TACTICAL MINE MANAGEMENT

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B. Eng., McGill University, 1997
M. A. Sc., University of British Columbia, 1999

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

In

THE FACULTY OF GRADUATE STUDEIS

(Department of Mining and Mineral Process Engineering)

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

December 2001

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Date ~~[illegible]~~ Dec. 18th 2001

DE-6 (2/88)

ABSTRACT

This thesis proposes a methodology that creates the core components of a tactical mine management system (TMMS) that adapts, for mining, the new information technology and management techniques that have proven to be successful for other industries. The resulting TMMS is intended to provide the motivation and means to make improvement initiatives through the use of modern management techniques that takes into account the particularities of the mining industry, operations, and culture. This work is considered important as tactical management in mining now has the opportunity to take advantage of the management technology currently available to other businesses.

The methodology was developed through investigations into the history and use of production management in mining and other industries. The particularities of mining were explored to define the issues a potential management system needs to address. The proposed methodology is organised into four development phases that each produces one of the four core components of a TMMS. The first phase develops a systems plan, whereby the evolution and implementation of the management system components are planned. The second phase involves the building of a data infrastructure appropriate for the use of modern management techniques in mining. The third phase designs a set of measures for evaluation of employee and mine process performance. The fourth phase establishes procedures in which the performance measures can be used to motivate and enable improvement initiatives.

Field studies over a two year period were used to develop and evaluate the TMMS methodology at several INCO Limited mines in Sudbury, Ontario. The TMMS methodology resulted in establishing the four key management components that subsequently led to motivating tactical mine managers to initiate improvement initiatives and the development of more complex management components. These initiatives were undertaken using modern management techniques such as simulation and activity based costing. The results revealed that an effective TMMS can be created using a methodology that takes mining's technical and cultural characteristics into account.

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LIST OF ACRONYMS

ABC	Activity Based Costing
ABM	Activity Based Management
AHP	Analytical Hierarchy Process
BPD	Business Process Design
BPR	Business Process Redesign
CAD	Computer Aided Design
CASE	Computer Aided Software Engineering
CI	Continuous Improvement
CSF	Critical Success Factors
E-R	Entity-Relationship
ERP	Enterprise Resource Planning
GF	General Foreman
GPS	Global Positioning System
GUI	Graphical User Interface
HR	Human Resources
IDEF0	Integrated Computer Aided Manufacturing Definition Zero
IE	Industrial Engineering
IS	Information System
IT	Information Technology
ITH	In-the-Hole (drill)
JIT	Just-In-Time
KPI	Key Performance Indices
MIMS	Mine Information Management System
MRP	Materials Resource Planning
PIMS	Process Innovation for Mining Systems

PLC	Programmable Logic Controller
PM	Production Management
SADT	Systems Analysis and Design Technique
SPC	Statistical Process Control
SSM	Soft Systems Methodology
TOC	Theory of Constraints
TQM	Total Quality Management
TMM	Tactical Mine Management
TMMS	Tactical Mine Management System
VRM	Vertical Retreat Mining
WMC	West Mines Complex

ACKNOWLEDGEMENTS

I wish to take this opportunity to acknowledge the support provided by the following:

Mr. Glenn Lyle for the support, direction, funds, effort, hardware, experience, trust, ideas, encouragement, opportunity, and constructive criticism throughout my time at INCO. The Lyle family for the friendship and home opened to a stranger undertaking a project across a continent.

Mr. Alan Akerman, for facilitating the INCO funding and the opportunity to complete this work in a mining operational environment. Acknowledgement is also due to NSERC for its funding assistance through the IPS program.

Mr. Rick Godin, Mr. Robert Booth, Mr. Denis Deschamps, Mr. Gary Gagnon, Mr. Jon Gill, and all the INCO West Mines Complex employees that facilitated the research, provided data, and a forum for this work.

UBC Committee members Mr. William Stanley, Mr. Kenneth Matthews, Dr. W. Scott Dunbar, and Dr. Rimas Pakalnis for their input, understanding, tolerance, and time in reading the many drafts of this work. Dr. Vassilios N. Kazakidis (Laurentian University) for his guidance and friendship.

