. The maintenance shop performs approximately 7000 person-hours of work a month on mine support equipment ranging from small equipment such as lightplants, welding units and compressors to heavy haul trucks.

One of the major objectives for this research is to develop a prototype Mobile Equipment Management System to track the lightplants that would be accessible to all seven divisions at Syncrude mine site. A typical lightplant is shown in Figure 6.4. A lightplant consist of a diesel engine, which generates power to several 1500-watt bulbs.

Figure 6.4: Typical Lightplant on Syncrude' s Mine Site

The cost of one of these plants is approximately 40 to 50 thousand dollars. Lightplants are use in all areas of the mine for providing light during night-shift operations. Millions of dollars in lost revenue can occur from poor maintenance, poor scheduling, and under utilization of equipment such as the lightplants. These pieces of equipment are always overlooked from any mining software applications. Such a system is much needed at Syncrude for three basic reasons:

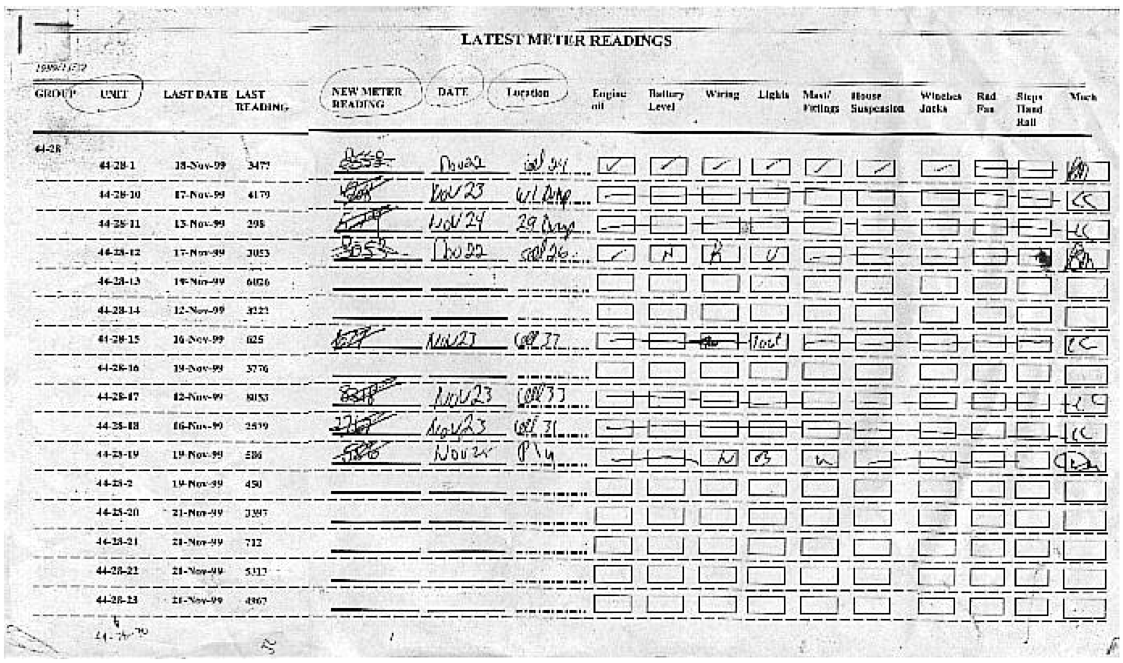
1. It requires many person-hours to locate these pieces of support equipment for either scheduling or maintaining;
2. Manual downloading of data retrieved from the maintenance personnel can be prone to data entry errors. The implications from this result in major cost to the company and;
3. Improving ways of managing and sharing this information among the seven divisions in a more cost-effective manner.

6.3.1 Improve Planning

On a mine site of this magnitude with thousands of employees it is very difficult to locate the lightplants by manual methods. Keeping track of the lightplants' location and schedules on paper is very inefficient since the information is not properly shared among all users. This piece of equipment can be located at one quadrant of the mine today and within hours be relocated to a new area kilometers away. The new location information may not be passed on to the correct authority for a few days or in some instances the location is not noted. This may lead to many hours being spent for searching for that particular piece of equipment. There are also instances when the lightplants are double booked by different personnel or even scheduled for maintenance and cannot be utilized for that required shift. This situation results in downtime and loss in production. Scheduling of support equipment is vital to this operation since mining is carried out at different areas of the mine site simultaneously.

6.3.2 Reduce Human Errors

Currently, a maintenance person goes out looking for each lightplant to collect information about that particular unit.


