1 INTRODUCTION

This section is intended as an overview of the dissertation and reference should be made to the main dissertation for further detail if required. This dissertation investigates an approach to the choice, implementation and management of communications technologies and systems, that is geared to strive for maximised system life and benefit for the deep level gold mining industry. It quantifies, to some degree, the potential cost benefit of a communications system. As a necessary step it identifies the needs of the deep level gold mining industry, and the qualities and aspects of the technologies that are important to the issue.

The **main technical issues** covered by this dissertation are; firstly the radio coverage issues, and secondly the pertinent properties on the emerging bus technologies for process control.

The **main technology management issues** covered are; firstly the trends investigated in the emerging and converging field of communications, and secondly methods to manage these in the deep level gold mining industry.

Finally the **engineering management issues** to the dissertation are; firstly the potential cost benefit quantification, secondly the project management process to implement such projects, and thirdly the management methods to maintain the continual review of current systems and the spread of best practice.

The dissertation is written such that **Chapter** 3 covers the needs analysis of the deep level mining industry, firstly explaining the typical business process of the industry, secondly grouping the common needs in preparation for the fitting of available technologies. **Chapter 4** explores issues from an engineering management perspective, firstly identifying and quantifying the tremendous financial benefit communications systems potentially have for the industry, secondly proposing a sound project management process tailored for the communications type project in the underground mining industry, and thirdly looking at methods to continually manage the dynamic technology issues of communications systems, finally packaging this together as a 'Communication Systems Life Cycle Management plan'. **Chapter 5** analyses issues around available technology, identifying qualities we need to look for when choosing communications technology, and also exploring the main technologies available today and the trends they seem to show. **Chapter 6** handles the technical issues behind radio transmission underground. In this case an RF (Radio Frequency) simulation model was developed to investigate reception probability. Radio is the most technically challenging of the media and hence deserved its own special chapter. Finally **Chapter 7** pulls the picture together proposing a model for each category of mine, and emphasises controls to be followed for future management of this technology.

2 BACKGROUND

The gold mining industry has been through a boom phase during the early 80's and now faces a tough competitive phase that seems to be here for at least the medium term. In this competitive environment it is essential for mining companies to find competitive advantage. A major opportunity for productivity improvement is in the optimal establishment of communications backbones to support both process automation and business decision support systems. Various "legacy" systems exist in the mining environment due to haphazard implementation of technology to monitor and, in isolated cases, automate. The challenge remains now to establish communications backbones with a view to the future where demands on communications systems are expected to grow substantially.

This dissertation examines the mining process's communications needs in terms of data, voice and video. It investigates the currently available technologies on the market, their strengths, weaknesses and intended niche, and matches these to the needs of the deep level mining industry.

2.1 An Overview of Literature and Work Done

This approach to technology management of communications systems from a user perspective is relatively unique, particularly from a deep level gold mining perspective. Consequently literature for this dissertation was difficult to find.

In overview, the literature seems to have been available in pockets of narrow interest, for instance take the references [1], [2], [3] and [4]. A large function of this dissertation was to assemble the big picture and develop an optimum communications infrastructure, managed as a utility for the deep level mining industry. A dissertation was found that was similar in the respect of generating a generic communications model, but more on the IT specialist side of electrical engineering than on the communications side [5]. It was done by the student, E. Reinecke, for a MSc. in Electronic and Computer Engineering. The dissertation investigates a single network solution for a multi-vendor, multi-network environment which strives for architecture and protocol transparency. This was a transitionary solution to allow networks to migrate to the OSI layered model and to achieve integration. The main objective was the design model for such networks. This is a thesis very similar to this dissertation, only in the IT environment where this dissertation is in the process control and mining world.

The nature of the subject has led to many of the references being taken from the Internet. Technology trends are also of major importance in the decision of which systems to invest in.

In areas of the communications field the commercial competition from the suppliers is fierce (e.g. Fieldbus Foundation and Profibus - [6] and [7]), and one needs to objectively evaluate what the technology will do in the long term. The dissertation did do its own technical investigations to supplement or extend the investigations found in literature ([8], [9]). In this instance, the radio field where specific underground environments had to be modelled.

A large part of the thesis was in technology management necessitating the need for technology management theory ([10],[11]).

3 NEEDS ANALYSIS

3.1 Macro Process Description

The mining process can be viewed as a number of sub-processes feeding each other. From the mining itself where the rock is broken, to the transport of this rock to surface, and finally the treatment of the rock itself in the metallurgical plant where gold is extracted. The sub processes are defined and the communications needs analysed in the following section.

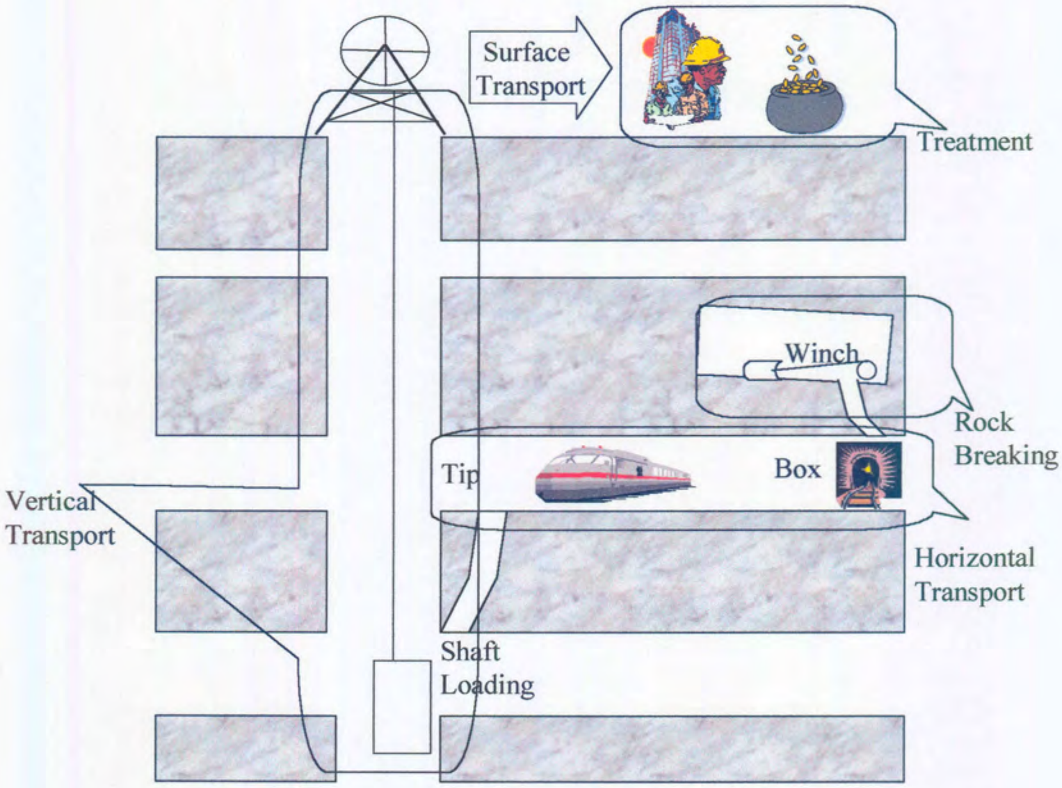

Figure 1: The Mining Process

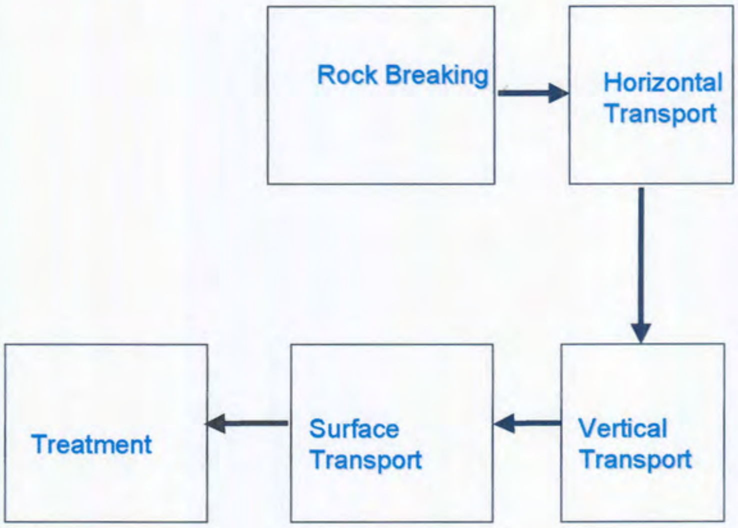

Figure 2: Macro Process Flow

The mining environment is best envisaged using the three dimensional diagram shown in Figure 3. Typically there are two main *shafts* the second shaft providing a second outlet for emergencies, and a return path for used ventilation air that is pumped through the mine by extraction fans sucking it out of the second. Large winders transport men, material and rock between underground levels.

The *haulage* (tunnels) to the working areas carry battery powered locomotive transport as well as providing a travelling way for pedestrians. Haulages also are normally laid out in parallel, one for ventilation supply and a second for return ventilation.

Once the reef (Ore body) is reached, "cross cuts" are used to access the area below the inclined narrow tabular reef body. A travelling way upward towards the reef is developed for access of men, material and equipment. A box hole is developed down from a suitable point close to the mined reef body in the "stoping area" (the area where the reef body is successively blasted and extracted).

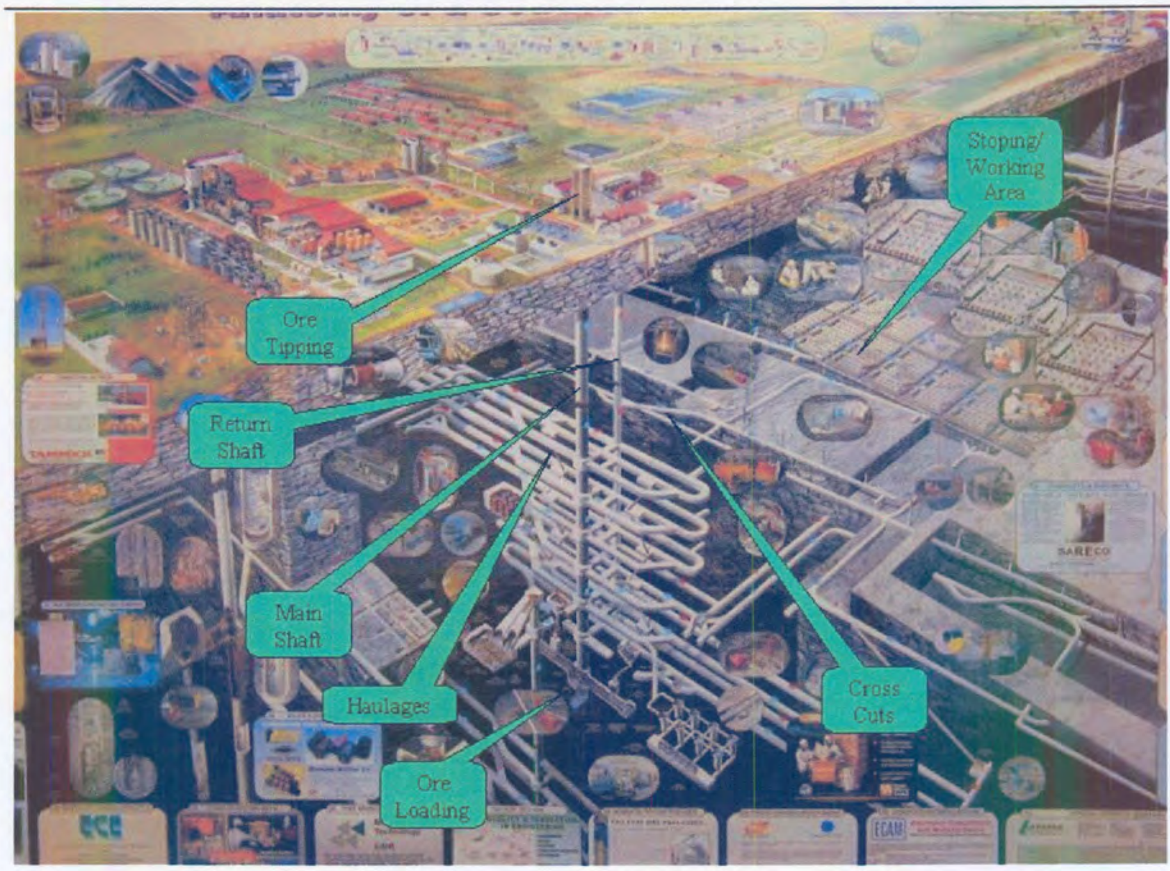

Figure 3: Three Dimensional Overview of a Deep Level Mine

3.2 Micro Process Description

This section defines the sub processes and analyses the communications needs. Refer to Figure 1, Figure 2 and Figure 3.

3.2.1 Rock Breaking

The ore bodies encountered are narrow and tabular resulting in small *stope* (working face) height. This seriously restricts access for machinery into the stope area making automation very difficult.

Currently pneumatically powered, manually operated, drills are used to drill holes for explosives. A working team in a stope consists of about 15 to 17 people split into a team leader, mining assistant, winch driver, drilling team and support team (who work behind the drillers installing support for the roof and other miscellaneous work). Anglogold has a target of installing 10 drill rigs (rigs for the mounting of drills upon and hence reducing some manual effort for labourers, additionally leading to more precise drilling) by the end of 1999. These rigs will allow the start of automation initiatives but in the short term they will only be implemented as a manually supervised system leading to increased labour efficiency, increased safety for personnel and mainly improved rock stress management and blast control. If automation initiatives become feasible then video might become a need. This would probably be fixed camera with transmission via hardwire, but a possibility exists that mobile video would be required.

Rock is blasted then pulled to the boxes (storage cavities underground) using electrical winches.

Due to the manual methods and extremely rough environment the main need is for mobile voice communications. Monitoring of equipment status, i.e. Run/Stop conditions of winches and ventilation fans, would lead to improved management of the process with benefits derived from scheduled maintenance based on duty monitoring, and also power savings due to stopping unnecessary fans.

The box is the storage cavity near the stoping area where broken rock is pulled into to wait collection by the horizontal transport. Figure 4 is explanatory regards basic layout.

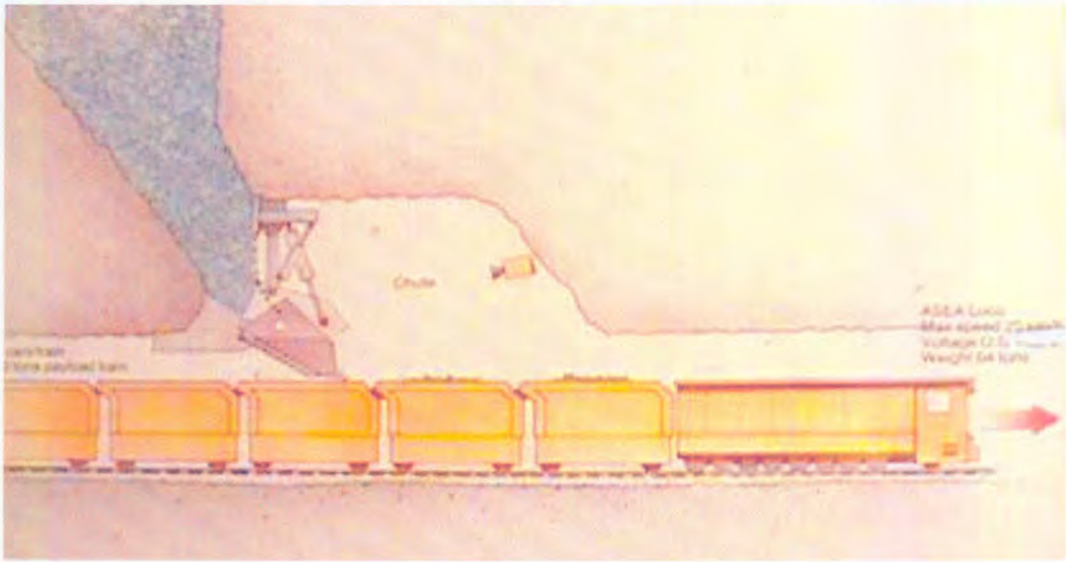

Figure 4: Typical Layout of Box

Further, in the following section it is seen that the level of boxes is required to improve the dispatching of tramming stock. The box is an extremely harsh environment to measure due to rock impact, dust and humidity/water. There are typically 100 to 200 boxes to be measured in the average mine and cost effective, robust means are important. The following means have been tried without success: laser, microwave, load cell and ultrasonic. Current thinking is for the box level to be inferred by means of measuring the activity of the winches feeding the box. This coupled with the measurement of what is taken out of the box by the tramming process described next, will give indication of remaining ore in the box. However further experimentation is required to correlate winch power consumed to rock successfully pulled into the box. This implies that winch power consumption should also be measured. These readings then need to be communicated to the central control system for interpretation. If this is implemented then there is no need for the winch status to be measured separately since power reading can infer the running status of winches as well.

In summary the needs for communications in the stope area then become mobile voice, Fan Run status, and winch power. Radio Frequency (RF) systems should have upgrade facility for video but in the short term only need cater for voice and low bandwidth data.

3.2.2 Horizontal Transport

Here underground battery operated locomotives are used to load ore from chutes under the boxes. They travel typically via single track back to tips near the shaft where their payload is discharged into the ore pass system of the mine. The ore pass is just a series of steeply inclined tunnels allowing rock to fall to the loading system where the winders operating in the main shafts draw it off.

The tipping operation is done with various methods but Figure 5 shows one and is helpful in understanding the operation.

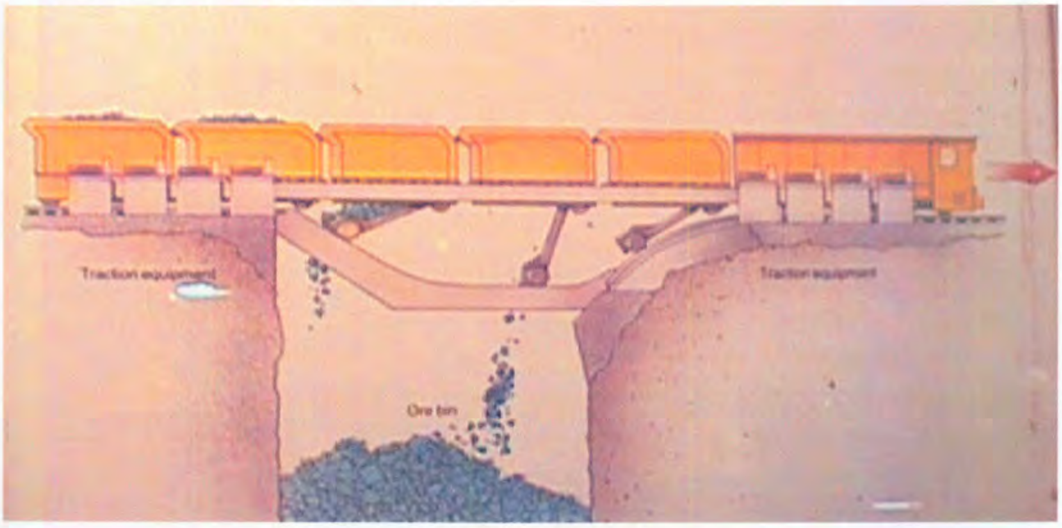

Figure 5: Tipping operation

A typical track layout plan is shown in Figure 6. This is dependent on the mine concerned but typically we have multiple locomotives competing for the use of a few tracks.