Dr. Malcolm Scoble, for his inspiration, encouragement, technical help, and friendship.

Not least, my wife, Omaia Dessureault for her support consistent, personal sacrifices, patience, tolerance, effort, and encouragement to complete this work.

Chapter 1 : Introduction

Tactical management, the control of all aspects of the operation not beyond a scope of one year, in underground hardrock mining operations has not significantly changed in the past fifty years. Systematic or optimisation improvements in underground mining have primarily focused around exploiting economies of scale instead of modifying the mining system itself.[1] The production management system is the heart of the mine yet most education and research in mining is dedicated to peripheral and strategic issues such as rock mechanics, metal markets, the environment, ventilation, mine design, automation, and equipment. As the real value of most mineral products continue to fall, the survival of the mining industry in the 21st century will require fundamental changes in both technical and managerial technology. These two sources of innovation allowed other business sectors to remain profitable. The manufacturing sector has primarily focused on the production and control system along which their products gain value. This focus on the production system has resulted in the development of technology and management techniques that can improve productivity, quality, and profitability. This thesis examines the successes of manufacturing to advance the development of tactical mine management.

This thesis proposes a methodology based on process management and accountabilities that creates the core components of a tactical mine management system (TMMS) that adapts for mining the new information technology and management techniques that have proven to be successful for other industries. Mining's unique cultural and technical particularities necessitate the retooling of new management technology. The core components of the methodology to create a TMMS include; first the definition and acceptance of an evolutionary plan, whereby both management and production systems can be continuously improved; second, a centralised integrated data infrastructure which can enable these changes; third, a set of performance measures that account for mining's organisational and workplace culture; and finally, a managerial infrastructure that enforces the proper use of the management system.

Information technology (IT) is the key enabler for modern management techniques.[2] The potential for IT was recognised in a recent survey of mining industry leaders, by the RAND Institute, which concluded that information and communications technologies represent the most critical priority for mining research and development.[3] The study acknowledged that much data already exists in most operations but that it is under-utilised. Knowledge management is the means by which such data can be converted into valuable information. Human factors were also identified by the mining leaders as playing a key role in the usefulness of the information. Humans, and the culture which influences their behaviour, are becoming "more critical to the success" of the technology that would lead to more optimal production systems.[3] Prior anthropological studies and the experiences of this thesis research indicate that the mining workplace culture has a dual nature: a management/engineering and a worker culture.[4] The mining production system also has a dual nature because it lies somewhere between an ongoing construction project and a hybrid batch-continuous manufacturing system. Mining processes also vary according to the nature of the workplace where the work is undertaken. Any application of information technology or management technique will need to take mining's unique culture and particular production system characteristics into account.

The TMMS methodology was developed by first identifying and analysing modern management techniques, the industries that spawned them, and the factors leading to their success. The characterisation of current mine production management systems also identified their most pressing deficiencies as well as the differences compared to those industries that have been more successful at controlling production. These differences were considered when the proposed methodology was designed to incorporate the best available management techniques. Developing a TMMS for all underground mines was not considered feasible, as the culture, workplace conditions, and processes are unique to virtually every mining operation. In the communication of new management techniques, the developers typically present general guidelines or a methodology whereby the key components of the new technique are discussed. This approach is used in this thesis, where a methodology to create the key components of a TMMS is proposed. The TMMS methodology is a procedure that would produce a tactical management system for an underground hardrock mine incorporating IT, the best available management techniques, key data elements particular to mining, and mine-specific cultural issues. This TMMS development methodology was applied and refined in field studies associated with three operating INCO Ltd. mines in Sudbury, Ontario, over a two year period.

The proposed methodology only provides the design of the development process for the core components of a TMMS. The use and success of the TMMS depends on evolving the management system in parallel with the mining system. The methodology's logic is organised in four development phases and one operational phase. The four development phases provide the steps and issues that are pertinent to each stage of TMMS development. The development phases are composed of systems planning, data infrastructure building, design of performance measures, and establishment of a management infrastructure. The description of the operational phase offers recommendations on implementation and maintenance of the management system. Figure 1-1 is a graphical representation of the logic of the proposed methodology. It reappears throughout the thesis to link the logic to the issues discussed.