LATEST METER READINGS

GROUP	UNIT	LAST DATE	LAST READING	NEW METER READING	DATE	Location	Engine oil	Battery Level	Wiring	Lights	Mast/ Fittings	House Suspension	Winches Jacks	Rad Fan	Steps Hand Rail	Mech
44-28																
	44-28-1	18-Nov-99	3477													
	44-28-10	17-Nov-99	4179													
	44-28-11	13-Nov-99	298													
	44-28-12	17-Nov-99	3053													
	44-28-13	19-Nov-99	6026													
	44-28-14	12-Nov-99	3123													
	44-28-15	16-Nov-99	625													
	44-28-16	19-Nov-99	3776													
	44-28-17	12-Nov-99	8053													
	44-28-18	16-Nov-99	2539													
	44-28-19	19-Nov-99	586													
	44-28-2	19-Nov-99	450													
	44-28-20	21-Nov-99	3397													
	44-28-21	21-Nov-99	712													
	44-28-22	21-Nov-99	5312													
	44-28-23	21-Nov-99	4967													

Figure 6.5: Data Collection Sheet for Lightplants

The information collected is then written on a spreadsheet as shown in Figure 6.5. Manually downloading data retrieved from the maintenance person is not always correct due to user error such as transposing numbers when recording the unit' s meter reading. The implications from misreading the unit' s meter reading can result in major costs to the company since this determines the servicing schedule. The diesel engines that run these lightplants are costly and require maintaining after working long hours. Errors are also made in the description resulting in inaccurate locations of these units. Other important information such as fuel consumption is not recorded.

6.3.3 Information Management

A better way of managing and sharing this information among the seven divisions in a more cost-effective manner is needed. Obtaining and relaying the right information is crucial to the decision making process among all parties involved. Using conventional methods to relay information may take days before reaching its destination. Syncrude's operation requires a smooth flow of current information between, and even within, their seven divisions. This could be accomplished by implemented a GPS-based data collection system along with the Mobile Equipment Management System that stores the information in an almost real-time database.

6.3.4 Syncrude's Local Datum

Another area of consideration is the local datum used at Syncrude. This is a concern since the data collection system is GPS-based and the coordinates from the GPS are in World Geodetic System 1984 (WGS84). The objective is to determine four datum transformation parameters in two stages. The first stage involves transforming from WGS84 to Universal Transverse Mercator (UTM). The second stage will transform UTM to Syncrude's Mine Metric grid. The transformation of coordinates would be carried out at the data collecting stage, therefore a function would be built into the software to accomplish this. A 2D-similarity transformation would be the methodology of choice since Syncrude is only interested in the horizontal location.

6.4 Solution

Developing an information management system for data collection, data management and decision-making can alleviate the problems that face Syncrude from the three basic reasons shown in the previous sections. Such a system would tie in all seven divisions together and allow users to maintain and share information collected by a GPS-based data collection system, see Figure 6.6. As mentioned before, obtaining and relaying the right information at the right time is crucial to the decision-making process in Mine Maintenance. Time spent being proactive rather that reactive is equally crucial to realizing efficiencies and creating a more effective operation. The Mobile Equipment Management System concept can help achieve this by accommodating an integrated network of hardware and semi-intelligent software. This would allow the efficient collection, processing, distribution and storage of pertinent information. It would eliminate the need for conventional methods of data collecting, thus removing errors that would lead to major cost. The Mobile Equipment Management System concept is quite simple: effective and direct information exchange between personnel. It is not a centralized data collection system; rather it is an open integrated network of events that when followed would increase productivity.