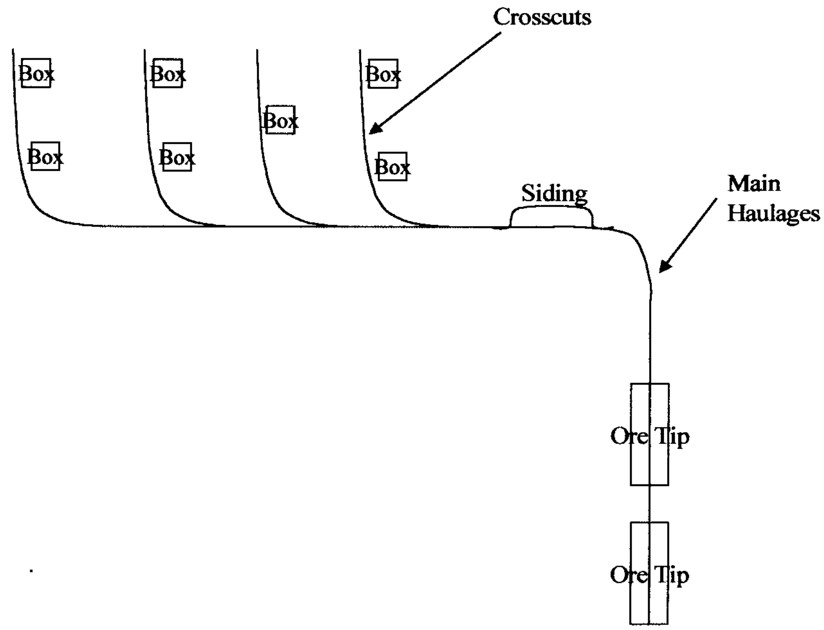

Figure 6: Typical Track Layout

Much improvement is possible in optimising the dispatch of locomotive stock to boxes that require unloading.

The current operation is very manual, but a number of automation initiatives have begun. Typically these initiatives involve a phased approach. Five levels of automation have been identified and the idea is to choose an optimum entry level and implement systems that allow growth into the more highly automated levels as working methods, and infrastructure allows. These levels are defined as follows:

- Level 1: Basic voice communications for drivers to allow them to communicate amongst themselves.
- Level 2: A centralised controller who directs assignment of trains to boxes.
- Level 3: Monitoring equipment is installed to assist the controller to know where trains are. If possible the status of main ore passes and boxes are given to the controller. This typically is presented on SCADA.
- Level 4: Expert control is implemented to begin optimising locomotive dispatch. More sophisticated algorithms are run on PC to infer ox level status. Rules bases are used to optimise locomotive assignment.

- Level 5: The tramming is made autonomous (driver-less) and the system is integrated into an Enterprise-wide Resource Planning system (ERP).

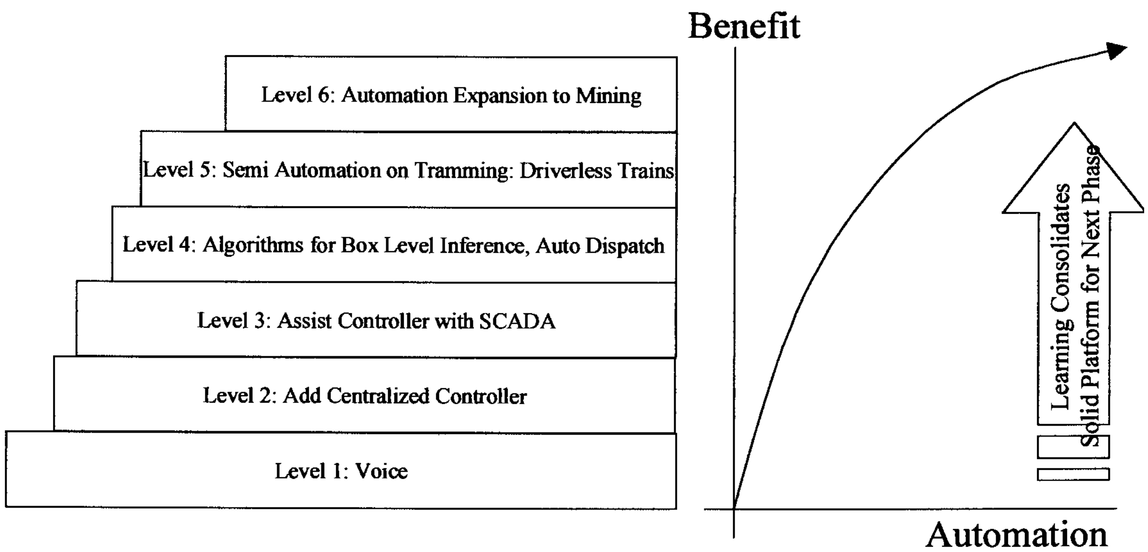

Figure 7: Phased approach for Underground Automation

Communications needs include mobile voice and low bandwidth control data, mobile video (point to point), and possibly capability of system upgrade to mobile video remote to central station control (for when level 5 automation becomes feasible). Typically level 5 requires tele-remote control from a central control centre on surface.

Another important technology within horizontal tramming is *tag reading technology*. To illustrate the need for this consider two typical uses:

- Zone control communications to locomotive control system

An option to enforce speed limits with underground locomotives is to define 'Go slow zones'. At the entry and exit points to the zone we have a 'Beacon' or RF Tag. With an on board tag reader the locomotive then picks up that it has entered a zone and according limits its own speed. Similarly the controller can deduce the exit of the zone.

The tag reader needs only to read a single tag at a time. Tags can also be used at reef and waste boxes and tips to ensure that only permitted offloading at the correct tip is done. This is achieved by interrogating the on board tag reader and deducing whether it has come from a reef or waste zone, and accordingly only permitting it to tip its load in the right tip using interlocks.

- Position reporting of locomotives

If the central traffic control system requires the position of the locomotives for monitoring purposes then this can be achieved as follows. Firstly the locomotive control unit can report which zone it is in, this being deduced by monitoring which tags it has passed. Alternatively, if a more accurate position of the locomotive is required, then an onboard navigation device can be used such as a gyroscope and once again, on polling, the position can be reported.

3.2.3 Vertical Transport

This is basically transport of rock from the ore pass system via the main rock winders up the shaft to the tips where it is stored waiting for surface transport to take it to the plants.
Winders themselves are highly automated. Loading and tipping systems are also substantially automated consisting mainly of conveyor belt control systems. The communications needs of this process are typically signalling, control data, cage (man conveyance) voice and low bandwidth data.
The transport of men, material and equipment can be viewed as a process in parallel where another winder requiring full control to all levels typically does this. Winders currently vary in degree of automation

3.3 Communication Domains Defined

Good technology management dictates that systems should be rationalised to facilitate simpler maintenance, easier integration, improved economy of scale benefits and reduced spares holding. Past practice has lead to numerous systems being implemented to service isolated automation, control, monitoring and inter-personnel communication needs. This now has to be taken into account in the form of catering for legacy systems while envisioning and moving towards an integrated, rationalised infrastructure. Currently no one system is considered to be able to service all needs, so as part of this dissertation 'Domains' have been defined and technology matched to each domain to provide a holistic solution. Each domain is discussed in detail as follows:

3.3.1 Shaft Barrel

This encompasses digital communications through the shaft. Current technology being implemented in long life mines is mainly fibre optics communications. Systems chosen have offered plug in electrical support for the major communications standards, such as RS485, Ethernet, and RS422. Voice PABX links and video networks are typically run through this backbone. Two systems showed potential to meet our needs, this was the Siemens Open Transport Network ('OTN') system and the 'Sonet Lynx' Systems. Due to slight cost advantage and a fuller range of interface cards, Anglogold has chosen the Siemens OTN technology.

Bandwidths available in this range are 36Mb, 155Mb, and 630Mb. The system is based on a network protocol similar to SDH. In fact the latest range of the system is based on SDH. An open network standard was desired for the fibre backbone but this is not totally achieved. The SDH is common to both Sonet Lynx and Siemens OTN however further compatibility is required in higher layers of the OSI model to achieve connections between nodes from competing vendors.

When it comes to the choice between multi-mode and single-mode cable, single-mode transmission equipment is more expensive but achieves greater transmission distance. The distance between nodes in the shaft backbone is however within multimode capabilities and in most case this then becomes the chosen technology.

3.3.2 Process Control Domain

This encompasses communications between PLCs and also between field instruments (including the emerging field bus standards).

The de-facto standard strongly emerging as an inter-PLC standard is TCP/IP Ethernet. Most PLC manufacturers now offer this as a network interface option.

The Fieldbus options are and will continue to be strongly influenced by the market war between Profibus[7] and Fieldbus Foundation [6]. The Fieldbus Foundation has established a standard at 31.5Kbaud termed, H1, which is also available as a bus-powered option. They are presently developing a 100Mb Ethernet option, termed H2. The latest reports show that Ethernet, as a field bus standard, might be the long-term winner as a de-facto market standard.

Technical comparisons between Profibus PA and Foundation Fieldbus (FFB) show that FFB will allow true distributed control intelligence and more flexible traffic management.

However Profibus PA currently has far more market share and many more devices are available from numerous suppliers.

The current cost per transmitter with Profibus PA is approximately R1000 more than conventional transmitters. This additional cost needs to be considered with respect to the cabling cost savings possible by installing single bus cabling as opposed to multi-core cables used to run individual loops to each instrument in conventional plants. This saving is more apparent in widely distributed plants where cabling, installation and engineering effort cost savings have been know to be in the order of 40%.

Further with FFB there is significant information that can be remotely accessed and used to optimise maintenance, resulting in cost savings due to predictive maintenance techniques as opposed to scheduled maintenance.

3.3.3 Remote Production and Environmental Monitoring

In underground mining there exist substantial networks of cable that are inferior for communications but if systems can use this infrastructure then numerous opportunities present themselves for a higher degree of production equipment monitoring. The two types of cable concerned are 3-phase power cable, and 'fire survival' cable (used for analogue, frequency multiplexing, bus powered, communications for fire detection systems underground). These cable types are particularly susceptible to noise and signal loss. The emerging standard from Echelon [12], 'Lontalk' has brought about a technology well suited for such cable infrastructure and generated a broad availability of products in the market place for users to choose from. Four systems have been installed in Anglogold mines to date, used as a technology for digital bus fire detection systems. Anglogold have a strong interest in developing this communications technology for power line born communications to collect winch status and power consumption information in stope.

3.3.4 Mobile Communications Domain

The Mobile Communications domain includes voice communications between personnel, data between mobile locomotives and base stations (in the future this is likely include video) and general data connections to mobile stations or remote fixed stations.

A fundamental choice needs to be made in underground radio systems, this being the choice between 'distributed point antenna systems' as opposed to 'leaky feeder systems' where Radio Frequency (RF) is intentionally leaked out of partially screened coaxial cable to allow a more controlled signal coverage. Problems have been encountered with the point antenna systems due to signal cancellation caused by signal reflection. This was seen during an overseas technology tour (see Section 5.1). On the other hand leaky feeder has more limited bandwidth capacity since at the higher carrier transmission frequencies (High UHF) it becomes impractical to design suitable leaky feeder cable. Some research and success has been found for leaky feeder attenuation characteristics ([1], [2] and [3]). Further a RF transmission level model was done for both stope and haulage conditions as discussed in section 6.2. Currently leaky feeder systems offer the most cost effective coverage of our underground tunnel networks for voice service. However leaky feeder has insufficient capacity to carry real time video for tele-remote operation of tramming stock. Further R&D is planned on this and will involve partnerships with suppliers in attempting to prove current claimed capacity and develop future video ability. This R&D is referred to in the final sections of this dissertation.

Tetra is an emerging digital protocol standard and would offer a widely accepted platform for vendors to develop on achieving interoperability. Unfortunately this standard offers no frequency in the VHF range, the frequency most common mining systems work at. It is also prohibitively expensive at this stage.

3.4 Specific Need Areas

This section groups the needs into areas for satisfaction by the final system solution.

3.4.1 Video

The main areas of video need are as follows:

- Monitoring video at winder shaft stations.

  Shaft stations are the places where people wait to board the conveyance pulled by the winder. Personnel on surface would like to monitor what is happening at the winder stations on every level. It is required to supervise that no unsafe activities are happening close to the shaft underground and also for security reasons, in case of labour unrest.

- Box chutes monitoring

  Boxes, as previously explained, are where the rock is stored once pulled out of the stope. The locomotives arrive at the chute to load the trains with rock. The drivers do this by manually operating the feed chutes at the box. With the imminence of driverless trains it is expected that personnel in a control room will operate the train by tele-remote control and remote control this loading function. Hence a future need of video is control quality video at every box chute. There are approximately 20 active box chutes per active level, and 5 active levels per mine. This implies that there are approximately 100 video cameras required in daisy chain configurations of 3 per crosscut

- Mobile video for locomotives

As automation initiatives progress it is expected that we will reach a point where operators based in control rooms must remotely control some trains. For this we require mobile RF video, of quality sufficient for control purposes.

3.4.2 Voice

The main areas of voice need are as follows:

- Voice coverage in stope

It is necessary to have two-way communications with key personnel at the stope face (refer to Figure 17 - page 55, and Figure 18 , for a diagram of the layout).

- Voice coverage in the haulage

This is mainly required for communication between and to locomotive drivers.

- In the shaft

This is primarily for maintenance personnel during inspections of the shaft. Additionally voice communications are required to persons on the conveyances during emergencies. This has not been included in the needs summary (Table 1) since it is a specialised system at this stage, delivered with the winder system.

3.4.3 Data

Data needs are extensive and are primarily addressed in the process control domain and the rugged medium domain. These needs can be classified as follows:

- Utility management

This monitoring information is mainly from utility systems monitored in the process control domain

- In stope data

Communications need to be development to capture status information of winches, ventilation fans, box levels

- Locomotive monitoring and automation

Presently data communications between locomotives and central control is necessary to track locomotives. In the future the data will be for remote control of locomotives

- Material tracking

An enormous amount of material is delivered to the work face daily. This is by means of loading this on surface on material cars (rail bound), and then scheduled delivery to the respective level during the material pulling shift and then delivery for the station to the workings after that. A means of recording what is loaded on the cars and then tracking cars individually to the workplace entry is required. Although this is a specific need it is not included in the needs summary table (Table 1) since RF tag reading is a specialised subject considered beyond the boundary of this dissertation (i.e. not backbone). The tag reader itself will need to comply with the backbone standard (most likely an Ethernet standard) and will plug in as the communications engineer sees fit.

- Asset tracking

Some items are of enough value or importance to merit having a permanent RF tag attached to them and then a tracking system is required, similar to the material tracking system, which will track where these assets have been delivered. This is also not included in the needs table for the same reason that material tracking was not.

Table 1: Communications Needs Summary

COMMS NEEDS		Video	Video	Video	Voice	Voice	Ctl Data	Mon & Ctl Data	Mon & Ctl Data	PDA LAN
		Shaft	Boxholes	Locos	Locos	Stope	Locos	Utility	Stope	ALL
Mines:	Long Term	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Medium Term	✓		✓		✓	✓	✓		
	Short Term							✓		

4 ENGINEERING MANAGEMENT ISSUES

4.1 Return on Investment Evaluation

The cost and benefit of a system such as a communications system is difficult to evaluate and must be looked at from a number of different aspects. Primarily the return on investment is the total benefit generated from the system after the 'Total Cost of Ownership' is taken into account. The best way to evaluate this is to use the method of Internal Rate of Return ([13]- IRR). In the following sections the total cost of ownership is detailed, followed by an evaluation of benefits. Then the IRR of typical scenarios are discussed. Reference is made to the benefits and cost analysis in appendix A. 7.

4.1.1 Total Cost of Ownership

The total cost of ownership is made up of three parts, the capital cost, the maintenance part and the replacement cost. These need to be slotted into the IRR analysis to evaluate their impact. They are now discussed in turn.

a. Capital Cost

This cost is the total project cost including equipment, engineering and installation components. In the case of Anglogold mining operation this is evaluated as a typical cost per mining level and then expanded to the typical number of working levels there are in a mine and further expanded to a total cost for all mines in the Anglogold South African Operations. This then becomes the total project capital investment necessary to equip all major levels in all mines in Anglogold South African Operations (a significant system – probably the largest deep level underground mining coverage area in the world)

The system budget that was done was made at a more extravagant figure than conservative. During analysis it was seen that there was large benefit values and that extremely attractive IRR figures were achievable even with pessimistic forecasts. It is difficult to estimate prices on these systems but a good feel for pricing has been gained through a number of exercises recently done in Anglogold. Prices are at times speculative since some of the systems are based on technologies in the development part of the technology maturity curve.

b. Maintenance Cost

The maintenance or running cost is made up primarily of skilled labour and spares cost. In this analysis this is calculated per level and per mine as in the capital cost calculation, and this expanded to the total Anglogold needs. Figures for skilled labour are generously estimated in the analysis leading to a conservative estimation on IRR. Spares requirements for the system are based on a percentage of the capital cost per year.

c. Replacement Cost

Eventually the system will outgrow its market support. It will reach a stage when spares become expensive or not available. Additionally technology would grow and mature to a stage where increased functionality or capacity starts to make an upgraded system look attractive. The analysis takes this into account by making a provision for new system after 5 years and increasing the benefit achievable from new functionality on a percentage basis (discussed later).

4.1.2 Benefits Analysis

The mining operations front is where the business is most susceptible to loss of revenue due to the inability to achieve the blasting of panels. The mining team in the stope is dependent on four supporting factors which all must be in place before they can do a blast and the sub-optimal management of these are the root causes for blasts which could not be achieved. A lost blast means that there is less gold available at the end of the month and from a business perspective then lost revenue.

- **Labour**

A typical team consists of a drilling sub team (who drill the panel/face) and a stope cleaning sub-team (who clean the area and put in support packs). At times the cleaning team are available to assist in other panels where problems might occur. This dynamic assignment of labour can lead to the reduction of 'lost blasts'. A good qualitative estimate is that 20% of total lost blasts could be avoided if a communications system was implemented, together with innovative management practice, for this type of dynamic and flexible labour gang use..

- **Services (Utilities)**

The mining team is dependent on the good quality supply of drilling water, compressed air and electrical power. Many times if there are problems in this supply the quick communication to the responsible person could avoid a lost blast. A good qualitative estimate is that 5% of total lost blasts could be avoided if a communications system was implemented allow quicker problem solving.

- **Material**

The mining team is also dependent on receiving consumable items such as wooden packs for support, on time. By the implementation of a communications system it is estimated that 10% of total lost blasts could be avoided.

- **Equipment**

Similarly for delivery/supply of equipment such as winches etc..., a good qualitative assessment of avoidable lost blasts is 5%.

This totals to 40% of lost blasts that could be avoided with decent communications systems and the necessary management practice to control. This can be translated according to two strategies:

a. Labour Cutting Strategy

The calculations show that increasing revenue is more attractive than cutting labour.

b. Production Increase Strategy

Calculations in Appendix A. 7 show that benefits are approximately R670 million to Anglogold a year. This translates to an Internal Return on Investment (IRR - [13]) of about 160%, and a payback period of less than 8 months, a very attractive prospect for any business.

4.1.3 Factors Affecting Cost of Ownership

Firstly the longer a system lasts the less expensive its cost of ownership is. This needs to be considered in relation to the length of service that the system can be retained for. A number of factors determine the length of service. These are discussed in turn:

a. Suppliers support

Often support for a system ceases when market demand for the new such systems ceases. Reputable suppliers do commit to provide spares for a system after replacing the system with a new version/model. Additionally the supplier may provide an upgrade option or an "Old Technology Buy Back" option. These supplier approaches are vital to consider when evaluating potential suppliers for new systems.