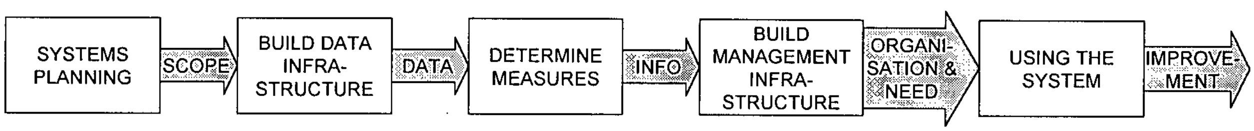

Figure 1-1: The logic of the Phases of the TMMS methodology.

The development of any complex system must begin with a plan, therefore, the first phase in the development of a TMMS involves laying out the scope, development, and implementation of the components of the management system. A template from which a TMMS can be justified, planned, and implemented is developed based on successful reengineering models used in other industries. The core elements of this phase are to first establish management support for change. The second element is to characterise the culture and mining system. A reengineering team that will design the management system must then be, built, educated, and inspired. The use of system modelling, process visualisation, planning, and creativity tools facilitate these activities.

The proposed methodology recognises that the information systems in mines are not designed for modern management techniques, therefore the second phase of the methodology involves the design and implementation of a data infrastructure that would allow the development of process-based management techniques with data elements that are particular to mining. Database design, data and systems modelling, and data collection mechanisms are issues relevant to the design and implementation of a data infrastructure. Other key issues addressed by the proposed methodology are mining's particular need for greater data integration, tracking of workplaces, and lack of automated on-line production data collection.

The third phase of the methodology involves designing the measures that convert the data into information that can measure performance, diagnose processes, and be used in the application of management techniques as improvement initiatives that require process information. These performance measures use the capabilities enabled by the integrated data infrastructure built in the second phase of the TMMS methodology. Since most modern management techniques focus management's attention on the core processes that generate value, the most basic measure is a comparison between the costs (inputs) and products (outputs) of each core process. Activity based costing (ABC), is a management technique used in many industries to undertake such a comparison and is discussed as it would be applied in the development of a TMMS. ABC differs from the commonly known 'standard costing' in that the ABC process costs include the overhead and support expenses that a process consumes. Performance measures, accountability structures, targets, and rewards are effective mechanisms to control behaviour of the managers and workers. Designing such measures must take the organisational culture into account. The cultural and technical issues of establishing the measures within a TMMS is discussed as the primary focus of the third phase of the methodology. Performance measures for management allow for greater accountability and should motivate managers to improve processes to align with the company's objectives. Diagnostic measures would also allow managers to identify sub-optimal processes that require improvement. Other measures may be required while undertaking process improvements that may be solution-specific. The techniques and issues in the development of ABC, performance, diagnostic, and solution-specific measures are discussed as the third phase of the methodology.

The fourth phase of TMMS development involves the design and implementation of management infrastructure to motivate the personnel within the particular culture of the mine to maintain and improve the production system. Organisational design, a field within Industrial Engineering, can be used to develop the meetings and procedures that would guide such behaviour. Organisational design is used in the fourth phase of the TMMS methodology to design such meetings and procedures. The meetings required for a TMMS would include performance reviews, improvement initiative design sessions, goal setting and planning, and an auditing function that ensures that the TMMS remains effective.

The methodology's four development phases should produce the core components of a TMMS, namely the justification, data infrastructure, performance measures, and management infrastructure. These basic components must ensure that the operation's culture is taken into account and that the required data infrastructure to apply modern management techniques is established. The operational phase of a TMMS consists of undertaking the procedures as laid out in the fourth phase of development (management infrastructure). Performance data is collected and converted into information such as performance or diagnostic measures. A series of meetings and analyses as stipulated in the management infrastructure, evaluates the performance of employees and either rewards for constructive behaviour or encourages improvement which should take the form of improvement initiatives. When undertaking improvement initiatives, the data infrastructure facilitate the use of modern management techniques, which usually require process-based information. Examples of both the development and operation of the TMMS are discussed.