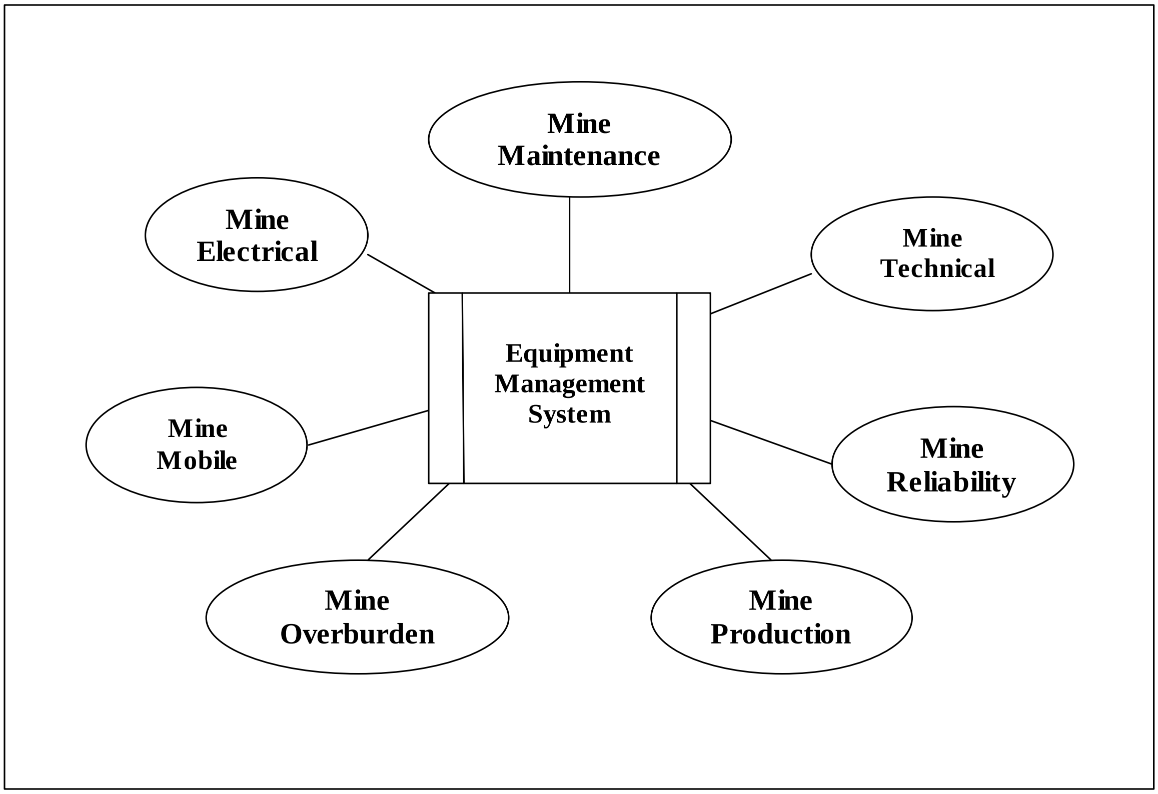


Figure 6.6: Typical Users of the Mobile Equipment Management System

The Mobile Equipment Management System incorporate GPS receivers for supplying location and velocity information, computers for data input, subsequent information output and databases for data retention and data accessibility of pertinent information. Updates from the field as to present location and attributed data can be transmitted back to the database for analysis at near real-time. Time currently spent verbally communicating changes to the equipment service history, schedule and location could be better spent managing and maintaining the equipment. Such a system could also assist in pinpointing the shortest route for the mechanics and emergency response vehicles.

6.5 Syncrude's Test Methodology and Site Results

Testing of the Mobile Equipment Management System was conducted over two days on Syncrude's mine site. A series of implementation tests on the software and hardware were carried out along with collecting and retrieving information from other databases for data management and decision-making. Six tests were categorized as follows:

Test 1: Setup the field and office hardware and MEMS software.

Test 2: Check the MEMS database connectivity to the Maintenance department databases.

Test 3: Locate all seventy-five lightplants using the in-vehicle data acquisition system.

Test 4: Send all of the lightplants information to the office database component for data maintenance and management.

Test 5: Test the decision-making software with users from different departments.

Test 6: Represent all of the lightplants graphically with the functionality of displaying all of their maintenance records.

6.5.1 Test Details

Test 1

The data acquisition component was mounted into one of Syncrude's pickup trucks as shown in Figure 6.7.

Figure 6.7: Data Acquisition Component in Syncrude's Truck.

The laptop was loaded with the data acquisition software. The GPS and communication radio was hooked up to the laptop's serial devices and the GPS antenna mounted to the roof of the truck. After the installation, the office and the decision-making components were successfully installed on a test computer located on the third floor in Mine Technical 41M building. A regular software installation was carried out on the Mobile Equipment Management System as shown in Figure 6.8. The Office software component, Management and Maintenance were connected to its own database for the storage of data acquired by the in-vehicle acquisition component. To test the system prior to Test3 and Test 4, field information was successfully collected and sent back to the demo database via radio communications. This initial test showed the system was ready for field use.