There reaches a point where spares cost becomes excessive when considered in relation to a reducing system life of the current system. The impact on the IRR of the system needs to be taken into account when deciding on replacement systems. With the substantial benefits available with these systems, replacement cost does not impact much on IRR, hence it is better to ensure system availability and reliability considering the high cost of downtime.

b. Functionality delivery

As technology grows so does the functionality of new systems on the market as compared to the existing systems. There comes a point when it makes financial sense to upgrade the system.

c. Capacity for expansion

A communications system is a good example of the wisdom of considering future need up-front. A lot of times people, when seeing the good that comes from communications, increase their requirements after system implementation. A full needs analysis is required before system specification.

4.1.4 Factors Affecting Benefit Delivery

It is sometimes extreme speculation to estimate monetary benefit of a communications system since its final benefit delivery is often due not only to the presence of the communications system, but rather in using it as a tool supporting a greater effort at improving a process efficiency or capacity. The communications system becomes the catalyst to supporting initiatives leading to improved system management. It can become the empowering tool for the work team allowing them to make better decisions or shortcut normal delays caused by the lack of communications. This implies that it is not solely dependent on the communications system for realisation of benefit but also on initiative and innovation of management practice empowered by the communications system. To provide for this element the concept of risk (in achieving this benefit) needs to be used. This leads to the concept of Potential Value Add (PVA) for a system. One can never really guarantee that improved communications will realise the PVA, so a measure of confidence needs to be given.

Factors affecting the follow through from the management team can be greatly enhanced by following a few principles. Referring to the recommended project management process (Figure 8 on page 22), it is critical to get the following aspects correct for proper "buy in" from the client (production management team). These include the following

- Involvement of the production team in the project - discussed later
- Actively addressing the fear of automation as a threat to jobs

Automation and job enhancing technology such as communications systems should rather be looked at as opportunity generators than job threats. With improved efficiency work teams can mine previously unplayable ground. This approach must be actively marketed before and during projects.

- Creating total dependence on the system

  New technology systems often fail when implemented since people cling to the old ways. When implementing a new technology system such as a communications system one should immediately enforce dependence on the system. In this way the people fix problems rather than bypassing problems.

4.2 Project Management of Communications System Projects

A project management process, tailored for communications system type projects, is proposed in Figure 8. This is now explained in the following paragraphs step by step. Project management practice should be made up of other components such as cost management and planning, but the aim of this dissertation is to explore the unique aspects of the approach for communications systems. As such this is discussed in the following few sections with emphasise on the aspects most important from a communications system viewpoint

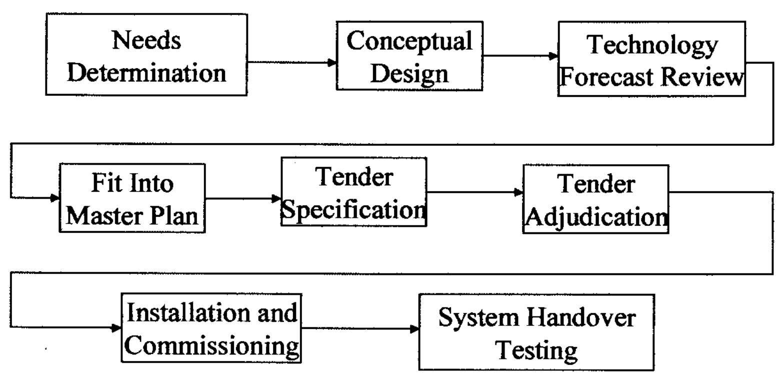

Figure 8: Recommended Project Management Process

4.2.1 Needs Determination

The needs determinations must be done for all disciplines and processes. The best way for this is to hold a workshop with role-players. Facilitating such a workshop is a demanding task since you must not only listen to needs but also sketch a vision of a future system. You must understand the business process, where the gaps are, and realise the potential of the technology. Then marry these to capture everyone's current and potential needs.

The objective is to group needs so that these could be serviced by a rationalised number of communication systems.

4.2.2 Conceptual Design

This is really a 'big picture' documentation of the envisaged solution. It considers system protocols, standards, hardware platforms, network nodes and entities, information transfer, and interface strategies. The documentation of this details systems, interfaces and services.

4.2.3 Technology Forecast Review

Technology forecasting is a continuous process and normally done by a few experts in the field. What is preferred is to identify which technologies need matching and then to formalise viewpoints with the compilation of 'contemplative stances'. It then becomes a formality to involve the key technical experts at this point to debate the conceptual design and align this with their forecast (contemplative stances) of where the industry standards and technologies are headed. This can have substantial impact on lengthening prospective system life and capturing current technology features available.

4.2.4 Master Plan Fit

A key concept to Anglogold in the controls for communications engineering is to have master plans per business unit. Once the conceptual design is complete it needs to be formally incorporated into the master plan, approved and implemented. This control measure is vital to avoid the haphazard proliferation of small communications systems into the organisation.

4.2.5 Tender Specification and Adjudication

The tender specification is normally a more detailed version of the conceptual design. In the mining industry a major portion of the communications system detail design is left to the external supplier. It is desirable to stimulate pricing and quality competition between suppliers, but depending on technology maturity there might be insufficient suppliers of the technology for adequate competition. In that case it is preferred to approach the supplier directly and negotiate the specifications of the system. In some case to even agree on a reasonable and fair profit for the supplier. The advantage of this is that a better-fit system solution is obtained, flexible to any changing needs from the mine.

4.2.6 Installation and Commissioning

Installation in the underground environment is often difficult for the supplier so it is best for mine personnel to install cabling under the specification of the supplier, then for the supplier to install electronic equipment and configure and commission equipment. Performance tests are necessary to be done to quantify system operation. Typical tests are reception coverage tests for radio systems, data rate throughput and data package error rates for data systems. Also interface between systems needs to be thoroughly tested.

4.2.7 System Handover

Finally handover to the client occurs. The client in this case is the operational staff of the business unit. It is important to get formal client acceptance even with a "punch list" of outstanding items. The objective is for the client to take ownership of the system.

4.3 Technology Management Strategy for Anglogold Communication

4.3.1 Existing Problems

In the past we have found that when operations personnel have required a system involving communications then they have bought these without any thought to the macro communications picture. This ends up in causing numerous problems when it comes to managing the communications system later. Downtime and expansion constraints become issues that cause major production or production opportunity loss. As will be seen later the returns on investment on communications systems are tremendous but consequently the loss during downtime is also high so these issues must be carefully considered during the engineering phase.

Further some of the main value adding opportunities are expected to come from the general information enablement derived from the availability of all these measured statuses. To capture this the integration of all the systems is critical and this will only be possible with planned communications engineering.

4.3.2 Communications Plans

In the same way that the mine's high voltage reticulation is planned, so too should our communications systems. Through our 'Best Practice Reviews' (discussed in that section), we are now implementing communications plans for each business unit. There will be a plan for each domain. There will also be a communications champion appointed by senior management who will take responsibility for these plans, and no system will be permitted to be purchased before approval is received from this communications champion. This champion will actively solicit the input from all disciplines and process managers at the business unit, identifying future communications needs and obtaining "buy in" from key stakeholders to these communications plans.

4.3.3 CIC Best Practice reviews

Further to the communications plans a system has now been implemented in Anglogold where on a bi-monthly basis business units present their CIC practices and receive constructive criticism and rating from a panel of their peers from other business units. With the dynamic nature of communications technology this method of regular practice review is suitable to continually ensure that best practice and optimum technology is used in the communications systems of the business unit. As part of this review the communications champion presents his communications plans to the group and in this way the champions are stimulated to track technologies and needs closely.

The first best practice reviews have been held and an example of the results in shown in Figure 9.

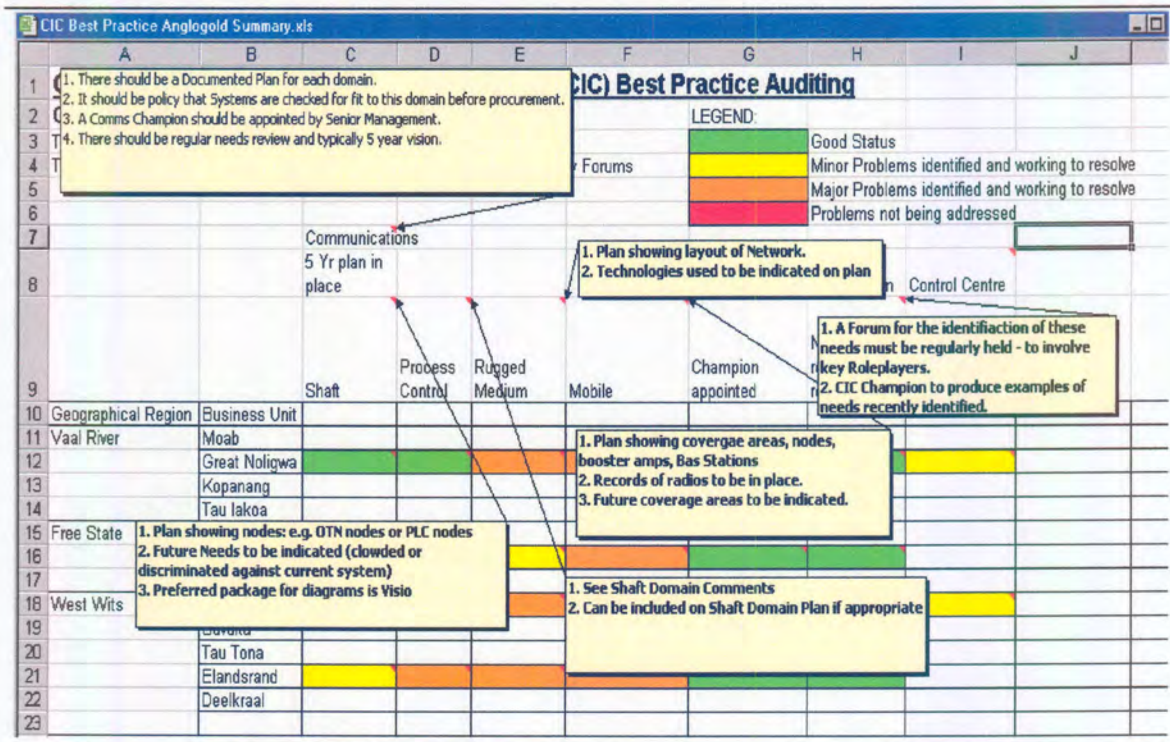

Figure 9: Example of Best Practice Audit

The best practice audit is done according to criteria that are dynamically updated, and leads to a continual improvement in standards, a method appropriate to the dynamic technology scenario on communications.

4.4 Communication System Life Cycle Management

Integrating the concepts discussed above we arrive at the model in Figure 10. The key to communications systems management is to continually review needs and technology. In the process the networked professionals review current systems in the Best Practice reviews. Business units, facilitated by the CIC champion, review future needs in formal forums. A project can be initiated from either source. The networked professionals additionally keep a watching brief on identified key technologies. The resulting 'contemplative stances' are used in the technology reviews during the project process.

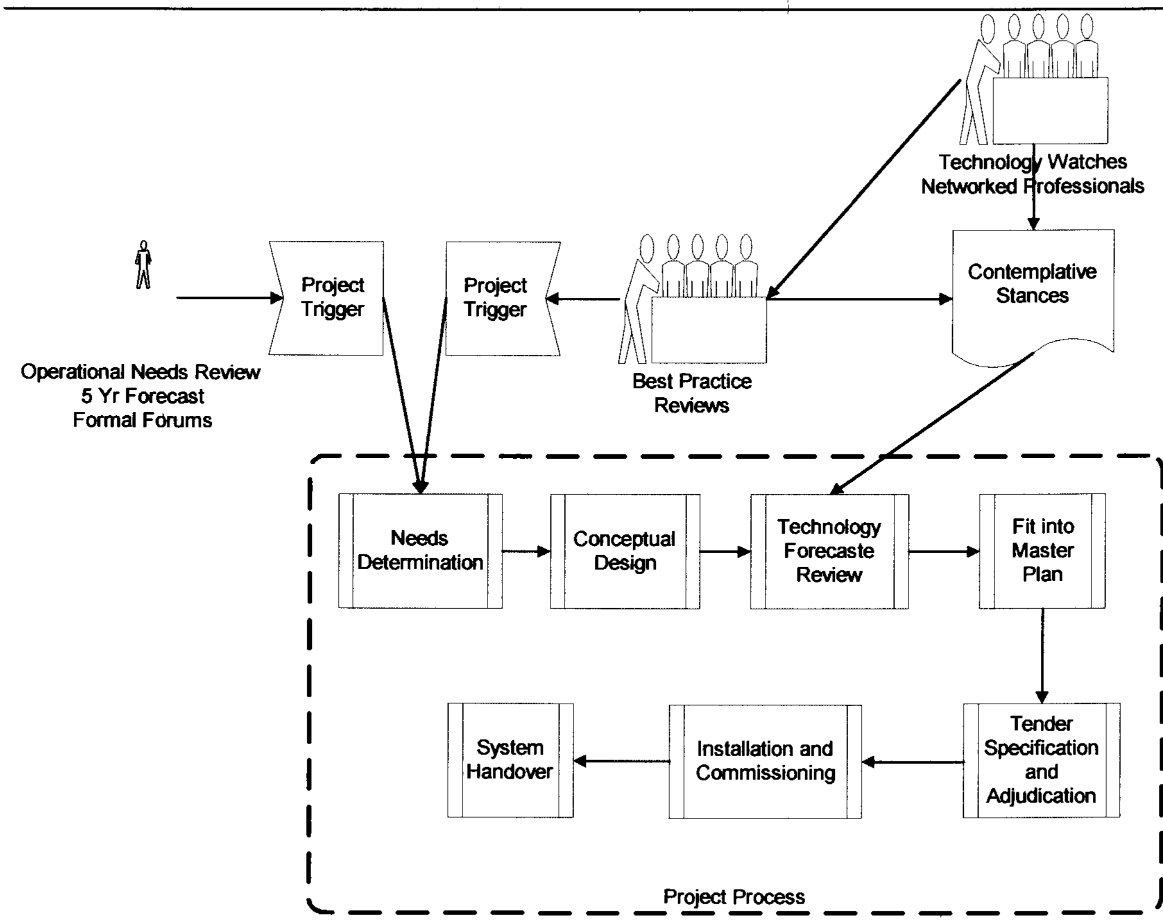

Figure 10: Communications System Lifecycle Management

5 TECHNOLOGY ANALYSIS

5.1 Review of Automation Approach Trends Internationally

An overseas trip was undertaken specifically to evaluate approaches and trends in automation and communications systems. The places visited, together with brief detail on the motivation for each visit, is given below:

- The UK Underground Railway Systems

  More specifically we visited the recent rail system expansion at Heathrow Airport to evaluate technologies used to communicate with high-speed trains and for use with maintenance and rescue staff in tunnels.

- LKAB Kiruna mine in Sweden

  This was to evaluate their high degree of Automation and Digital high bandwidth communications infrastructure. LKAB are world leaders in autonomous Trackless drilling and Rail bound autonomous tramming.

- Modular mining in Tucson Arizona

  Modular Mining is an automation company specialising on automatic traffic despatch systems for large surface vehicles. They are expanding to offer similar systems for underground tramming applications and are suppliers for two major tramming management systems installed in Anglogold mines. The visit was primarily to discuss the next generation of communication backbones for their future systems.

- Echelon Development Centres in Los Angeles

  This was to evaluate future trends on Echelon communications technology, a communications protocol we are using to enable data communications across bad quality cable such as the Fire detection cables and power lines.

- Noranda Technology Centre, and the STAS company in Montreal, Canada

  Noranda are a technology development centre for a group of base metal mines. The prime purpose of this visit was to review Noranda's successful technology development methodology that develops required technology from concept to commercialisation. STAS is the commercialisation partner company for Noranda.

- Inco Mining and the El-Equip company in Sudbury, Canada

  This was to discuss future leaky feeder radio system developments with El-Equip, suppliers of our two biggest leaky feeder systems at our Great Noligwa and Kopanang mines respectively. The visit included a visit to Stoby mine where Inco Mining have installed autonomous trackless LHD vehicles navigated by 'Light ropes'.

The main trends found in approaches to automation are discussed in the following points.

- Technology Transfer

  On of the main problems encountered in successfully transferring developed technology to the production/operations environment is the production team taking ownership after the handover of the project. A key approach taken by mines must be for them to appoint a champion in the production environment to push the technology into successful operation as soon as possible. This champion must be involved at project conceptual design phase.

  Another problem is benefit estimation and the realisation of this benefit for technology projects such as communications and automation. We find ourselves qualitatively guessing benefits rather than quantitatively calculating these. The overseas mines have a greater labour cost and hence it is easier to justify automation and labour productivity initiatives.

  An approach proposed is the phased implementation of the successive levels of technology sophistication. This is outlaid in Appendix A. 8.

- Communications Backbones

  Overseas R&D is generally done on the latest communications technology (such as Kiruna mine who implemented full blown ATM), or on proprietary protocols when the development is abdicated to commercialisation partners. At the stage of R&D technology trends are not normally considered and this is an issue we believe important in our deep level mining industry.

- R&D and Commercialisation

  The approach worldwide is to do R&D in-house where concept and design are proved, and then develop technology commercialisation partners to get the product to market. This is a good approach as it is not in a Mining House's interest to make money out of selling the technology but rather using it innovatively to improve production efficiency or increase output.

Resulting from this visit we put out a standpoint for automation (appendix A. 8), which was primarily centred on the horizontal transport where we had a production bottleneck at the time.

5.2 Key Characteristics of Market Technologies

This section discusses what are considered to be desirable qualities or aspects to be considered when choosing or engineering communications systems.

5.2.1 Determinism

This is the ability of the communications system to provide a communications service in a predetermined time. This is important with systems that cannot withstand a delay outside certain limits. For instance voice connection quality is reduced when delay is introduced. The accepted sampling period for voice is 125μs. If the discrete levels of voice are represented with 8 bits (256 discrete levels) then this translated to data bandwidth becomes 64Kbps. However if 64Kbps is allocated alone to the voice channel then full determination is required. Techniques such as Streaming have been developed to allow networks with intermittent peak loading to deliver the required data stream in low periods and play this back as a stream. Similar techniques have been applied to video transmission to overcome lack of determinism in networks. Video bandwidth is similarly quantified in section 5.6.

Control critical data can require guaranteed transmission within a certain time. Considering the OSI 7 layer model, each layer must be built to provide this determinism. For instance the medium access method of CSMA/CD used by typical Ethernet hardware is detrimental to determinism. Care must be taken not to allow too many devices on an Ethernet Network since competition for airtime can seriously effect time delay sensitive equipment. The delays that are tolerable in an Ethernet network are quantified to a degree in section 5.3.1.

5.2.2 Redundancy

Redundancy is the provision of alternative communications paths or equipment that can be used immediately on failure of the in-service path. Depending on the criticality of the control of the process, a risk assessment needs to be made through which it should be decided whether the expense of designing in redundancy is financially attractive.

5.2.3 Bandwidth

This is the effective rate the data is transferred at. It is different to the communications rate since an overhead is needed according to the protocol used.