1.1 Research Approach

Between January 1999 and December 1999, the author undertook a background review of the management techniques adopted in all industries. This identified the key management techniques and infrastructure requirements necessary to employ those techniques. A review of tactical management in mining operations identified the deficiencies of both infrastructure and standard management systems. A methodology was designed to develop the core components of a TMMS that would eliminate the issues of current systems and enable the benefits of modern management techniques.

Throughout the later half of 1999, a search for an industrial sponsor with an operating mine willing to implement changes in their tactical production management systems resulted in the opportunity to collaborate with the INCO Ltd., Ontario Division. Further refinement and application of the TMMS development methodology began in January 2000 and continued until November 2001 at Ontario Division' West Mines Complex. The mines within the study included Coleman/McCreedy East, Creighton, and Crean Hill. The work was completed under the academic supervision of Dr. Malcolm Scoble and assisted by Dr. W. S. Dunbar, Dr. Rimas Pakalnis, Mr. W. Stanley, and Mr. K. Mathews. Industrial supervision was accommodated by Mr. G. Lyle and Mr. A. Akerman of INCO Ltd.

1.2 Hypothesis

Tactical mine managers currently have less ability to control, forecast, and monitor the production system than their contemporaries in other industries. The unique culture and dynamic production systems of mining have a limiting effect on the use of modern management techniques. The perceived need for better control, new information and communications technology, and the knowledge management needed to gain value from that information has focused attention toward tactical management. Other industries have gained great advantage from implementing new management techniques that appear to be adaptable to mining. This thesis therefore addresses the fundamental need for an organisational development methodology to establish a TMMS in operating mines that permits the successful application of modern management techniques.

Several basic assumptions that are not directly discussed in this work are the necessity of a viable orebody, skilled and motivated workforce, functional safety program, and appropriate strategic planning. A large, high-grade, orebody can mask deficiencies in management, as well as provide sufficient funds for effective employee training. The importance of training the employees in the technical and social skills needed for effective management cannot be understated. The effectiveness of the TMMS resulting from the application of the proposed methodology depends on the level of skill and training of the employees at the mine. However, tactical management systems can provide some direction for management training programs and increase the effectiveness of strategic planning. For example, a gap in technical knowledge may be revealed during the implementation of an improvement program where managers must apply statistics or process mapping techniques. Information at a strategic level would be improved as aggregated tactical-level information similarly improves.

1.3 Research Objectives

It is the purpose of this thesis to advance the effectiveness of tactical production management systems for mining. This is accomplished by developing a methodology that produces the core components necessary for the use of modern management techniques. These components provide the basic infrastructure for a Tactical Underground Mine Management System. The emphasis has been placed on issues concerning tactical mine production, management techniques, culture, and information technology.

The objectives of the study are to:

- Explore the history and intricacies of modern production management techniques
- Determine how mines are currently managed at a tactical level
- Characterise how the management systems of a mine differ from other industries

- Consider how modern management techniques can be applied in a mining system
- Develop a methodology that would allow the creation of a TMMS that would lead to the application of modern management techniques
- Evaluate the applicability of the proposed methodology in mining operations

1.4 Contributions

Major contributions made by this thesis are considered to include:

- A discussion of the issues of current tactical underground mine management
- A concise review of the evolution of modern management techniques and current mine management.
- An analysis of the differences between the tactical management of a mine and that of other industries
- The development of a methodology that uses modern management techniques to facilitate the creation of the core components of a TMMS that itself is capable of using modern management techniques. The contributions within this proposed methodology include:
  - The establishment of a reengineering model based on the successes and failures of other models
  - The framework of an integrated mining data infrastructure
  - The identification of performance measures and issues for mining
- An exploration of the cultural issues of a mining operation in terms of its impact the production system.
- The first thesis on the development a modern framework for tactical mine management that considers new information technology, modern management techniques, and the mining culture.