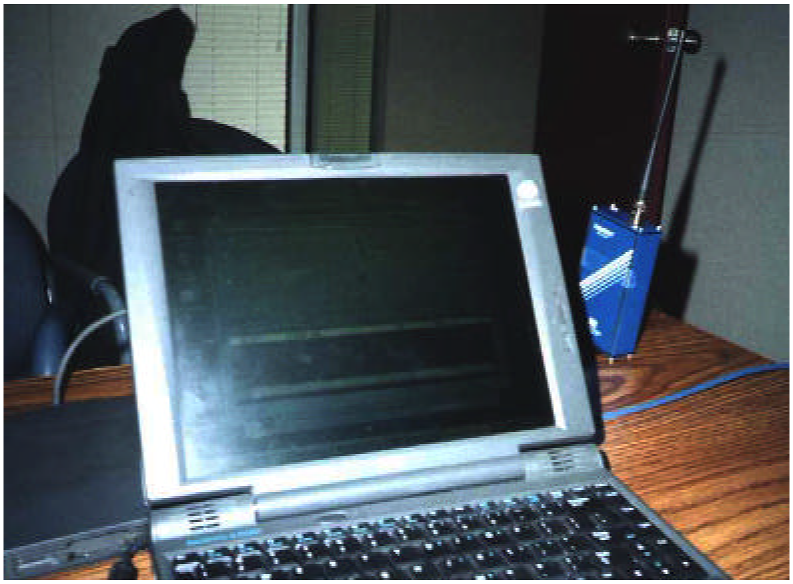


Figure 6.8: Office Component Located in Building 41M.

Test 2

The Office software component, Decision-Making requires database connectivity to all of the different databases. It allows for data manipulation and interpretation for providing decision-making on different aspects of the lightplants. The software was loaded onto the office computer and connected to the management and maintenance and the auto mechanic's databases for retrieving location, lightplant maintenance, fuel, repair history and scheduling information. Performing an initial fuel scheduling showed that the decision-making software was connected to all of the databases.

Test 3 and Test 4

After completion of all software and hardware installation, the task was to locate and collect the pertinent information on all seventy-five lightplants located in different areas of the mine site. One major problem encountered in the field was the pervious location of the lightplants were descriptive (located in the south end of Coke Cell 5) and not all locations were known. It took approximately seven hours to complete the task of locating all of the lightplants.

All information was sent back from the field to the demo database as shown in Figure 6.9. Returning to the office for data verification on all information collected in the field showed that the data was correctly stored in the database. The field information was stored in the correct database fields. This showed that the communication between the in-vehicle acquisition component and the office component was successful. Figure 6.9 also showed that the communications were successful.

Test 5 and Test 6

This test showed that changes to the equipment service history, schedule and location can be accessed through the office software components where decisions were made on that piece of equipment. Figure 6.10, 6.11 and 6.12 shows that 71 units required servicing after 10 hours from their last service history. The series of figures shows the different types of information users have access too.