5.2.4 Supported Mediums

In the mine environment the communications infrastructure is normally comprised of different types of media, i.e. UTP, fibre optic, power lines and radio. The ability of a communications system to transmit over multiple media is important since this allows us to have one system integrated over multiple media. This leads to simpler maintenance and system management.

5.2.5 Multi-Media Communications

Medium refers to the type of information transported, i.e. is it voice, management information data, control data or video. It is sometimes difficult to incorporate all these into one communications system since each has different transmission quality and interface needs, and making one system to solve all of these is sometimes extremely expensive. On the other hand if multiple needs are combined then one can afford to spend more money on a quality system as opposed to buying many smaller systems. Effectively this is achieving an economy of scale by combining needs.

5.2.6 Topology Allowed

Essentially this describes the network connection arrangement. It is necessary to ensure that your serviced points/nodes can be suitably reached with the topologies supported by the system.

Typical topologies are bus, tree, hub/tree, ring and star. The topology chosen is often influenced by the physical layout of the stations. For a mine the most suitable topology is a combination of bus and hub/tree.

5.2.7 Interoperability

Interoperability is a measure of a technology's ability to interface with other technologies. From another aspect it is the property of the engineered system that allows multi-vendor equipment implementation. With a multi-vendor environment, market competition from suppliers leads to lower prices, better support and better quality. Resultant manufacturing volumes lead to economy of scale, and system life is extended due to continuous market support.

To achieve interoperability one needs to define protocol and hardware interface standards. The larger the acceptance of the standards, the better the chance of achieving interoperability. Standards should preferably be developed by a non-product biased workgroup with wide representation. At times suppliers can achieve such a degree of market acceptance that their standard, as long as it is open, can become the *De-facto* standard.

One tends to be overwhelmed with the claims to openness from suppliers. There are essentially only three levels of interoperability that benefit the user. These offer increasing value to the user and are listed as follows:

- Proprietary systems

  These systems are prevalent in emerging technologies where companies tend to implement systems without disclosure regards protocols and hardware platform standards. This has no potential for the evolution towards a vendor independent system. This interoperability benefits are taken as the zero base.

- Physical layer compatibility

  With systems that can share the same physical medium the benefit becomes cost savings due to rationalised physical infrastructure.

- Peer interoperability

  At this level of interoperability the systems can communicate with each other to exchange process information. Typically point to point connections can be made to exchange data between equipment of different vendor origin. Standards at this stage should have been published and formally accepted internationally. This is the level of interoperability that the seven layer OSI model hopes to achieve. The value that this adds for the user begins to show itself by supporting the information enabled environment sought after by new generation business management.

- Full interoperability

  Here interoperability even extends into the application layer of the OSI model. Typical examples of this full interoperability are when the system nodes can be managed fully with respect to internal diagnostics, remote configuration and dynamic configuration when nodes are plugged into the system. All this functionality must be achievable independent of which vendor supplies which equipment. The benefits realised here are simpler engineering and system management complexity, leading to even more information enabled business decisions.

5.3 Emerging Standards

5.3.1 Ethernet and TCP/IP

Ethernet is derived from the computer communications industry. It helps to examine the standards background in this industry. There are 3 main international bodies that have driven the standards:

- International Standards Organisation (ISO)
- Institute of Electrical and Electronic Engineers (IEEE)
- International Telecommunications Union (ITU-T)
  Formally called the CCITT.

Essentially the ISO and IEEE produce Computer Communications Standards and the ITU-T produce standards related to Public Switched Networks. There is substantial cooperation between the organisations.

In addition to this the United States Department of Defence funded research into computer communications through the Defence Advanced Research Projects Agency (DARPA). This led to the interfacing of many computers from a large number of universities into an inter-network known as ARPNET, finally to evolve into the well known Internet. Subsequently the Internet protocol suite was establish, known as Transmission Control Protocol/Internet Protocol (TCP/IP)

The world has adopted Ethernet TCP/IP as a major standard. Ethernet card prices have dropped tremendously illustrating the benefits of buying technology with wide market share. Video and voice are already carried on this standard and any limitations in terms of determinism problems due to media access methods are being overcome by over designs in network speed capacity. Studies done show that a 10Mbps network running at 2Mbps loading can be depended on to have a 50ms maximum delay [14]. Extending this to a 100Mbps (10 times the speed) and to 30% loading it is reasonable to assume that communications delay will be better than 20ms (The benchmark PLC algorithm delay for mining process control). The figure already mentioned as reasonable for deterministic response within an Ethernet network is 30% loading, and extending this study supports the figure.

Most PLC manufacturers have Ethernet TCP/IP as a standard interface. This seems to be a standard that is here to stay and is the most unifying communications technology today especially at LAN and multimedia levels.

More detail on the technical issues around Ethernet can be found in the Appendix A. 2
Future developments in this field are expected to be Gigabit Ethernet for Network switching, and IP version 6 which will cater for multimedia COS requirements

5.3.2 Hi-Speed Broadband Networks

There are a number of technologies to cater for mixed media signals, i.e. data, video and voice. However when looking at the market the main competing technologies are:
FDDI II, ATM, Siemens OTN, and SDH
The main technical points of these are discussed in Appendix A. 1 and the technology trend forecast curves are shown in Figure 11 on page 42.
The main domain this technology is applicable to is the Shaft Backbone domain. When looking at the needs of this domain a full ATM solution is an overkill since most connection points are point-to-point traffic without complicated switching requirements as delivered by ATM. Technology seems to be converging on ATM as a universal broadband solution but this is taking longer than expected and when the prices of ATM drop to the levels of OTN then this will be a very attractive solution.
Siemens OTN solutions offered a full range of interface cards for the mines' needs (mainly RS485 and RS 232 etc..) while the competing SDH and FDDI solutions were slightly more expensive and did not offer the full range of Interface cards. Siemens OTN now offers their same system with optional SDH cards. This does move somewhat to interconnectivity and vendor independence but further standardisation is required in other portions of the OTN before full "Plug and Play" interconnectivity is achieved.

5.3.3 Fieldbus

Fieldbus essentially replaces the old analogue 4-20mA standard (refer to Figure 31: Profibus PA comparison to 4-20mA conventional standard on page 91 for a look at how the field equipment requirements are reduced). It is a network between field input and output devices (I/O) which allows the transfer of information such as an analogue value of a measured parameter (e.g. a level, temperature etc..).
The special requirements for a network technology specifically for field I/O devices are summarised as follows:

- Suitable power supply arrangements. Typically the more developed bus technologies offer power off the same wires that carry the data stream. In this way the cabling to each device is reduced (one cable instead of separate signal and power supply cables).

There are a number of ways to carry this power on the same wires as the communications signal. The IEC1158 physical layer standard effectively transmits the signal by controlling loop current. Power for the device is taken off this loop current in the high periods. Many times the power supply requirements determine the transmission distance limitations. When instrument power is too high to supply by the integral communications cable then a separate power supply is taken to the instrument (e.g. magnetic flow meters, valves etc..)

- Deterministic Response: The transmission of a value must be guaranteed to ensure control loop integrity. Most field bus technologies/standards implement a synchronous type of communications protocol where each device is allocated time space in the data cycle. In this way a device is guaranteed adequate communications space all the time. The emergent Ethernet standard is an exception to this. Ethernet is a Collision Detect type of Media Access. Hence devices compete for the use of the bus. The logic in this case however is that with the high bandwidth Ethernet options available today one can afford to significantly under schedule communications on an Ethernet network and hence effectively allow communications space to devices when required. In effect determinism is practically achieved by the oversupply of bandwidth.

There are a number of different field buses available on today's market. Numerous comparisons on technical criteria have been done and some of these are available on the Internet (references [15], [16], and [17]). Some of the more prominent ones are:

- Ethernet

Discussed in detail in the rest of this dissertation.

- Fieldbus Foundation

Discussed in detail in the rest of this dissertation.

- Profibus

Discussed in detail in the rest of this dissertation.

- Modbus (and Modbus Plus)

Process Automation, typically derived from Modicon PLC environment

- ControlNet and DeviceNet

ControlNet is a bus technology that handles both the real time deterministic demands of control traffic, as well as the system management non-deterministic traffic demands such as PLC monitoring and programming. The technology is based on a 'Producer

Consumer' model allowing peer to peer communications and multicast type transactions. The technology is particularly suited to analogue I/O transmission. It is derived primarily from the Alan Bradley PLC environment. Future developments are that ControlNet would be encapsulated in TCP/IP Ethernet, and progress in conformance testing.

DeviceNet is a technology intended for use for the connection of discrete field I/O, mainly used by the manufacturing industry. CAN bus is based on the 'Producer Consumer' model. The message length is 0 to 8 bytes ideal for low-end devices.

- Interbus

This technology is primarily for process, factory and process automation.

- AS-Interface (Asi) bus

A bus developed in 1990 as an alternative for hard wiring of binary field devices. ASi has been accepted as part of the EN50295 international standard, attaining recognition as a vendor independent standard. ASi is particularly suited to digital I/O and is a bus-powered technology. The system is Master/Slave configuration with only 4 bit cycles per device, achieving only 5ms cycle time, well within most PLC determinism requirements. The topology is typically conventional tree structure and includes line, star and ring configurations. Limits are 31 devices per segment with a maximum of 124 I/O. Current development expectations are an increase in capacity, both nodes and I/O is imminent, as well as enhancements for handling analogue I/O, and improved diagnostics.

- Hart Protocol

A signal protocol implemented on top of the analogue 4-20mA signal and decoded at the receiving end. Primarily used for process automation. Hart has the most market share world wide of pressure transmitters [16]. It does not capture cabling savings advantages since it still requires cabling per analogue I/O. However it can be relatively implemented on existing analogue I/O transmitters by replacement or upgrade of the transmitter units, avoiding the need to re-cable the installation.

- CANbus

Originally developed by Bosch in the mid 1980s this bus is mainly used on vehicle on-board bus applications. It is a bus powered technology and really only defines the data link and physical layers. Further standardisation is achieved with the higher-level protocol (HLP) and this is used to implement the communications systems management functionality. HLP has also been used on top of DeviceNet as well as other similar standards.

- LonTalk

A bus technology particularly suited for inferior medium cables. Derived initially from the building industry and used for power line borne communications. This technology implements full seven layer ISO functionality, and provides connection orientated communications service depending on the connection class chosen. The strength this technology has is the ability for it to be implemented on different mediums and the amazing freedom one has with putting down network topologies, to the extent of achieving loop back redundancy fairly easily. The Lonmark Association [12] is the conformance and interoperability certifying authority worldwide. Echelon is the product development company primarily driving the core component developments and these are often marketed under the name of Lonworks products.

There are significant benefits to be realised by implementation of a fieldbus and these are considered in turn (Some of these were taken from the reference [18]).

- Installation and maintenance benefits: A Profibus design and installation done by the Anglo American Technical Design Offices estimated realised benefits from fieldbus to be approximately 40% of control and instrumentation project cost, a significant amount of money. Further the article "Dawning of the Digital Age for Process Control", written by Ian Verhappen [16], cites possible cost impacts of up to 41% savings in terms of installation and engineering cost for fieldbus systems as opposed to conventional analogue systems. The bus allows wiring of field and control devices onto a single pair of wires. This means less:
  - Wiring (cables and cores), panels (e.g. marshalling cabinets), junction boxes
  - I/O and control equip (including card slots, power supplies)
  - Design effort and planning requirements
  - Ease of maintenance and reconfiguration
- You can remotely access parameters and set-up the installation.
    - With the additional information available via the bus, predictive maintenance as opposed to scheduled maintenance can be implemented. This leads to optimum maintenance (less and better quality). An example is maintenance on a valve according to the number of operations it has completed.

- Quality Benefits:
  - Better accuracy of the signal

    A conventional 4-20mA standard relies on two aspects which impact on signal accuracy:
    - In conventional systems the signal is converted from its process value to a representation on the 4 to 20mA scale via an analogue conversion stage. This has certain zero (offset) and span inaccuracy. At the receiving end the 4-20mA signal is converted to a digital representation incurring similar zero and span inaccuracy. With a fieldbus system the analogue conversion stages are reduced and hence span and zero errors.
    - The signal is typically sent a significant distance in 4-20mA form with some inaccuracy introduced by cable capacitance. Although with small signal variation this effect is minimal. With a digital signal the value is represented discretely along the transmission path between device and control room and eliminates this potential source of inaccuracy.
- Distributed Control
    - Some fieldbus technologies provide for a substantial processor on board the field device. This coupled with the communications functionality available from the bus system allows peer devices to take on control functions/algorithms in the field. An example of this is the Fieldbus Foundation technology. Distributing the control functions this way now opens up a great number of options in where one can put the control algorithms. For example one can have a level transmitter with its own PID controller on board (i.e. on its own CPU) communicating directly to a peer field device, the valve. If communications on an upstream or downstream segment of the bus fails then this control loop can go on controlling even after getting disconnected from the plant master control system. This produces significantly reduced risk of failure.
  - Redundancy

    By completion of buses into loops (by means of specially designed termination units if required), implies the potential for bus redundancy. If the bus is severed it can transmit back to plant master control via the remaining loop section.
- Increased Management Information

- The amount of information available from field devices increases dramatically. The challenge becomes in how this is analysed and not in how to get it. It can be used for fault and maintenance system diagnostics and predictive maintenance.

Technology seems to be converging on two of these fieldbuses, namely Profibus PA and Foundation Fieldbus (FFB). We now consider the technical points of these two:

5.3.3.1 Fieldbus Foundation (FFB)

Foundation Fieldbus is able to implement far truer distributed control functions (i.e. PID control on the instrument itself). The network has flexible network traffic control so scheduling and bus cycle time is adjustable. Similar to Profibus the H1 standard is implemented with layers 1,2 and 7 of the OSI stack. The H1 standard is based on the IEC61158 standard. This is a reliable implementation of current loop type control with Manchester Encoding. A new version is currently being developed, called H2, and this is based on high speed Ethernet as a physical layer standard, and TCP/IP as the Transport and Network layer standards. The development began on this product in 1998 and the first commercially available H2 products are expected in early 2000 [16]. The architecture of the Foundation Fieldbus is for H1 from the field I/O concentrator to instruments, and H2 from the concentrator back to the control centre (also called the 'home run'). It is also conceivable that H2 might become options for field instruments further unifying this communications domain. With the convergence of communications worldwide onto these standards as unifying standards, this approach will certainly have cost and compatibility benefits for the user. .

The Standards driving committee is remarkably vendor dominance free, which could result in a more widely accepted standard in the long term. Unfortunately there is significant disagreement found amongst the Fieldbus Foundation committee members, which is hampering wide product availability. The latest consequence of this disagreement is the recent decision of the IEC standardisation committee to implement the Data link layer standard of Foundation Fieldbus with eight different Protocol options [16], effectively giving the eight major market fieldbus suppliers options for their protocols. This slows down the achievement of full interoperability benefits (refer to section 5.2.7), but at least achieves some degree of medium compatibility benefit.

More technical detail is available on the standard in Appendix A. 4

5.3.3.2 Profibus PA

Profibus is a standard primarily originating in Germany and driven traditionally by Siemens. The standard has three versions, namely FMS (Field Messaging Service), DP (Distributed Processing), and PA (Process Automation). The PA standard is based on the Physical Layer standard IEC 61158, the same one as used for the Fieldbus foundation H1 standard and described in that section. The standard does not effectively support distributed control intelligence down to field instrument level, i.e. it does not provide for the control algorithm to be implemented on a transmitter or other field device. It does however capture the savings available by the reduction in field equipment and engineering when comparing to the conventional 4-20mA technology.

The main advantage of Profibus is its currently wide market domination however there is risk that Fieldbus Foundation will supersede it in the medium to long term.

More technical detail is available on the standard in Appendix A. 3.

5.4 Technology Forecasting

5.4.1 Factors Influencing System Life

It is important to maximise system life by buying systems that will have market support for the maximum period. However other factors also influence the lifespan of a system. The following points look at the factors that affect system life, especially those concerned with market support:

a. Functionality Offered

The functionality is essentially the capabilities, services and features the technology offers. This can include speed of communications (Data rates and factors improving quality of transmission for digital sampling of analogue values – e.g. voice and video), Error performance (improved error performance leads to reliable communications links and less need for protocol overhead which slows down throughput rate). One needs to evaluate which Functionality Factor is most relevant and influential to the likelihood for long-term market support. For example, a key functionality factor in fieldbuses is the ability of the fieldbus to distribute control algorithms within field instruments, and this is a factor used later in the fieldbus trend analysis (Figure 15). The more aligned the products features are with that of the market need, the more likely that product is to sustain itself commercially in the market, and hence be around as an option for the user.

b. Interoperability

Connectivity is a major issue when it comes to growing a system to meet future or phased need (sometimes termed the "scalability" of the system). It is important when considering the integration of systems (current and future), especially in this "information age" where enterprise wide data is such an important advantage. Interconnectivity is fortunately an issue actively pursued by market leading product suppliers and is slowly bringing benefits to users as convergence is seen on the major technology standards. The compliance of a vendor's equipment to dominant standards is a major value factor for consideration.

c. Other Factors influencing system life

With systems bought in the mining industry, future support is a major issue and reputation is a factor to be considered. The more financially established a company is the more likely it is to be around for future support. Alignment with internationally established vendors is an important advantage in today's world as it is the international market which drives the formation of market standards and hence the commercial sustainability of a product. When looking for technologies in a niche application we tend to deal with emergent and not mature technologies. In such a case it is important to partner a technology company in establishing systems to our requirements, and rely on the technology company to get the product to the market effectively. The core business of Anglogold is gold mining not technology development. With communications technology it is more advantageous for the company to spread the technology across a wider external user base, than to retain ownership on the technology.

The first prize is to buy technology that is substantially developed approaching maturity but with still future growth to ensure it does not become redundant too soon after purchase. Typically technology goes through an S curve ([10]) where if the growth of the technology is monitored against a "Parameter of Performance' then typically one will see emergent growth followed by fast exponential growth and then tapering off growth when the technology reaches its limits. One can draw an analogy to this with factors similar to a parameter of performance. In other words there are other factors that are linked to this theory of the Technology S curves.

Two technologies have been evaluated using this S curve type approach, firstly the competing technologies for the Broadband (multimedia - Figure 11 to Figure 13) technology and secondly for the Fieldbus Technologies (Figure 14 to Figure 16). Factors plotted are Cost, Functionality, and Interoperability as described above.

5.4.2 Technology Trend Curves for Broadband Networks

In the curves for the competing technologies for Broadband service (multimedia – i.e. for Data, Voice and Video), the two main technologies in the current market for the industrial type environment are considered to be the ATM technology (emerging as an option from the IT environment) and the SDH technology (also emerged from the IT side but more firmly established as an 'off the shelf' solution for the industrial environment. Brand name examples of this are Siemens OTN and SonetLynx).