1.5 Thesis structure

The thesis is structured as follows:

Chapter 1: Introduces the topic and discusses the major contributions, research approach, and describes each chapter.

Chapter 2: Discusses the key concepts of this thesis and how the issues discussed in the appendices relate to this work.

Chapter 3: The mechanics of a TMMS: clearly defines the phases and issues of the methodology to produce the core components of a TMMS.

Chapter 4: The proposed methodology that was applied at several INCO mines. This chapter reviews aspects relating to its impact and implementation.

Chapter 5: Draws conclusions and outlines recommendations for future work.

A series of appendices provide a description of the background research that was required in the development of the TMMS methodology. Figure 1-2 shows the structure of the thesis. As can be seen, chapters 3 and 4 are the core of the work. These two chapters are organised according to the five phase logic as seen in Figure 1-1.

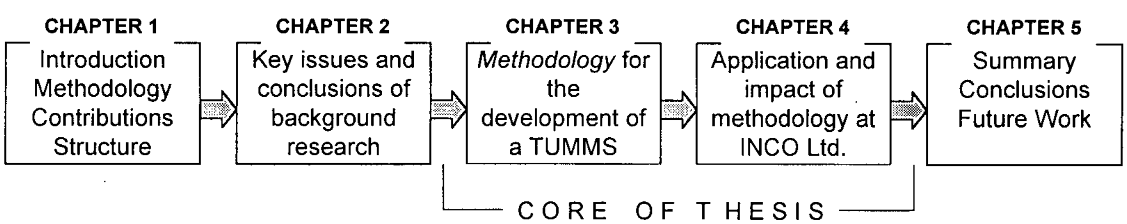

Figure 1-2: Thesis structure and flow

[1] Hustrulid, William A. and Jan-Olov Nilsson. "Automation and Productivity Increases at LKAB, Kiruna, Sweden." *Ann. Gen. Meeting, Can. Inst. of Min., Met., and Pet . May 2-5, Montreal, Quebec*, CD-ROM, 9p

[2] Davenport, Thomas H. *Reengineering work through Information Technology*, Boston: Harvard Business School Press. 1993.

[3] Peterson, D. J., LaTourette, T. and J. T. Bartis. "New Forces at Work in Mining: Industry Views of Critical Technologies." RAND institute online report. March 23rd, 2001. http:/www.rand.org/publications/MR/MR1234/

[4] Rouse, Michael J and Usher Fleising. "Miners and Managers: Workplace Cultures in a British Columbia Coal Mine." *Human Organization Journal of the Society for Applied Anthropology*. Vol. 54, No. 3, Fall 1995, pp. 238-248

Chapter 2 Concepts and Issues of Tactical Mine Management

Chapter 1 introduced the background to this research. It elaborates further on the issues and core concepts within tactical mine management. This thesis deals with the management of mining operations. These complex systems have both concrete characteristics such as technology, activities, procedures and materials, as well as esoteric concepts such as employee motivation and culture. This is a subject with very little prior study and many likely divergent precepts of the status of mine production. TMM requires research not only based on mining engineering but also on information technology and management science. This work is based on a critical review of prior and current mine management research and development, together with the observations made by the author whilst working in several underground mines in Canada.

The chapter begins by limiting the scope of this work by only considering the tactical management of underground hardrock mines. The purpose of this work is to develop a methodology that produces a TMMS which incorporates successful management techniques used in other industries. Many of these techniques are not directly applicable to mining due to cultural and technical differences. The second section of this chapter highlights some of the important differences between mining and other industries. The detrimental effects of these differences can be compensated for, once understood. The most important difference between mining and other industries is cultural. Incorporating issues of culture in tactical management is a key aspect of the TMMS proposed by this research. An analysis of culture is presented within the discussion of the differences between mining and other industries. Considering the complexity of the concepts and issues within TMMS, additional definitions and analysis used to develop the methodology are included in the Appendices. Most of the Appendices are based on research required to develop the methodology. Table 2-1 summarises how this supporting research contributed to the development of the TMMS methodology.