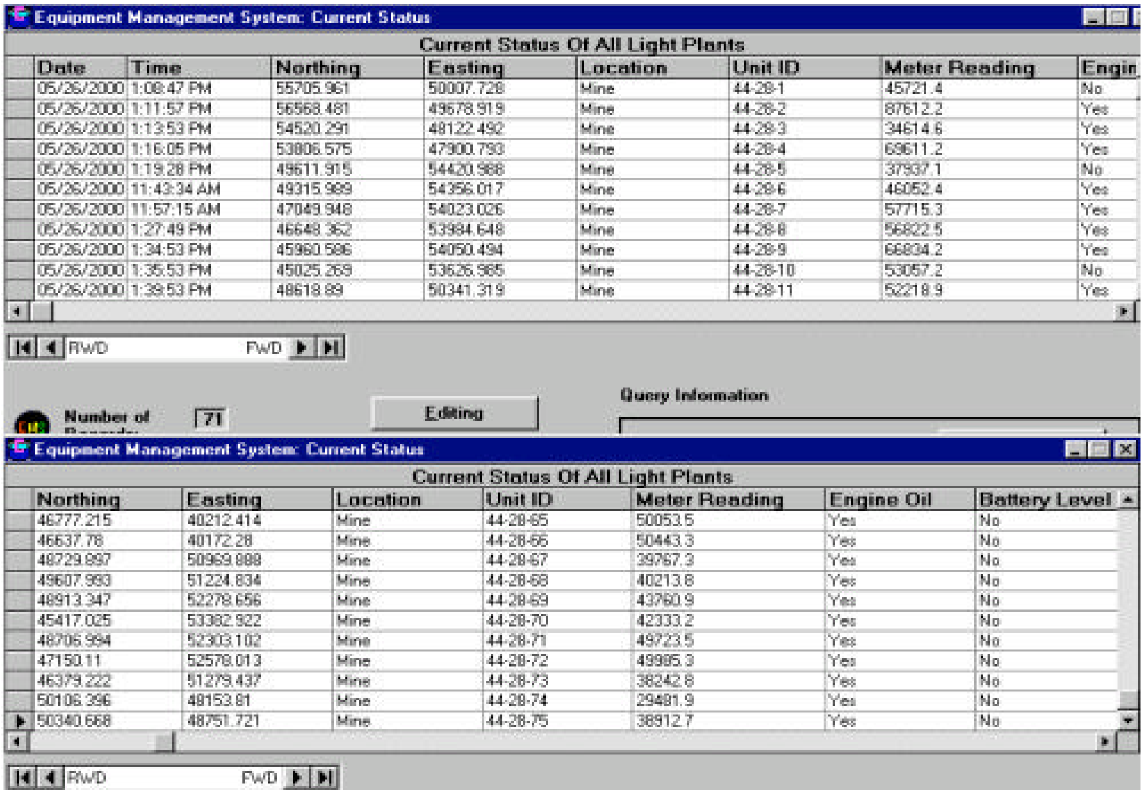


Figure 6.9: Location and Required Data on all Lightplants in the Database.

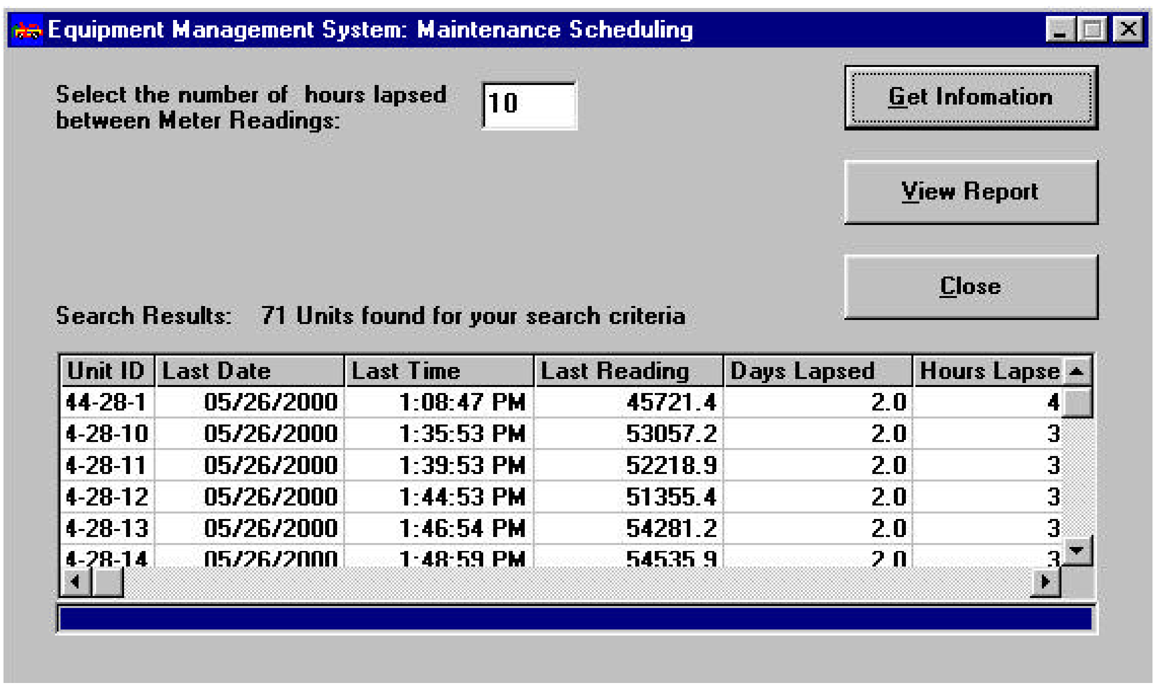


Figure 6.10: Maintenance Scheduling after 10 Hours.