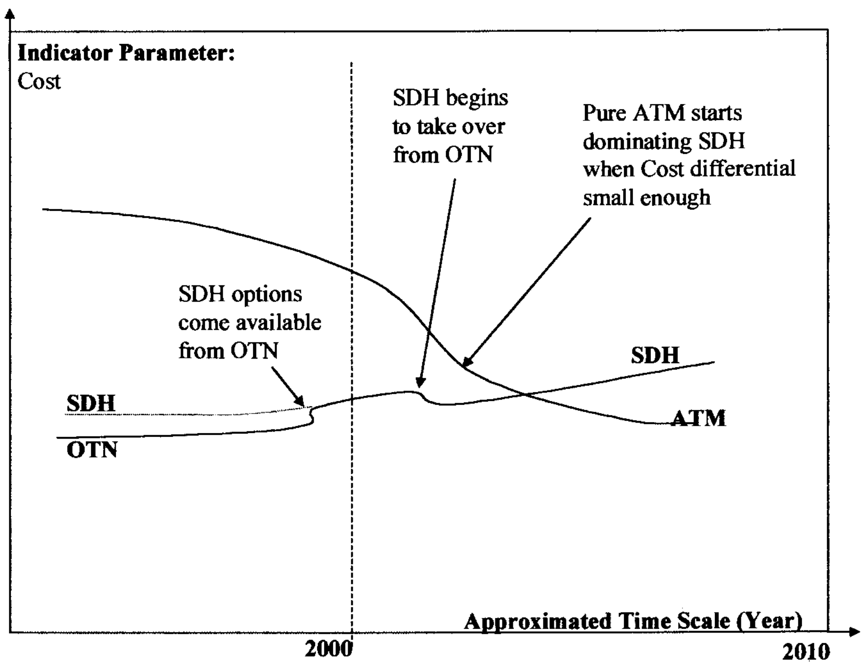

Figure 11: Technology Curves for Broadband Networks - Cost

Figure 11 considers the trends in costs. The graph is intended to be a speculation on the *trends* expected in this field, and should be seen in this light. ATM options are currently relatively expensive (approximately R300 000 per router, this price derived from the pricing for an eleven port Cisco 7500 series router, including approximately four cards with approximated legacy interface engineering requirements) as opposed to options from the SDH suppliers (around R120 000 per switch, these prices taken from Siemens OTN equipped node options). ATM however is eventually expected to capture significant market share and hence cost should drop, or more specific solutions might be offered for the Shaft environment. When this happens and the ATM to SDH cost premium gets attractive enough, then ATM would become the preferred solution, even as a 'Point to Point' technology, due to its potential routing and switching functionality advantages for the shaft network. Also for the reason that ATM might likely become the standard for a significant number of integrated systems downstream and upstream.

OTN was considered preferable for the Shaft domain since it offered interface cards for a number of legacy systems in the process control domain, while SonetLynx had some difficulty in catering for all legacy system interfaces required from a mine (RS 485 in particular).

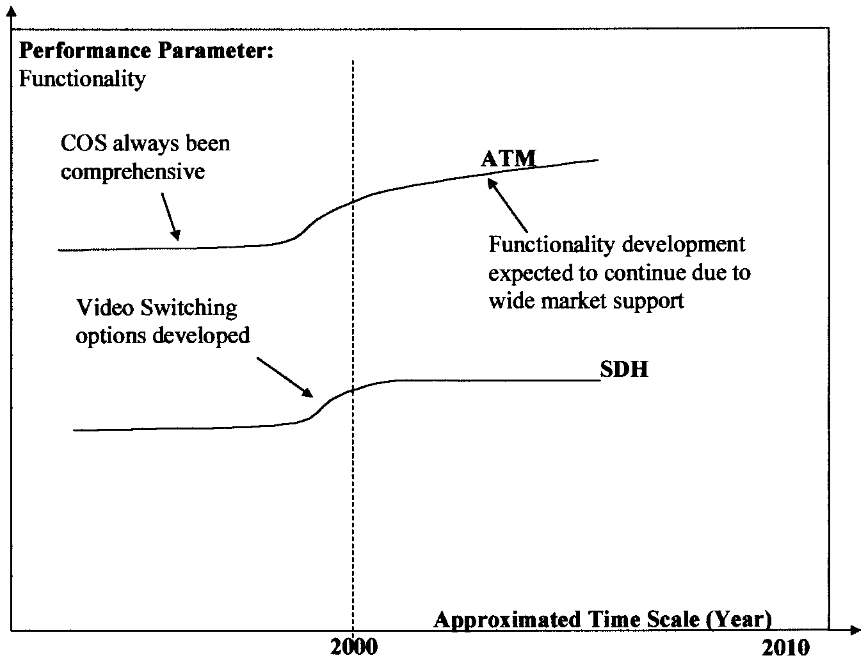

Figure 12: Technology Curves for Broadband Networks - Functionality

The prime Functionality Factor (Figure 12) to consider is the dynamic switching 'Class of Service' (COS) ability of ATM. SDH is Point to Point Technology and does not have the built in switching features of ATM. Recently *configurable multicast video switching* has become available on SDH systems. This has benefits for the shaft domain where analogue video cameras need to be concentrated to a few monitors on surface. ATM in the long term is expected to steadily increase its functionality seeing as it is likely to become the broadband technology of choice.

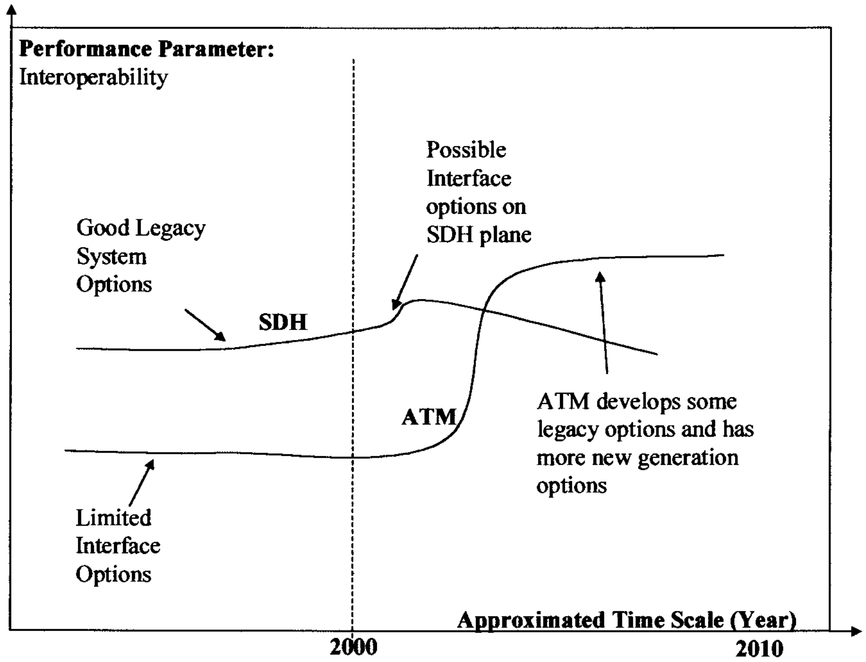

Figure 13: Technology Curves for Broadband Networks - Interoperability

Further interoperability is considered (Figure 13). There are 2 aspects to this, one being the interface ability to external systems, and the second being the ability for the system nodes to "plug and play" with other vendor equipment, i.e. on the same ATM or SDH backbone. In the first respect OTN was built more for the process control side and as such had a number of desirable Input cards for legacy standards such as RS485. ATM is expected to eventually have cost effective cards for some of these standards. Hence ATM interoperability is expected to increase when this happens. Further considering the expected long-term market support for ATM, the interface options for new generation standards will be sustained while SDH Technologies might stagnate in this regard. As regards Backbone interoperability ATM, as a standard, is expected to be adopted by many more Suppliers than SDH. Currently SDH is a Datalink layer orientated standard common to a number of product ranges, but further compatibility is required on the higher ISO layers for full interoperability. ATM achieves this full interoperability.

In conclusion ATM is predicted as a longer-term option but for current needs and medium term needs OTN/SDH is the preferred standard.

5.4.3 Technology Trend Curves for Fieldbus Networks

Looking at the fieldbus technologies, there is aggressive international competition between Fieldbus Foundation ([6]) and Profibus ([7]), to be the dominant fieldbus standard. Technology curves as shown in Figure 14, Figure 15, and Figure 16 illustrate a qualitative estimate of future trends in this field.

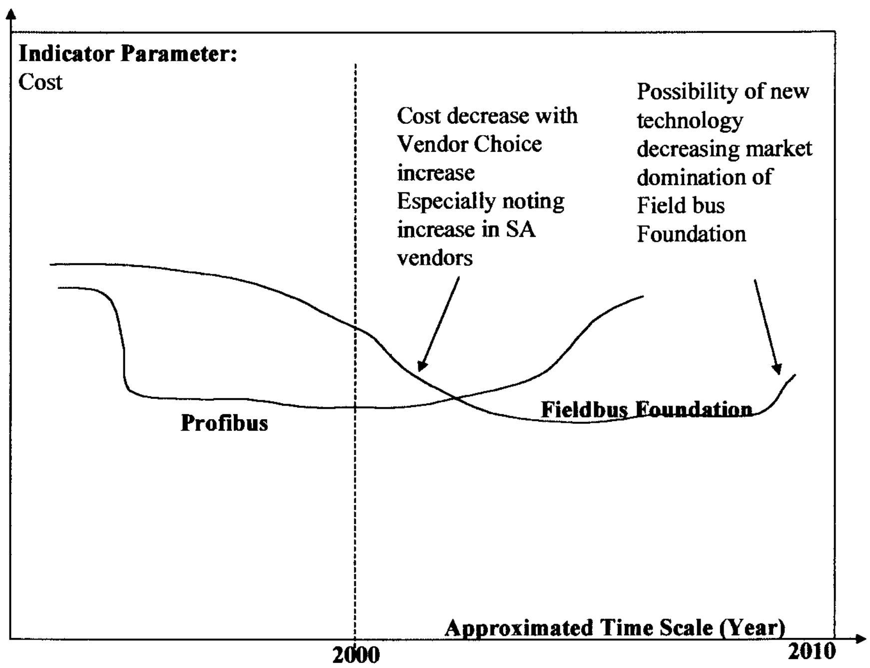

Figure 14: Fieldbus Technology Curves - Cost

Once again cost is of particular interest. Up until recently Foundation Fieldbus equipment has been significantly more expensive than Profibus, and this was mainly due to its limited availability in South Africa. The Foundation Fieldbus suppliers seem to have had a strategy to concentrate marketing effort within the United States and only recently we have seen equipment offered from manufacturers like Smar (represented by BRCS), Alpret, and Honeywell. Endress and Hauser market Profibus PA differential pressure transmitters at approximately R7000, approximately R1000 above conventional transmitters cost. Smar currently market Foundation Fieldbus differential pressure transmitters at approximately R7200, once again R1000 above their conventional transmitter cost. Foundation Fieldbus transmitters were approximately R3000 above conventional cost within the last 12 months, significantly reducing in cost to today's price. Savings with this technology are achieved in many areas primarily though in Cabling and Engineering Cost as described in 5.3.3.

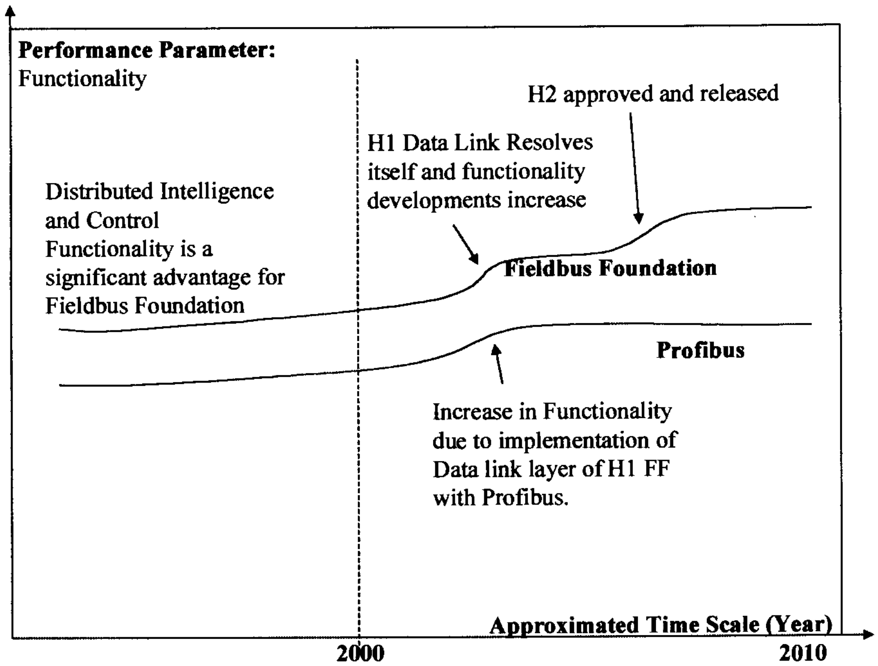

Figure 15: Fieldbus Technology Curves - Functionality

When considering functionality, the advantage Fieldbus Foundation has over Profibus is that the standard allows for control intelligence to be implemented on the field devices. This allows considerable redundancy advantage, i.e. the ability for control loops to function when the rest of the control architecture fails. Figure 15 gives a view on the trends expected on functionality within Profibus PA and Foundation Fieldbus. When the H1 data link standard is finally agreed on then this should allow suppliers to develop further functionality with confidence that their development money is aligned with international standards. Towards the end of 1999 Profibus was chosen as one of the seven datalink layer implementations for H1 fieldbus. This should give more impetus for the development of further functionality. When the much-awaited finalisation of H2 arrives this should give product developers considerable confidence in a stable international standard, removing any hindrance for functionality development.

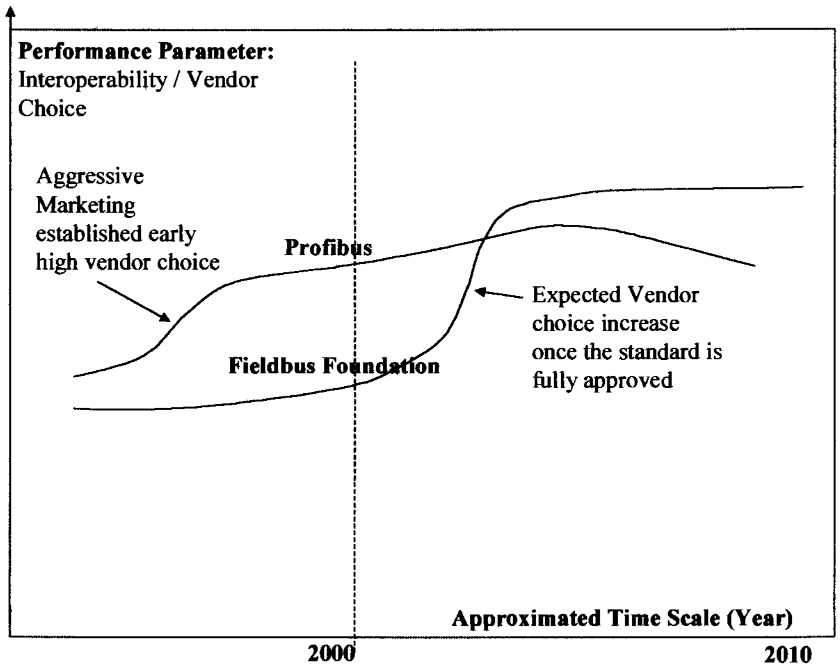

Figure 16: Fieldbus Technology Curves - Interoperability

Interoperability of Profibus has been successfully achieved. There are now well over two thousand vendors supplying Profibus Equipment. Fieldbus Foundation is now beginning to enter the same level of interoperability.

If Foundation Fieldbus equipment cost falls to the level of Profibus PA then it is very financially attractive to deploy Foundation Fieldbus technology with its increased distributed control functionality on new plants. However there is still debate happening on the Fieldbus Foundation H2 option which, once finalised as a standard, should mean great strides towards interoperability. Currently the main problem with H1 Foundation Fieldbus is the lack of availability of H1 interface cards for PLC's. It is assumed that manufacturers are awaiting clarity on the H2 standard before investing development resources in H1 technology. The Delta V PLC from Alpret supports H1 fieldbus most effectively in the current South African market. Modicon PLC's have reported that they are busy developing an H1 interface card, but this is not currently available in South Africa at this stage. The current decision of the IEC standard body to allow 7 different datalink layer forms for H1, effectively still constrain vendor independent interoperability, but with the envisaged natural selection of one of these implementation forms, and with the evolution of H2 interoperability is expected to increase dramatically.

5.4.4 Conference on Converging and Emerging Technologies for Industrial Communications

a. Background and content

As part of the efforts on this dissertation a conference was arranged to identify technologies in communications that are either converging to a standard, or potential standards and technologies that are emerging. Although the Delphi method ([10]) suggests that formal technology trend forecasting should be done individually rather than in a group, this conference was the most effective way to solicit group opinion amongst professionals outside Anglogold. The main worry from the Delphi theory is to eliminate extreme opinions and hence the specific objectives of the Chairman was to manage this by soliciting opinion from reserved attendees and to challenge opinions from outspoken participants.

The conference was arranged under the banner of the South African Council for Automation and Computation and was well attended (30 delegates from a cross section of industry – both suppliers and users). Presentations were given under the following headings.

- Fieldbus technologies
- Core backbone standards
- Radio technology
- General

The conference agenda and a summary of debate is given in Appendix A. 6.

b. Summarised findings from the conference

Suppliers and users in South Africa tend to hold back and wait for international trends. This is not surprising considering the market share South Africa commands in the international arena. Speculation was that there is significant convergence in both the fieldbus and core backbone areas.

There is still uncertainty when the successful development of a stable and mature Fieldbus Foundation Standard would occur, but it seems apparent that the functionality offered and non-supplier biased approach of the Fieldbus Foundation Standard would ensure a dominant standard. A significant number of instrument manufacturers already offer Foundation Fieldbus H1 equipment.

The overall unifying technology is almost certainly Ethernet TCP/IP. Already almost all PLC manufacturers offer this. The Fieldbus Foundation H2 system is along these lines.

Voice and video solutions exist on TCP/IP. Any determinism problems are being overcome by the emergence of extremely fast baud rates.

5.5 Interface of Process Control to IT environment

The main issue on interface between networks is that systems should be built on open standards. There is normally a wide selection of "converters" or gateways from reputable suppliers to provide interface between the dominant network standards.

The one issue to be considered here is the interface between deterministic networks and non-deterministic networks. The main instance of this in this dissertation is the interface between Ethernet LAN and fieldbus or between Broadband and Ethernet.

One needs to remember the needs of the Process Control function for the transmission of its data. The typical control software we use on the mine has acceptable software cycle requirement times of around 20ms. A 100BaseX Ethernet with 30% maximum subscription will perform at speeds far faster than 20ms response. Some software on advanced controlled equipment requires sub 2ms response. In this case connection orientated buses with deterministic response are required. These buses are normally handled as necessary specialist buses. An example of this is for some of our advanced control winders where fast response torque control algorithms are implemented to minimise rope stress.

We also find that most response and connection critical communications takes place within the fieldbus domain, and monitoring summary type information is the only type of information passed up to the Ethernet (Management Information System – MIS) LAN. There are times when some interlocking is done across the Ethernet LAN, such as inter-dam level control, but this information can withstand delays in the order of a few seconds which properly engineered Ethernet can easily provide.

5.6 Video Quality Aspects

Broadcast quality is typically taken as the PAL standard of 768 x 576 pixels. Black and White TV with 256 grey scales needs 8 bits to represent the intensity. Refresh rate is 25 frames per second. The resulting bandwidth becomes:

765 x 576 x 8 x 25 = approximately 88.128 Mbps

Colour will increase this by a factor of three to 264.384 Mbps

The development trends of compression and streaming techniques such as MPEG4 and wavelet compression are encouraging. Typical compression achieved with these techniques are in the region of 30:1. This implies that we could realistically achieve broadcast quality video transmission consuming bandwidths in the order of 8 Mbps or less.