Table 2-1: Appendices of Supporting Research.

Appendix Name	Description of Investigation	Contribution
Appendix A: Definitions within Scope.	Discusses the key concepts within the scope of work including a work hierarchy, culture, and soft/hard technology	Provides clarification and formal definitions of the key concepts within the scope of work.
Appendix B: Organisation of work.	Discusses and provides further examples of the organisation of work as discussed in Chapter 2.	Provides clarification and formal definitions of key concepts in many modern management techniques
Appendix C: Issues in Tactical Mine Management.	Critically examines the current deficiencies typical to the mining industry. Considers only published and public material. Does not discuss the industry leaders in these topics.	Provides a generalised list of issues that should be addressed through an alternative management system in mines
Appendix D: Thesis Evolution.	Describes how the tactical management of mines was identified by the author as a key issue from observations of the limited success of automation in mines.	Shows how the idea is original and will eventually contribute to the successful implementation of advanced technologies into mines.
Appendix E: Development of Modern Production Management.	Provides a history of the development of modern production management for all industries including a section that focuses exclusively on the development of mining production management.	By analysing the development of modern management systems in comparison to those used in mining, the differences between mining and other industries can be identified. Also introduces successful management tools.
Appendix F : Establishing a TMMS Framework.	Distils a reengineering framework for mining systems from successful reengineering models. Lists the prerequisites of a mining operation to successfully implement the TMMS methodology. Clearly defines a TMMS framework.	Provides the reasoning behind the methodology's development. Also lists the prerequisites of a mine prior to the application of the TMMS methodology.
Appendix G: Management Techniques in Development and Use of a TMMS.	Provides descriptions and examples of the management techniques used in the development and use of TMMS. Also provides a list of management techniques that are enabled by establishing a TMMS.	Provides those unfamiliar with modern management techniques examples of such techniques within the context of the TMMS.

2.1 Delineating the Scope of the TMMS development methodology.

This work deals with a methodology that is intended to be applied to underground hardrock mines. The methodology develops the core components of a tactical underground mine management system. These core components include a systems plan, data infrastructure, measures, and management infrastructure. Experience from other industries indicates that issues of workplace and regional culture must be included in any management system. Technology must also be considered in tactical management systems as management science, information technology, computers, and automation/mechanisation, and applied sociological science will continue to expand the abilities of management in controlling and improving production systems. There are many complex issues and concepts within this scope that are explored and discussed in the Appendices. The important concepts, which help limit the scope of this work, are summarised below:

- Limiting the analysis to underground hardrock mines;
- Disassociating the management of the mill from that of the mine;
- Exclusion of strategic and safety issues;
- Classification of a work hierarchy;
- Modern management techniques.

2.1.1 Hardrock Underground

This work is confined to hardrock underground mines as they are technologically and successfully tactically managed in different ways from softrock and surface mines. Softrock mines may use highly mechanical and continuous processes where shearing or tunnelling machines produce a near-continuous flow of material. The abilities of tactical managers in surface mines are also different from underground mines as the extraction methods, technology, workplaces, and machines are significantly different. The recent development and use of Global Positioning System (GPS) technology and dispatch systems, for example, allow surface mining processes to be monitored and optimised automatically in real-time.

2.1.2 Mine to Mill

This thesis also makes a distinction between the mine and mill. The operation of a mill is very similar to processing industries, such as chemical or petroleum plants. Much of the operation is process controlled using computers where the operating variables are well known and understood. Mines require the flexibility of a construction project and use processes that are as methodical as manufacturing processes. Therefore, only mining operations are considered in the TMMS methodology. Scheduling or quality issues stipulated by the mill are included in the scope since the mine's product is an important variable in the milling process. The mine's customer, the mill, should provide the product specifications required.