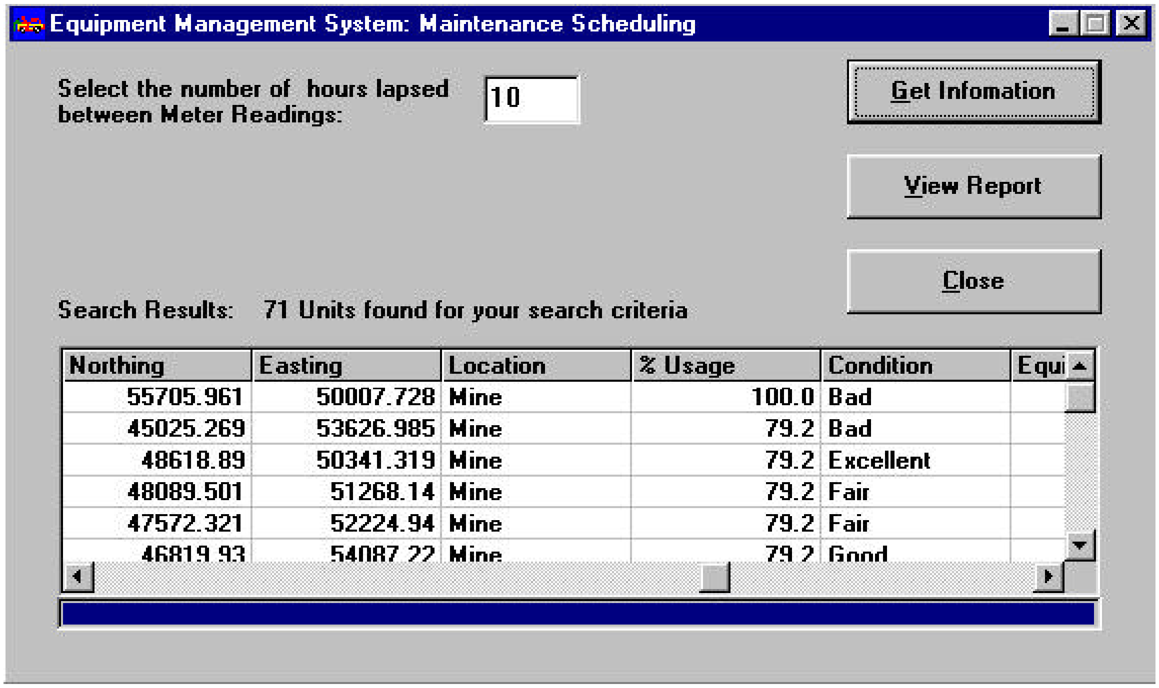


Figure 6.11: Different Information Provided to Users for Maintenance Scheduling.

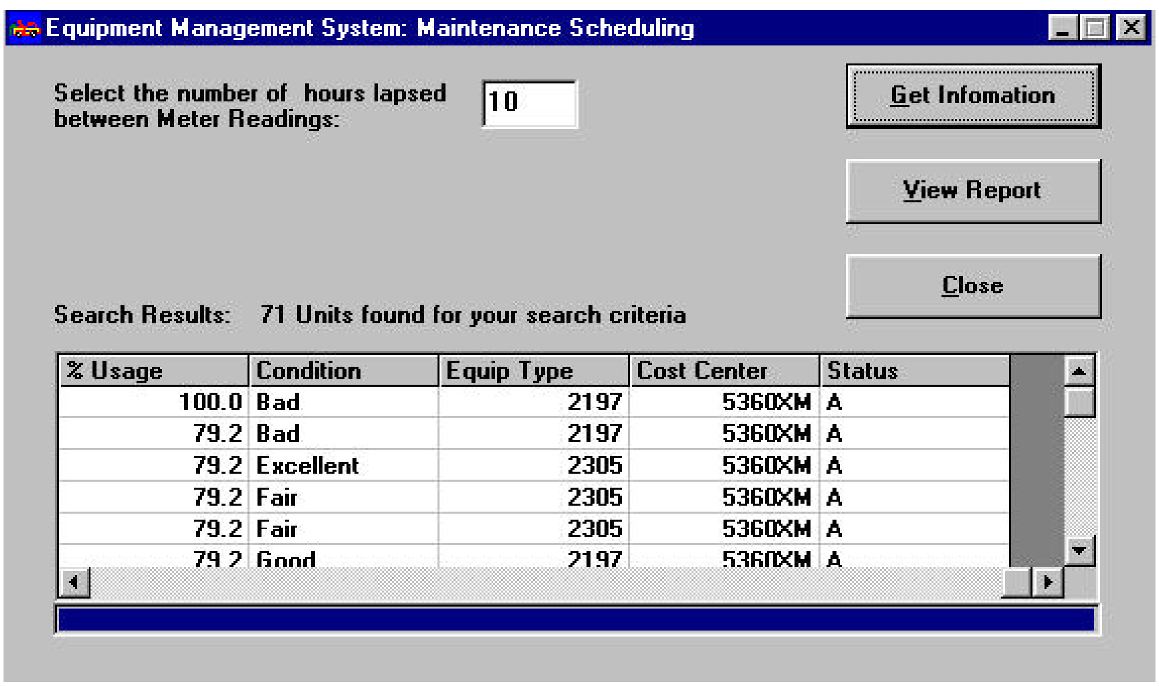


Figure 6.12: More Maintenance Scheduling Information.