Cameras from Norway suppliers (Norco cameras) are available with inbuilt wavelet compression and other techniques similar to MPEG4, and offering LAN type outputs (plug in ports directly on the camera). Compression achievements of 100:1 are claimed. The cost per camera is approximately R9000.

The company Intervid (Durban based) claim to have seen technology offerings from Germany on overseas exhibitions in March 2000. This technology dynamically approaches compression from both quality and speed viewpoints. Video signals have two interlaced fields. One of these fields is compressed for resolution/quality aspects and the other from a 'frames per second' viewpoint. The exact detail of how this is done is still proprietary but the point of this is that compression is dynamically configurable from camera to monitor. The packaging of the product is in the form of a separate unit that can accept 4 camera inputs and 'publish' this on a single TCP/IP network, incorporating substantial MPEG type compression. Costs per unit are approximately R17 000 but this can be considered in the context that it services four cameras. With dynamically adjustable quality and speed we will be able to compromise on each aspect to meet the needs. Two classes of need are envisaged as follows:

a. Monitoring quality video

   This should be high resolution, low frames per second. Perhaps broadcast resolution but around 3 frames per second. (hence reducing bandwidth by a factor of 8)

b. Control quality video

   This should be low resolution, higher frames per second. Typically reducing broadcast resolution down by an estimated factor of 5 is sufficient, but retaining 25 frames per second, hence reducing bandwidth consumption by a factor of two or four. This could even be black and white, reducing bandwidth demand by a factor of 3 again, but further work is required to confirm this.

In summary, with emergent compression ratios of 100, and reduction of quality or speed by a further factor of 8 for monitoring and 15 for control, we can expect to obtain adequate video transmission with the following bandwidth consumption

264Mbps / 100 / 8 = 330Kbps

On a fixed fibre LAN of say 100Mbps capacity, loading this to 30%, we can have the following cameras on each LAN:

100 * 30% / 0.330 = 90 cameras

With this in mind both stationary and mobile video needs should be migrated, as costs and technology availability allows, to TCP/IP video.

Capacity potential on the RF LAN is covered in section 6.4.

6 RADIO COVERAGE ASPECTS

6.1 Bandwidth and Baud Rates

When we look at the current radio situation we see that VHF leaky feeder is currently the technology of choice for voice solutions in the tunnel type haulages. Leaky feeder is a radio technology using a braided type of coaxial cable as described in the Glossary of Terms. It operates at 150 – 175MHz. This is by far the most popular way the mining industry is equipping itself for mobile voice services and consequently prices of this technology are very attractive compared to other technology solutions (installed cost of systems are typically around R30 per m).

When we consider future needs we see that leaky feeder will be inadequate for mobile video and mobile data (in the Mbps order). We do need to quantify this by examining theory on the issue and reviewing market availability of technology for this need.

The theory to do this is found in the book "Fred Halsall; "Data Communication Networks and open System Standards"; " ([19]) – sections 2.2.2, and 2.3.4.

According to Nyquist theory a bit rate of C bps can be transferred on a noiseless channel of W Hz where:

$$C = 2 \times W \log_2 M$$

M = the number of levels per signalling element

W = the Bandwidth of the Channel in Hz

However in practice this is reduced by noise and Signal to Noise Ratio Ability of receivers, however this is taken into account with the following formulae

$$R = B \times W$$

Where W is the frequency bandwidth of the channel and B is the bandwidth efficiency factor.

There are a number of ways of improving the bandwidth efficiency, namely:

- Modulation Technique

  The main types of modulation are Amplitude Shift Keying (ASK - where the amplitude of the carrier wave is adjusted according to the bit stream), Frequency Shift Keying (FSK - frequency adjusted) and Phase Shift Keying (PSK – the Phase is adjusted). Typically FSK

- Multi levels in modulation

Instead of just two levels for 0 or 1, you can increase the levels to 4, 8 or 16 (such as the Quadrature Phase Shift Keying – QPSK).

You can also combine modulation techniques and obtain more bandwidth say by using PSK and ASK to produce a QAM (Quadrature Amplitude Modulation).

All these techniques substantially increase Bandwidth Efficiency.

Bandwidth Efficiency can vary widely from 0.25 to 3.0 $bpsHz^{-1}$ but typically RF modems have Bandwidth Efficiencies between 0.25 to 1.0. A typical 9.6Kbps modem requires 20KHz bandwidth and 10Mbps requires 18MHz.

In the VHF range current technology is 25KHz (or more recently 12.5KHz) channel spaced radio for underground. This implies that bit rates we can expect from this are around 9.6Kbps.

In the RF LAN Spread Spectrum modem range we can expect an order of magnitude jump in capability since we are seeing equipment at the 2.4GHz range that accomplishes 11Mbps (Qkon RF modems)

When we evaluate what the needs for the mining industry (refer to section 5.6) are likely to be, we see that they are of this order. The video mobile technologies are most likely to be digital video (TCP/IP) due to current technology convergence. We are already seeing video systems emerging requiring 200 to 300Kbps per video channel. It seems likely that we will be able to obtain video at less than 100Kbps. However we can speculate that at worst video can be achieved with 1Mbps type bandwidth, and this puts us in the 2.4 GHz RF Spread Spectrum range.

6.2 RF Coverage Model

6.2.1 RF Coverage Modelling Summary

In order to evaluate whether the RF Technologies chosen would be effective or not, a Simulation model was done. The modelling was done by Software called "SuperNEC", developed by the company Poynting Innovations. Dr. Derek Nitch from the Poynting, who initially developed the Software [28], did the modelling, verification of the results and wrote the final report. I was involved in the specification of the input data to the model, and jointly involved with Dr. Nitch in the measurement during the verification test, and the interpretation of the final results. The Software uses a Hybrid Method of Moments and GTD (Geometric Theory of Diffraction) approach which implements an Asymptotic Solution to Maxwell's Equations (i.e. it makes assumptions when the frequency becomes relatively high). The method of moments approach allows the software to model at lower frequencies than the GTD approach which is limited to about 2 wavelength model dimensions. It considers both the near and far field effects/calculations.

The model showed that leaky feeder at VHF-170MHz should give acceptable coverage (a fact we already new by experience), but further that we could expect good coverage in the stope area from point antennae (Refer Figure 24). We also did preliminary investigations into the coverage we could expect from 2.4GHz spread spectrum modems, and Figure 26 shows an optimistic view of achievable coverage.

6.2.2 Model Input Data

- Stope area

Figure 17 best explains a typical stope. The mine as explained in Figure 3 on page 7, is mined by approaching the narrow tabular ore slab (sloped at about 20 to 30 degrees to the horizontal) from below. Then a travelling way is made steeply up to the ore body and a gully is developed up the slope of the ore body, called the centre gully. From the centre 'Gully Advance Strike Gullies' (ASG) are developed to the side to be mined. The ASGs are kept just ahead of the panel being mined and panels are mined in a pattern similar to that shown in Figure 17. When the one side of the stope reaches its mining limit (about 90 m normally) then the other side is mined in a similar fashion. The centre gully is normally between 250 to 450m, and as such the maximum stope to be covered for radio is about 180 x 450 x 1.5m.

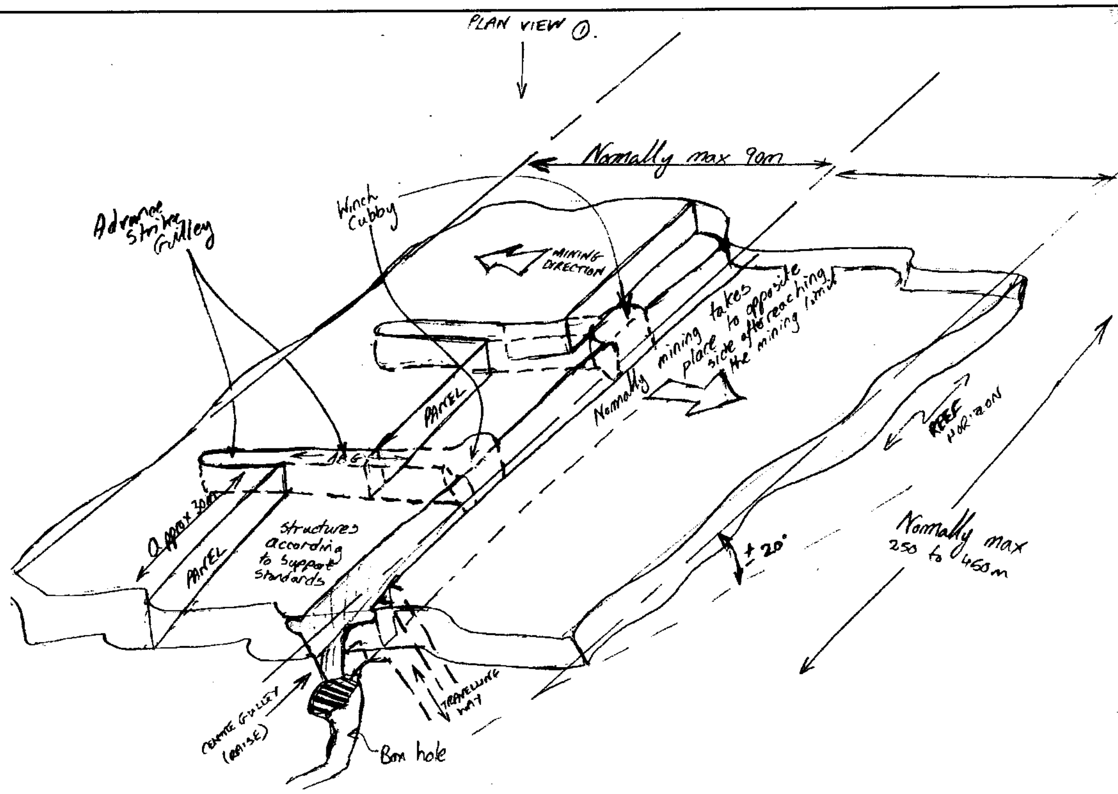

Figure 17: Sketch of a Stope Layout

The area behind the panel is supported by wood packs or a concept known as backfill (where solid cement like blocks are made to support the roofs). Dimensions of these support arrangements are given in Figure 18 and Figure 19. A diagram of support packs is given in Figure 20.

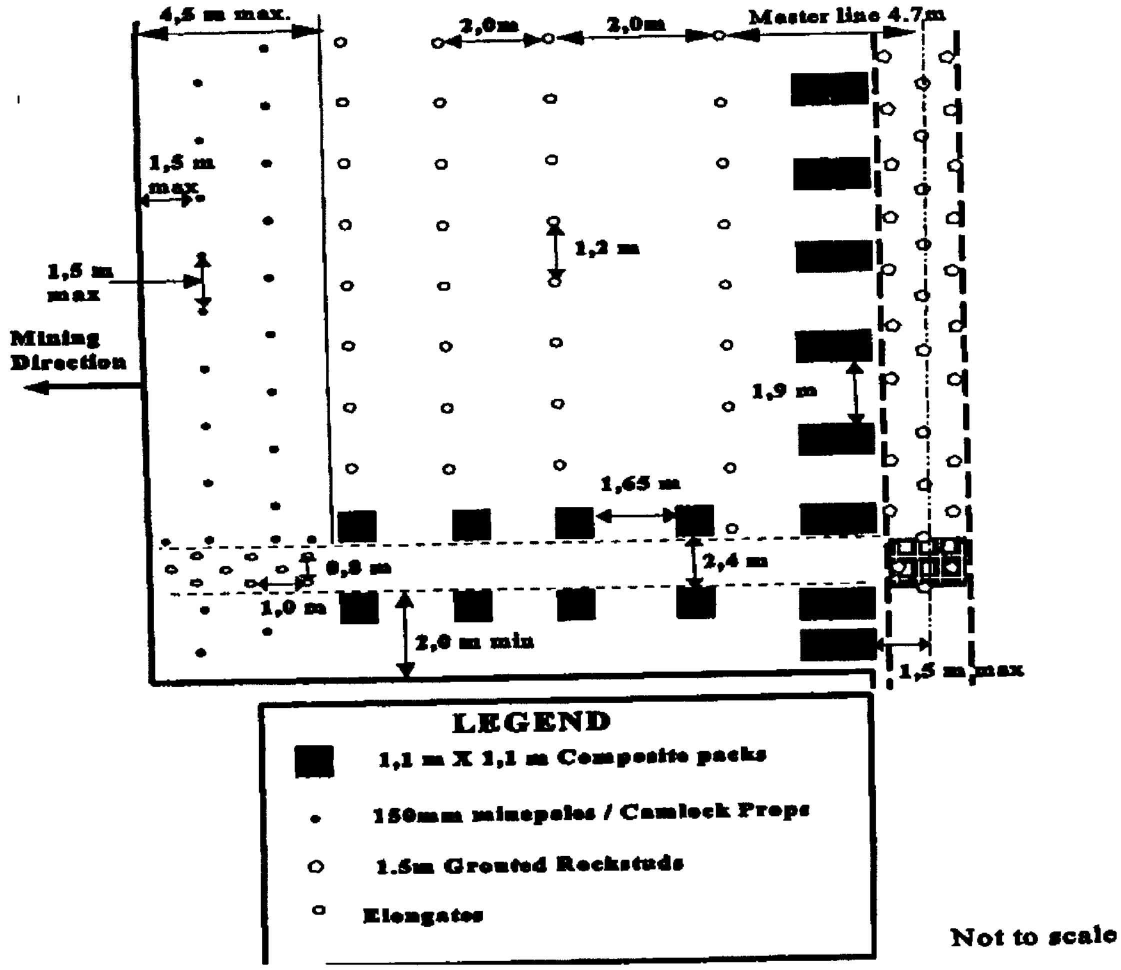

Figure 18: Conventional Support Arrangements

- Haulage

The haulage dimensions can vary between 3x3m to 4.5x4.5m. In the case of the modelling done, the dimensions used are shown in Figure 21. The haulage in the model had "meshing and lacing" on the side and roof walls. This is a type of steel mesh pinned to the wall. The apertures of the mesh are in the order of 10cm and this is far smaller than the wavelength of the radio waves at 170MHz (frequency of the model). Effectively then the mesh acts as a perfect reflecting lining and can be modelled as such. The floor remains as a lossy medium.

6.2.3 Modelling Method

The modelling was done by Software called "SuperNEC", developed by the company Poynting Innovations. Dr. Derek Nitch, who initially developed the Software [28] did the modelling, verification of the results and wrote the final report. I was involved in the specification of the input data to the model, the measurement of the verification test, and the interpretation of the results. The software uses a hybrid method of moments and GTD (Geometric Theory of Diffraction) approach which implements an asymptotic solution to maxwell's equations (i.e. it makes assumptions when the frequency becomes relatively high). The method of moments approach allows the software to model at lower frequencies than the GTD approach that is limited to about 2 wavelength model dimensions. It considers both the near and far field effects/calculations.

The leaky feeder was modelled as a series of segment sources (dipoles each a 1/10th of a wavelength in length), closely spaced inline (spaced ½ a wavelength apart) with each source reducing in strength by a factor suitable to simulate the loss per meter of the cable.

A simulation of a haulage was done to verify against actual measurements on the Anglogold mine Elandsrand. The results of these measurements were compared against the SuperNEC model results and the resistance and permittivity of the walls were iteratively determined.