Upon completion of the retrieval of maintenance and scheduling information showed that the database connectivity between the MEMS office component software and the scheduling databases worked. Users from different areas were able to run the decision-making software to perform fuel, location and maintenance scheduling along with graphically viewing the location of all 71 units on site shown in Figure 5.22.

This concluded a series of six tests carried out on Syncrude site which, showed that the Mobile Equipment Management System has the potential to improve productivity in all divisions from Maintenance to Planning. All users have access to a wide variety of information on all units for different levels of decision making. They can efficiently schedule equipment at the right place in the right time knowing the unit reliability history.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Investigation of the system architecture, development and testing of a prototype system for a mobile equipment management system were the major objectives of this research. The existing approaches for mobile equipment management methods are neither automated nor efficient, require large paper trails and extensive person hours. These objectives were met and were successfully executed out in the field under an operational environment at Syncrude' s mine site. In the following, conclusions and recommendations drawn from this research are summarized.

7.1 Conclusions

The following conclusion address the major findings obtained from this research.

1) An open system architecture has been investigated and developed for mobile information management which includes three components, namely, field data acquisition system, data communication system and office data management system. The new system architecture provides an efficient way for the integration of satellite navigation, wireless communication and data information technologies for mobile information management. Having an open system can prevent costly re-handling of massive amounts of data and it is also essential for ensuring transportability, adaptability and expandability of the developed system.

2) A prototype Mobile Equipment Management System (MEMS) has been developed including hardware integration and software development. The prototype system not only demonstrates how new and existing technologies can be integrated to achieve new applications but also can create efficiencies in collecting, processing, distributing and storing pertinent information of mobile equipment. The prototype system was designed for the area of mine maintenance where all large and small pieces of equipment can be located, maintained and scheduled efficiently for the day-to-day operations. The software system, based on a Windows operation system platform that is extremely user friendly and affordable to all sizes of mining operations, was written to keep the system modular whereby additions and customizations can be made and also not to restrict users in the selection of hardware.

3) Field tests have been conducted to evaluate the performance of the developed prototype system under an operational environment. The obtained results have showed the Mobile Equipment Management System assisted in crucial decision making and help maintain a smooth flow of up-to date information between, and even within, different areas of a large open-pit mining operation. The system concept proved desirable to such organizations since it makes it possible to:

    a) Reduce unnecessary cost – through real-time data collection and information management on equipment location and maintenance history, costly repairs, maintenance and service can be avoided. The maintenance person can now locate and service the equipment without relying on other people to inform him / her where that piece of equipment is located.

b) Reduce personnel errors in the field – information is collected electronically using reliability checks in the software preventing erroneous values from being entered. The field information is automatically updated into the database. This eliminates the need for paper trails, which can be lost, misplaced or simply left sitting on someone’ s desk.

c) Improve efficiencies and quality assurances – information on every piece of mobile equipment can now be actively accessed by all users. This provides users with the necessary information for assessing, locating, and scheduling equipment that is closer to their work site, ensuring that the equipment is available and is in good working condition. This makes for quicker response times.

d) Enhance management and coordination of all supporting equipment – real-time information access to all information on every piece of equipment from different database locations makes it easier to manage and coordinate equipment without leaving one’ s office.

e) Reduce excessive person-power in the office and field – MEMS provides an automated system whereby information is automatically collected and updated to the network, eliminating the need for data entry personnel. The field personnel can now generate the equipment location and maintenance history for determining what equipment needs servicing. There is no need for several people having to drive out to each piece of equipment for a visual inspection to determine if it needs servicing.

f) Reduce downtime and equipment delays – MEMS' open architecture to distributed information give schedulers and mechanics the advantage to determine equipment availability. Also the equipment rating, condition and fuel consumption is known. Having this information prevents costly delays and downtime.

g) Improve human safety – the MEMS graphical map display shows the location of every piece of equipment. In so doing, areas of high risk can be noted and precautions used. Also knowing exactly where the equipment is located makes it easier for the field personnel to navigate to, rather than blindly searching for it.

7.2 Recommendations

This thesis represents an area that is significant but goes on-touched by a large number of applications in the future. In fact, millions of dollars are being spent yearly on support equipment and the Mobile Equipment Management System is a cost-effective way of saving operational expenses. While the Mobile Equipment Management System presented in this thesis cover a wide range of technologies, there are many more related research avenues that should be perused. The following recommendations are made for future research:

1) Cellular or satellite communications (GEO and LEO Satellite link) for the mobile in-vehicle data collection system, this will eliminate the need for communication licensing by the government.

2) Create LCD touch screen for the mobile unit making it extremely user friendly.

3) Fully integrate two-way communications to the mobile unit for navigation and guidance.

4) Develop the ability to publish monitoring data over the Internet using standard WWW browsers in graphical form.

5) Create sensor monitoring over the Internet whereby information can be sent back to the office as requested.

6) Develop fast and efficient wireless data transmission to the Internet using the Wireless Application Protocol known as WAP.

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APPENDIX A

COORDINATE TRANSFORMATION FORMULAE

A.1 Transformation of (f, l) to (x,y) UTM Grid Coordinates

In order to compute the y coordinate from a given (f, l) the meridian arc-length must be computed prior to the calculations [Bomford, 1971; Krakiwsky, 1973]:

$$S_f = a(A_0 f - A_2 Sin2f + A_4 Sin4f - A_6 Sin6f + A_8 Sin8f)\,, \tag{A.1}$$

Where f is the latitude of the point in radians,

$$A_0 = \left(1 - \tfrac{1}{4}e^2 - \tfrac{3}{64}e^4 - \tfrac{5}{256}e^6 - \tfrac{175}{16384}e^8\right), \tag{A.2}$$

$$A_2 = \tfrac{3}{8}\left(e^2 - \tfrac{1}{4}e^4 + \tfrac{15}{128}e^6 - \tfrac{455}{4096}e^8\right), \tag{A.3}$$

$$A_4 = \tfrac{15}{256}\left(e^4 + \tfrac{3}{4}e^6 - \tfrac{77}{128}e^8\right), \tag{A.3}$$

$$A_6 = \tfrac{35}{3072}\left(e^6 - \tfrac{41}{32}e^8\right), \tag{A.4}$$

$$A8 = \tfrac{315}{131072}e^8\,. \tag{A.5}$$

UTM (x,y) grid coordinates can now be calculated from [Thomas, 1952; Krakiwsky, 1973]:

$$\begin{aligned} x = {} & x_0 + k_0 N[\Delta l * \cos f + \frac{\Delta l^3 \cos^3 f}{6}(1 - t^2 + h^2) + \\ & \frac{\Delta l^5 \cos^5 f}{120}(5 - 18t^2 + t^4 14h^2 - 58t^2h^2 + 13h^4 + 4h^6 - 64h^4t^2 - 24h^6t^2) + \\ & \frac{\Delta l^7 \cos^7 f}{5040}(61 - 479t^2 + 179t^4 - t^6)], \end{aligned} \tag{A.6}$$

$$y = y_0 + k_0 * S_f + k_0 N[\frac{\Delta l^2}{2}\sin f \cos f + \frac{\Delta l4}{24}\sin f \cos^3 f(5 - t^2 + 9h^2 + 4h^4) +$$
$$\frac{\Delta l^6}{720}\sin f \cos^5 f(61 - 58t^2 + t^4 + 270h^2 - 330t^2h^2 + 455h^4 + 324h^6 - 680h^4t^2 + \quad \text{(A.7)}$$
$$88h^8 - 600h^6t^2 - 192h^8t^2) + \frac{\Delta l^8}{40320}\sin f \cos^7 f(1385 - 3111t^2 + 543t^4 - t^6)],$$

where

$$\Delta l = l - l_0, \quad l_0 = -111^\circ \text{ for Fort McMurray,} \quad \text{(A.8)}$$

$$t = \tan f, \quad \text{(A.9)}$$

$$h^2 = \left(\frac{a^2 - b^2}{b^2}\right)\cos^2 f, \quad \text{(A.10)}$$

$$N = \frac{a}{\left(1 - e^2 \sin^2 f\right)^{\frac{1}{2}}}, \quad \text{(A.11)}$$

$$x_0 = 500{,}000.0 \text{ m},$$

$$k_0 = 0.9996 .$$

A.2 UTM (x,y) Grid Coordinates to Syncrude's Mine Metric

Using 2D transformation parameters developed for Syncrude's mine metric [Ramsaran, 1995].

$$y_0 = 6259002.107 \text{ m},$$

$$x_0 = 427550.619 \text{ m},$$

$$k = 0.9996,$$

$$e = -16^\circ 53' 53''.305,$$

$$N_{mm} = \frac{(N_{UTM} - y_0)\cos e + (E_{UTM} - x_0)\sin e}{k} \ , \qquad \text{and} \qquad (A.12)$$

$$E_{mm} = \frac{(E_{UTM} - x_0)\cos e + (N_{UTM} - y_0)\sin e}{k} \ . \qquad (A.13)$$