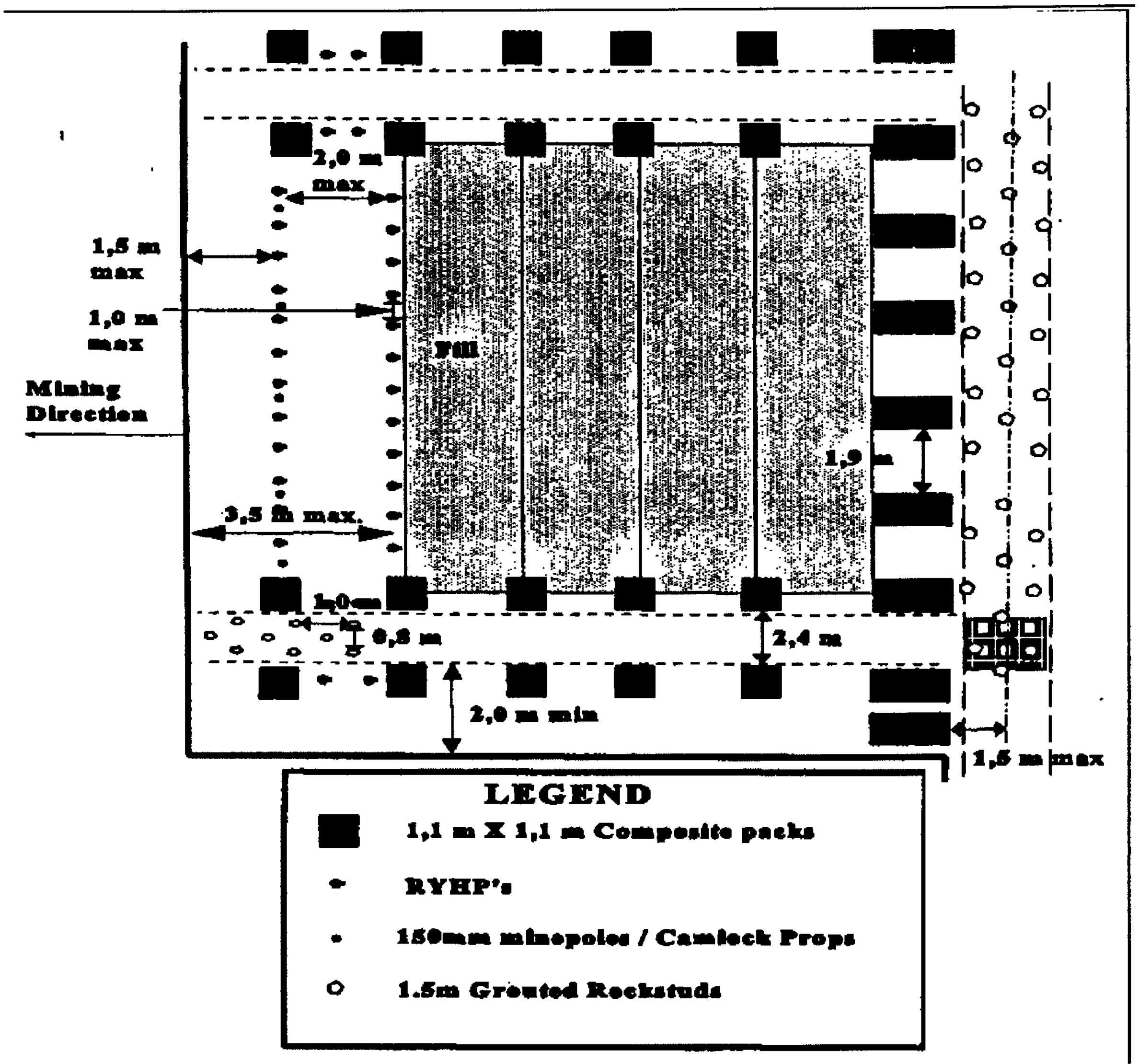

Figure 19: Backfill Arrangement

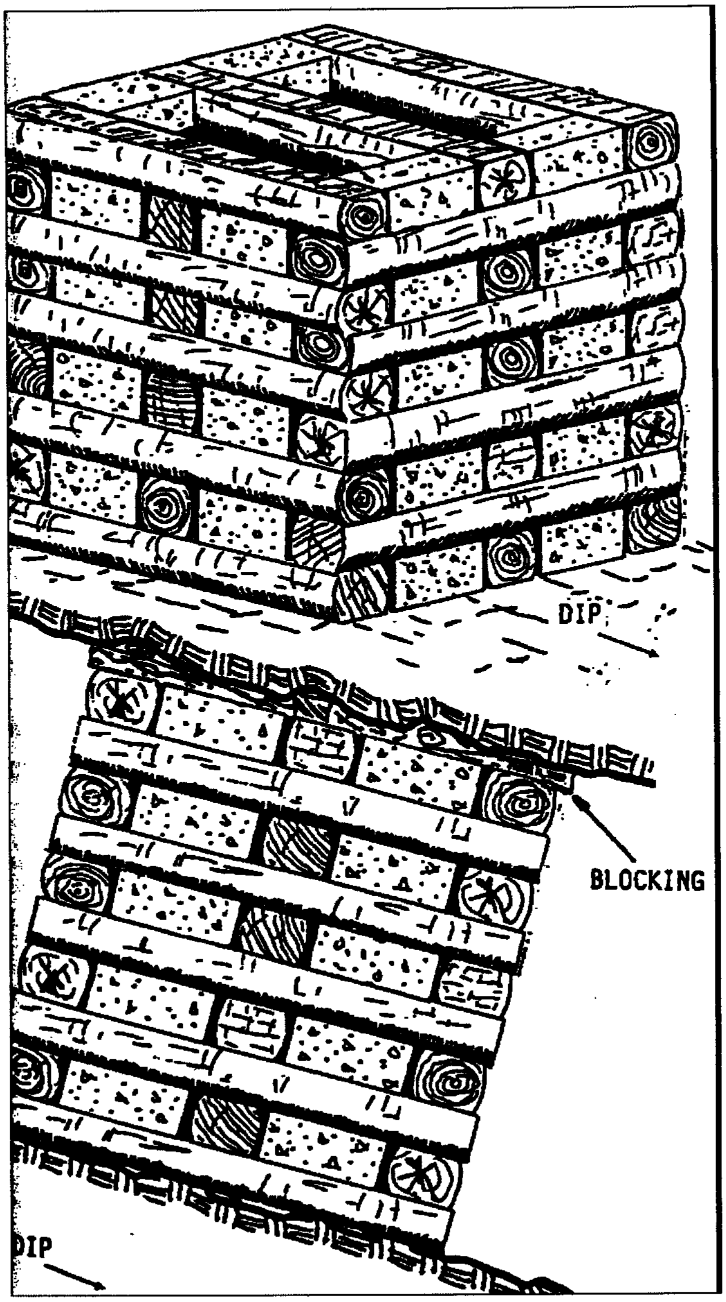

Figure 20: Conventional Support Pack

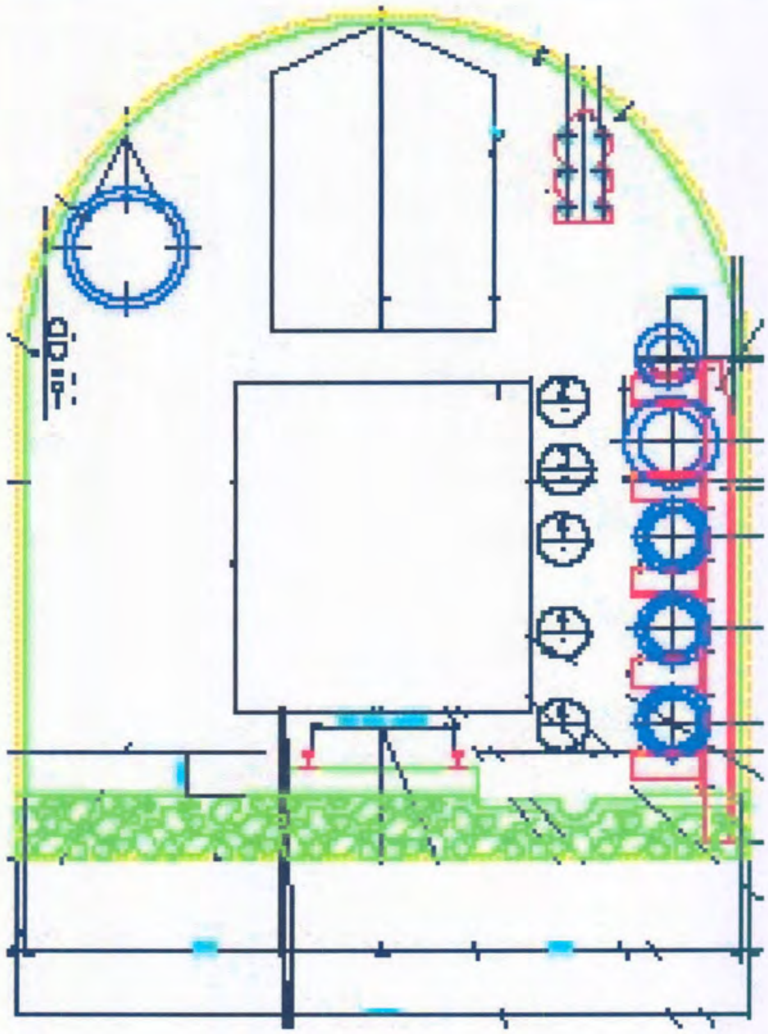

Figure 21: Haulage Layout for Modelling

6.2.4 Results of the Modelling

There is a detail report done by Poynting Innovations on the results of the model. The results of the verification were good. The model was further verified against another version of software. This propagation code is called CINDOOR. These results also showed good correlation.

Three scenarios were modelled:

- Haulage

The software gives the signal strength in the form of a colour map. The haulage was modelled and results are shown in Figure 22.

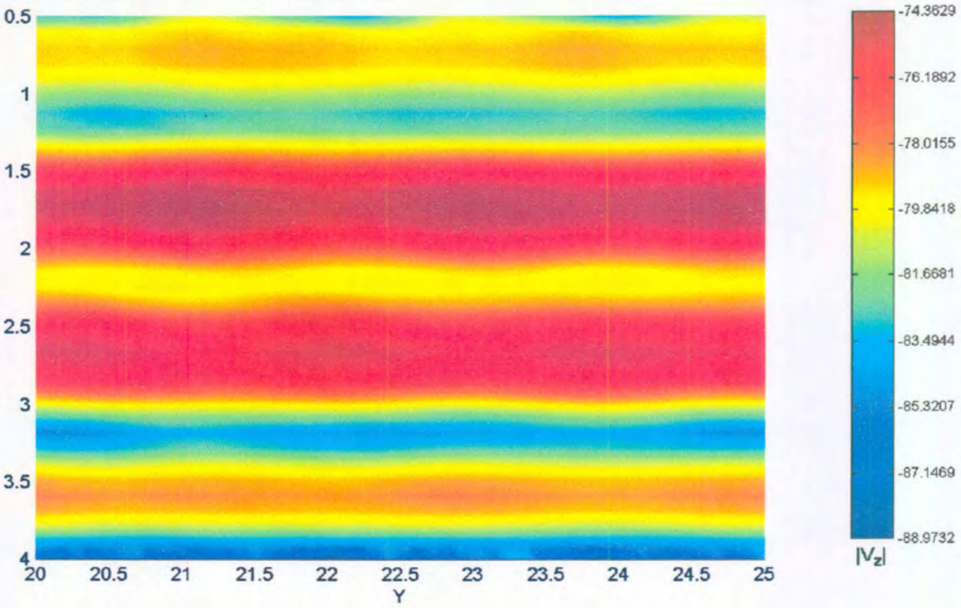

Figure 22: Signal Strength in a Haulage at height of 2.0m

- Stope without Packs

A stope with no packs similar to the arrangement shown in Figure 24 was modelled and the signal strength is shown in Figure 23.

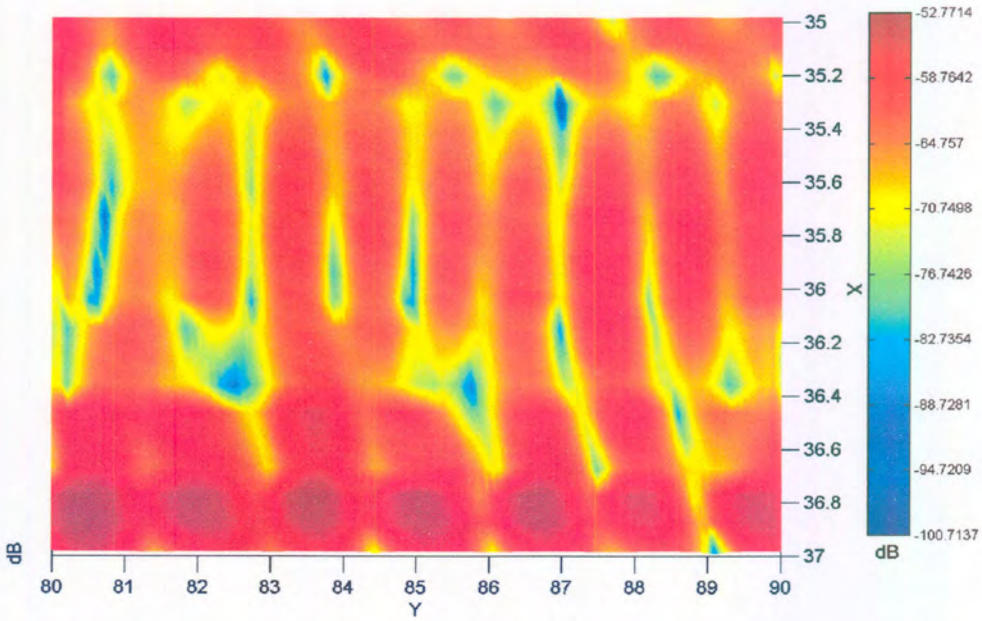

Figure 23: Signal Strength in a Stope with no Support Packs

- Stope with Support Packs

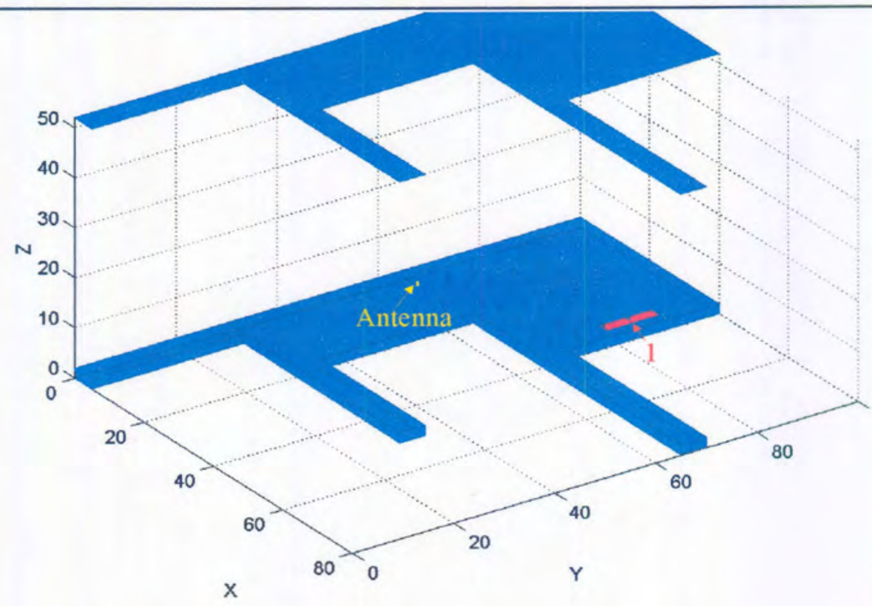

Figure 24: A top view of the stope with supports

This again is modelled as per Figure 24 and results are shown in Figure 25

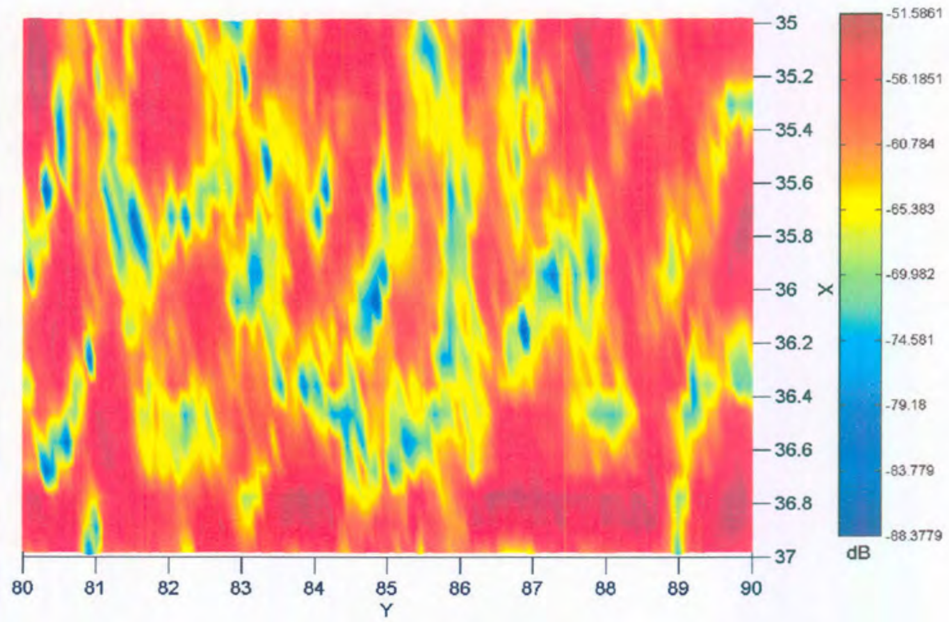

Figure 25: Signal Strength in Stope with Support Packs

- Haulage at 2.4GHz

A preliminary model was done of haulage conditions with a frequency of 2.4GHz. The conductivity and permittivity of the haulage rock surface was kept the same as used at 170MHz, however it is likely when taken up to this frequency. The work done by

Bryan Austin [20] found that for a frequency change from 0.3 to 6GHz the change in conductivity was in ratio 18/1. This implies that conductivity will increase as frequency increases further contributing to mutual interference from reflected waves. This will most likely increase severity of nulls and peaks, hence making this assumption of constant conductivity and permittivity an optimistic outlook. However on the other hand this simulation is done with a quarter wave unity gain antenna and with improved antenna design it is felt that we could achieve acceptable coverage.

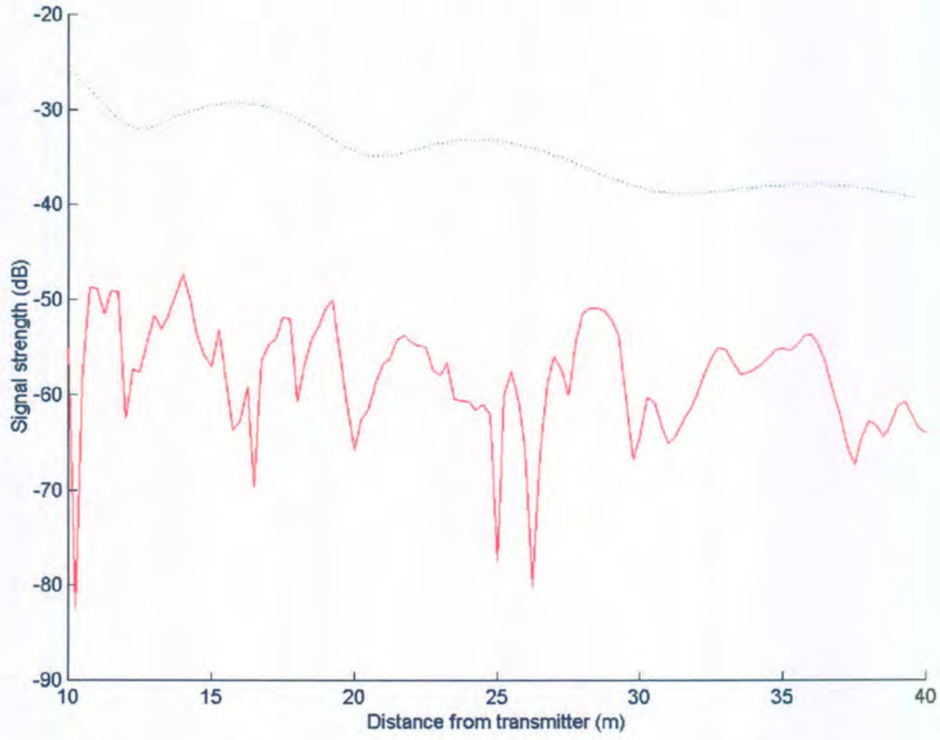

Figure 26: 2.4GHz Haulage Coverage (Optimistic)

6.2.5 Discussion of Results

The results show that signal strength at 170MHz is acceptable for radio transmission using conventional radios with Signal to Noise Ratios of –96dB. The results of the in-stope coverage with packs showed that the packs helped by smoothing out the patterns improving the signal strength dip potential.

Further work is recommended in the form of a pilot project to determine optimum design and positioning of the antennae. These results show that acceptable coverage is achievable.

For the 2.4GHz haulage option, we see that significant dips are expected but it is believed that with antenna design and a pilot system this could achieve acceptable coverage.

6.3 RF Topology

The layout of underground haulages is very linear from a topology viewpoint. Reflections from walls, roof and floor also lead to problems at certain frequencies. The leaky feeder concept of distributed antennae wire suites this layout of haulage very well. The leaky feeder in effect has optimum RF emission along the run of cable to control its RF coverage very well for the type of haulages we have, hence avoiding any reflection problems.

Another topology that would suite the haulage layout is mini-cells. If one could pass from cell to cell as you go along the haulage then RF emission could be reduced to levels where reflection is not a problem.

This leads us to the concept of an integrated RF LAN and leaky feeder. If the cell transmitters are integrated to the booster amplifiers then we have a simpler system to manage. Preliminary results from the RF modelling undertaken in the Poynting project, show that coverage of cells at 2.4GHz is ideally done with about 40m cells or less – considerably less than the current spacing of the leaky feeder booster amplifiers. This would have to be addressed in the design of the antennae.

6.4 RF LAN Considerations

Current RF LAN Technologies implement spread spectrum RF techniques and this is comprehensively covered by IEEE802.11 (Refer Appendix A.2.3 for more technical detail to the standard). The use of spread spectrum techniques underground introduces specific complications to the antennae and topology engineering. The "near far" problem, detailed in the appendix, implies that direct sequence technology might be unsuitable for confined space use like our underground environment. However this requires further test work to establish. Current data rates for these technologies are 1Mbps with frequency hopping and 2Mbps with direct sequence (non-standard performance of 11Mbps with direct sequence have been claimed but this needs further development).

If you consider a single access point every 300m in the haulage, then one can expect no more than 3 mobiles working in each cell. If video coverage is achieved in 300Kbps per channel then we see we have Ethernet capacity at less than 33% and can achieve deterministic response.

7 ASSEMBLING AND MANAGING THE ARCHITECTURE

When looking at what is best for the mines, it becomes a choice between catering for existing standards (some considered *legacy* systems), and re-engineering (or in the fortunate position of new shafts to engineer from scratch) to align the communications infrastructure with the expected standard of the future (Ethernet TCP/IP). Considering the effort of re-training, additional expense of buying equipment before it is mature in the market place, against the benefits of extended system life from buying "state of the art" systems, three different approaches were developed (detailed in the next sections). Only long term shafts (15 years plus) were considered as warranting "cutting edge" solutions. Medium Term Mines would tend to taper off in communications infrastructure roll-out within the next 2 to 5 years, and already had a communications systems population of 80% of envisaged maximum. Long term mines on the other hand would have automation infrastructure growth such that communications systems were currently only 50% or less rolled out.

7.1 Model for Long Term Shafts

The vision for long term mines is to reduce the communications systems to three domains with a unifying technology namely TCP/IP.

As such first choice Plug In for video, voice and data will be Ethernet 100baseX (Fibre or if required UTP).

The Control and Monitoring architecture remains principally the same as current implementations. The SCADA (supervisory software) remains on surface communicating with distributed PLC's. A process control database is generated for integration to the Business Systems IT environment. This will be on an SQL compatible database standard. The video systems, of which a significant amount are expected to be for security purposes, will be integrated into the IP environment.

Voice phones will be UTP TCP/IP compatible plugging into the nearest hub.

Field instruments are expected to be on the latest fieldbus standard, and this is expected to be Fieldbus Foundation Ethernet option H2 (further complimenting the global Ethernet environment).

Voice radio is still expected to be in the VHF leaky feeder arena, but high-speed data transmission will be on RF LAN Spread spectrum modems that will implement a roaming TCP/IP environment for PDA and IP video. The clarity, resolution and frame speed of video should be achieved with the MPEG 4 or MPEG 6 standard should allow us to connect acceptable quality video with 300Kbps bandwidth. Current spread spectrum capacities allows us then to implement RF TCP/IP Video.

The conceptual plan can be seen in Figure 27.

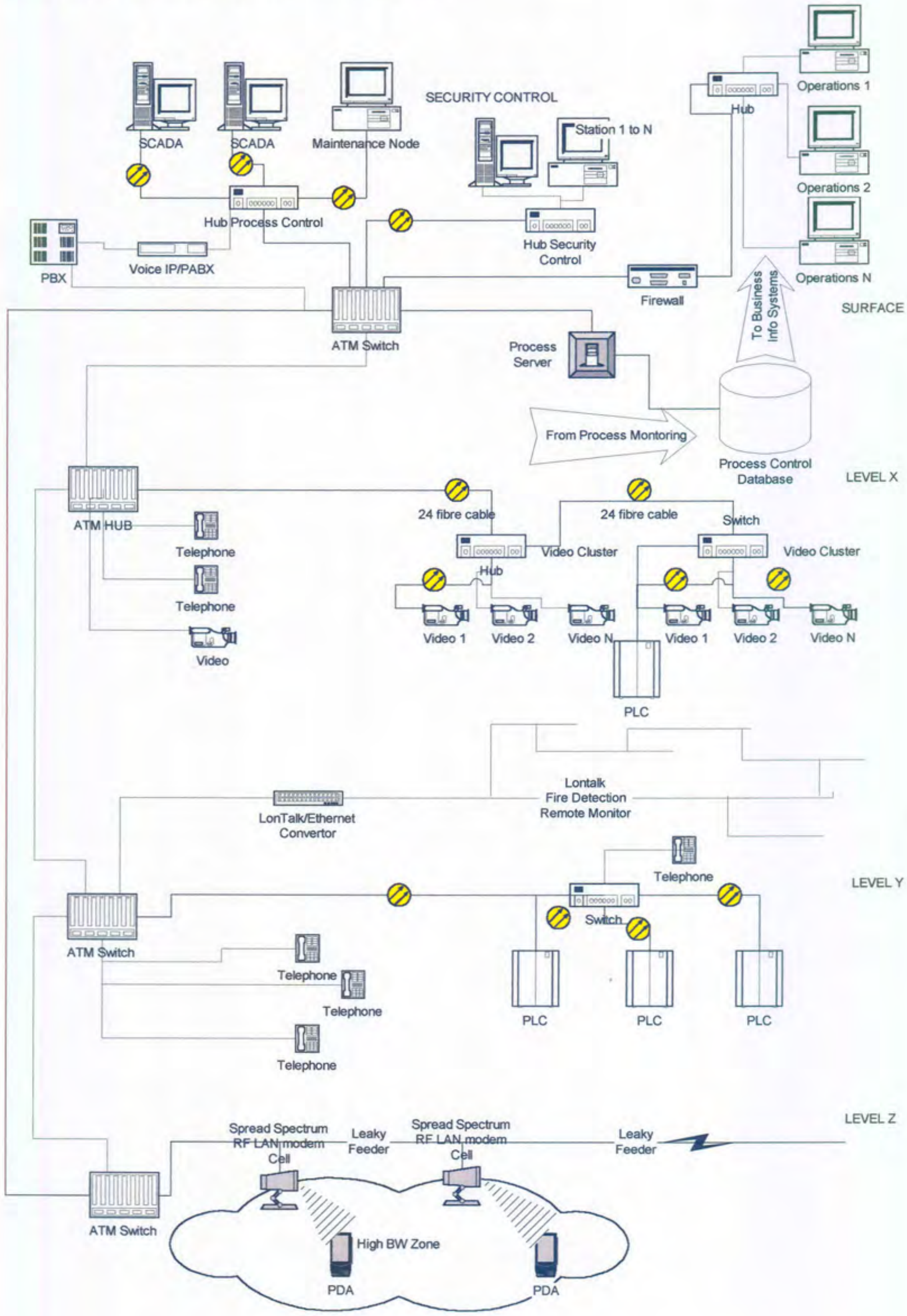

Figure 27: Long Term Mines Communications Model

7.2 Model for Medium Term Shafts

The vision for Medium Term mines is to reduce the communications systems to four main domains catering for legacy systems where appropriate.

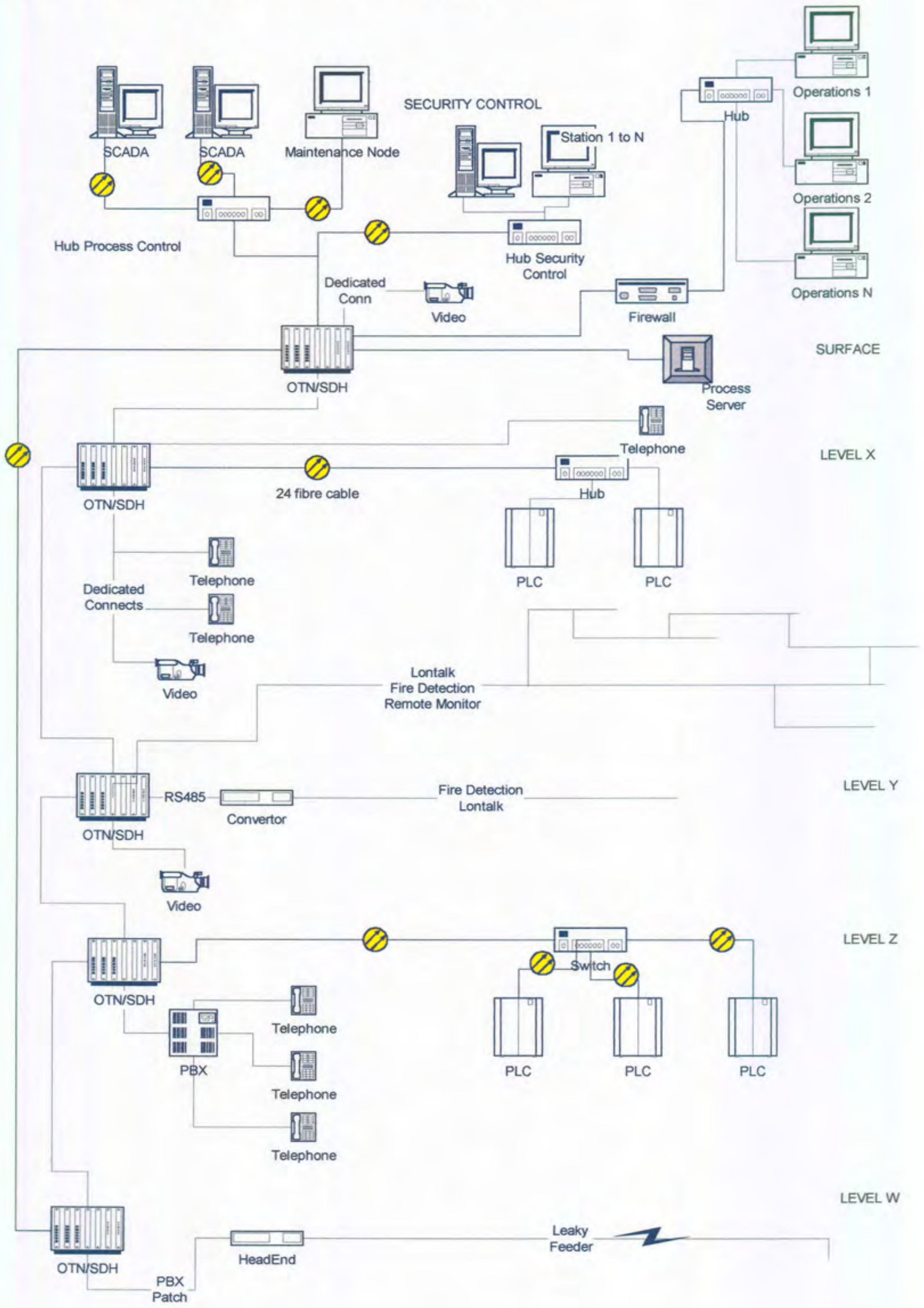

Figure 28: Medium Term Mines Communications Model

The domains can be seen in Figure 28 and are: Shaft domain (OTN/SDH), process control domain (PLC and Fieldbus), rugged medium domain (Echelon - Lontalk) and the radio domain (voice alone).

The most appropriate backbone standard became one that could provide Legacy system interface integral to the unit (i.e. as a plug in card option). The SDH aligned technology "Siemens OTN" was chosen. There are separate video and voice domains but these effectively plug straight into the SDH boxes

7.3 Model for Short Term Shafts

Short-term shafts do not merit any additional costs for replacement infrastructure but with the purchase of new systems the following criteria should be used for System Choice.

a. Current skills base

One needs to buy systems that the current technical support teams are trained in. We need to remember that downtime will be dependent on their knowledge during system failures and that substantial re-training will probably not be attractive considering the short life these mines have.

b. Interconnectivity to existing systems

Existing systems will not be replaced so we need to connect to them. We still need to strive for full system connectivity to harness the benefits available from information enablement.

c. Market support over expected life

One needs to look at the likelihood of Supplier support for such things as spares, and technical support. These are essentials and if they do not exist it can lead to substantially premature system replacement. Supplier market history is the only way to evaluate this.

d. Openness for future systems

Next in priority is buying systems suitable to connect to current market de-facto standards realising that potential future systems will probably be based in these standards.

A. 1. Radio Frequency Spectrum Management

The underground situation is fortunate in that presently the competition for "air space" is small. Signals generated underground do not emerge to the surface due to natural signal decay through the rock, hence the underground radio frequency spectrum is not subject to national legislation governing the generation of radio frequency. However when we consider the critical safety systems that will be communicated in the RF Communications domain, we need to be careful and manage this spectrum. The best document for guidance on surface frequency reservation is the report on the SABRE project [27]. This gives insight to current reservation as well as future frequency plans (currently being proposed in light of international trends)

Safety critical systems need further care regarding RF transmission and this lead to the establishment of a Code of Practice guideline on RF systems for the business units (Appendix A. 5), that was done as part of this thesis.

A. 2. Technology Watch Framework

According to theory presented in [11], a suitable framework for managing technology in a complex environment is the "technology balance sheet". In similar way a technology framework has been developed for the Communication Technologies in the deep level gold mining environment (Table 2). The principle of the framework is to relate communications aspects that influence each other, and use this as a tool to monitor changes in each aspect translating their effect to other aspects of the framework.

The three aspects used in the developed framework are the required 'technology watches', the domains identified to assist in system rationalisation, and the needs of the mines. These are detailed further in the next few paragraphs. The principle is that when needs change these reflect directly on the domains. Similarly technology changes in the market place can strongly influence the domains, empowering or inhibiting them in servicing the needs.

- Technology watches

  This is a listing of technologies that are available, or potentially available, on the market place, and have been identified as suitable for the defined domains. It is necessary to track these technology's trends.

- Domains

In some mines there are more than the proposed four domains in existence and these have been included in the listing.

There are essentially two options for the shaft domain, namely the integrated option defined primarily for medium and long term mines where it motivates investment in a fibre broadband network, and secondly the 'fragmented shaft domain' where systems run down the shaft separately.

The 'haulage fibre' domain is for long term mines with a vision for fibre networks distributed down the haulage. Essentially the vision is for an Ethernet hub/tree topology servicing multimedia needs.

The 'PLC to PLC', and 'Fieldbus' sub-domains form the 'process control domain'. With the convergence of these technologies in the technology arena onto the unifying standard, Ethernet, this could form one domain with no sub-domains. At this stage they need to be monitored separately.

The four RF sub-domains are listed separately since different needs and technologies affect them.

- Needs

The needs are taken from section 3.4 and previously summarised in Table 1.

A tick in Table 2 represents a relationship that requires consideration between either the need and the domain, or the technology and the domain.

Table 2: Technology Management Framework Table

							COMMS NEEDS		Video	Video	Video	Voice	Voice	Ctl Data	Mon & Ctl Data	Mon & Ctl Data	PDA LAN
									Shaft	Boxholes	Locos	Locos	Stope	Locos	Utility	Stope	ALL
							Mines:	Long Term	✓	✓	✓	✓	✓	✓	✓	✓	✓
								Medium Term	✓		✓		✓	✓	✓		
TECHNOLGY WATCHES								Short Term							✓		
Ethernet	ATM	Fieldbus Found.	Profibus	Lontalk	Leaky Feeder	RF Modem	**Domains**										
✓	✓						Integrated Shaft		✓	✓	✓	✓	✓	✓	✓	✓	✓
✓		✓	✓	✓			Fragmented Shaft		✓	✓	✓	✓	✓	✓	✓		
✓	✓						Haulage Fibre			✓					✓	✓	✓
✓		✓					PLC to PLC								✓	✓	
		✓	✓				Fieldbus								✓	✓	
				✓	✓		Rugged Medium								✓		
					✓		RF Haulage Voice and Low BW					✓		✓			
					✓		RF Stope Voice and Low BW						✓			✓	
					✓	✓	RF Haulage High BW				✓			✓			
					✓	✓	RF Stope High BW									✓	✓

8 CONCLUSIONS

8.1 Benefits and Needs Analysis

The cost benefit impact that a communications system has on a deep level mining operation is unclear since it is a key tool in improved management, a catalyst to improving efficiency, and not the complete solution to achieving the benefit. However a qualitative and conservative estimate was made and showed an Internal Rate of Return (IRR [13]) of around 160%, very attractive for any business.

The main driver for the sophistication of the communications system is the automation vision of these mines, and the main factor in how much automation they plan is the remaining 'life of mine'. Considering technology shelf life, automation vision and system benefit realisation, we can group our mines into essentially three categories, namely; 'long term mines' (15 years plus life remaining), 'medium term mines' (8 to 15 years), and 'short term mines' (Less than 8 years). With this in mind the needs were explored and summarised in a table (Table 1 on page 17). This table was taken forward to the Technology Management Framework (on page 71). In preparation for the matching of technology and the rationalisation of systems four ***Communication Domains*** are defined.

8.2 Technology Analysis

When a communications system is chosen or engineered then there are key qualities, aspects or properties that need to be strived for. Firstly we need to look for **open, interoperable** systems that can be implemented on **as many mediums as possible**, and that can carry **multi-media traffic**. This allows us flexibility to maintain or expand, and secures the benefit of increased supplier competition with "spin offs" of competitive pricing and quality. It also combines traffic needs to enhance economy of scale. The **topology** that the technology can be implemented with is also a contributing factor in the flexibility the Network has for expansion.

Secondly the required technical quality aspects to the network need to be built into final system engineering. **Determinism** is a quality that must be considered against the time delay robustness of the traffic on the network. **Redundancy** needs to be considered against the reliance that the control architecture has on the network. Finally **bandwidth** must be matched to traffic loading and used, when appropriate, to achieve determinism.

The major technologies for the different domains are discussed in turn, expounding the more relevant technical points. Following this, the emerging standards for the major **fieldbuses**, and the core **backbone/broadband architecture** were qualitatively analysed in the form of **S curve technology forecasts**. This can be seen in Figure 11 and Figure 14 and was used in the formation of the final models.

Radio remains the most challenging technology for implementation. The two main process needs that determine which radio technology to implement are mobile video and mobile PDA type data. Both require in the order of 1 to 10 Mbps bandwidth and current RF spread spectrum technology gives us this. Leaky feeder provides a method ideal for the immediate rollout of VHF infrastructure in the haulage. Extending this VHF infrastructure to the stope areas is the next natural step. In fact the tremendous financial benefits in getting voice communications to the stope make this an urgent project. The radio coverage modelling done in this dissertation shows us that we should get acceptable coverage in the stope area with the currently used VHF frequency radios. Further modelling was begun to investigate coverage we could get with the RF spread spectrum frequencies. This showed that we can expect potential dead spots (nulls) in the haulage, however with antennae and reception algorithm design, and the intelligent use of the cell concept, we should be able to engineer an acceptable solution. This then becomes a challenge to be engineered by the end of the year 2001 in preparation for the first high speed data radio requirements.

8.3 Implementation

Communications technology is a dynamic field with technology becoming redundant at a frightening rate. The trick is to stay optimally ahead in the emerging technology market conditions and take note of converging standards that indicate the long-term winners amongst the supplier products. Methods are proposed in this dissertation to manage this. Firstly by means of best practice reviews, where the cumulative expert resource of a company like Anglogold is used to speculate on technology forecasting and to spread these approaches and knowledge. Secondly by appointing communication champions and implementing 'approved plans' for all communications domains, so that we have control over the purchase and engineering of such systems. Finally with the implementation of the technology framework developed in Table 2, to give us the relationships between the domains we identified, the technologies we need to watch and the needs we must take cognisance of.

Further there is a tailored project management process identified in Figure 8 that is geared to fit in with the macro technology management issues around communications systems.

The dissertation provides effectively 2 models for medium and long term mines (Figure 27 and Figure 28) that are the generic communication blue prints for shafts in these categories.

8.4 Summary

The mining environment and the communications technology field are both unique in their own way, requiring a defined strategy to achieve successful implementation and management. This dissertation, developed six methods to effectively manage communications systems in deep level mining, namely:

- Best practice reviews,

  Where peer professionals in Anglogold meet and present their plans and methods, and from which best practice is identified, developed and spread.

- The communications project management process,

  Where needs, technology forecasting and system implementation control are emphasised. Integrating this with the best practice review methodology results in a recommended life cycle management plan for communication systems (Figure 10).

- The RF code of practice guideline,

  Where the critical issue of RF spectrum management is taken care of and safety issues around RF in general are addressed.

- The appointed CIC champions and domain plans,

  A person must be appointed to enforce and manage the planning process, and identify future needs.

- The mine communications models,

  Where three separate generic models/approaches are presented appropriate to the value they are likely to add to the business.

- and the technology framework,

  Where a framework was developed to watch technology developments against communications needs, contextualised in the domains identified to rationalise the number of communications systems there are.

These practices and models must be integrated into the macro-management policies of existing mines to achieve the full benefit available.

As a follow on from this dissertation, both the stope antennae and RF spread spectrum haulage units need to be developed and successfully demonstrated in a pilot system.

This is only required by the end of the year 2001, and the chances of success of this development is estimated as good considering the preliminary results available from this dissertation.