2.1.3 *Tactical*

This research also only considers tactical issues. Tactical mine management, deals with issues or procedures that sustain day-to-day or month-to-month production. The scope of tactical management decisions would not normally extend beyond one year. For purposes of comparison, strategic management involves the decisions that affect the long-term results of the mining system or industry. Major changes in the mine that will affect fixed costs, long term productivity, workforce relations, metal markets, communities, or the economy are all issues that can be considered strategic. These types of changes will most likely require capital and corporate involvement.

Safety systems are already well established in most operations.[1] Tactical management systems cannot be disassociated from safety issues, for example, performance measures for mine managers frequently have a measure of the safety record over the period of evaluation such as lost time accidents. However, since safety systems are already well studied and include considerations for mining culture, no additional analysis of safety issues is included in this research.[2]

2.1.4 *Organisation of Work*

This thesis deals with work management. Work classification is a term relating to organising work. Figure 2-1 shows is a linguistic mechanism of organising work into a hierarchy common to many modern management systems. [3] The example used here shows how several tasks can make up an activity, several activities make-up processes, and all processes are considered part of the system. As work is organised into increasingly lower/detailed actions, the issues involved in managing the work components change. For example, managing at the task level is undertaken by the miner. A miner is typically responsible for operating the drill in an efficient manner so that the tasks of collaring the hole through to moving the drill are undertaken as quickly as possible within the quality constraints. Comparatively, activities are managed by the foreman. For example, foremen must ensure that the workplace is set-up appropriately, that the drill is ready at the appropriate time, that the drilling is undertaken efficiently and properly, and that the drill set-up is dismantled on-time. Issues of supervision, quality, and schedule pervade managing at the activity level whereas issues of physical productivity are key at the task level. Appendix B provides an in-depth discussion of this work classification system along with additional examples.

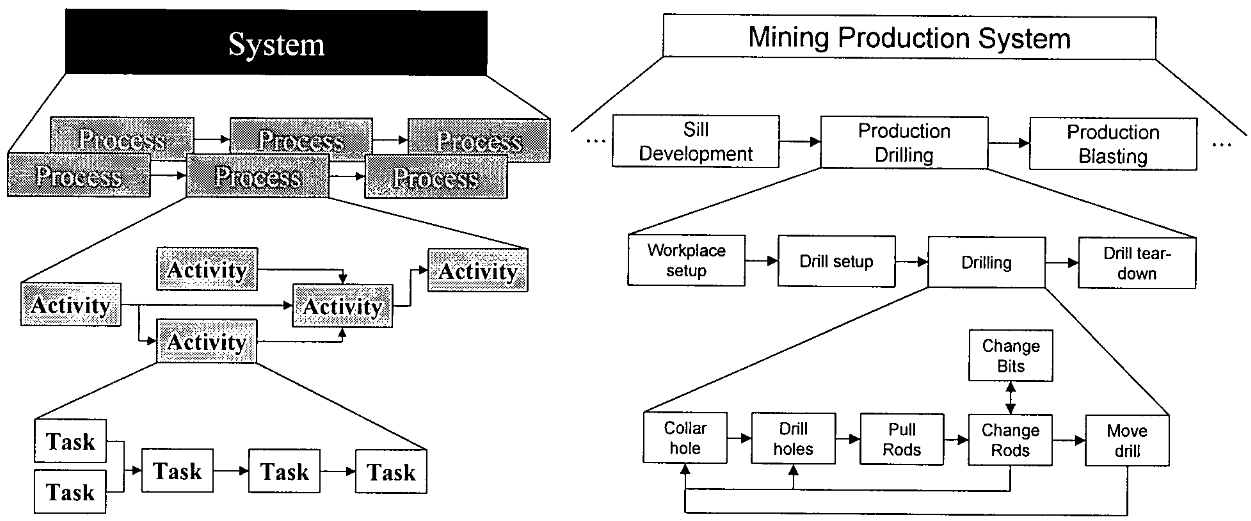

Figure 2-1: Conceptual breakdown of work, nomenclature and example.

2.1.5 *Modern Management Techniques*

Modern management techniques have been developed to help achieve organisational goals. These techniques may be considered to be part of industrial engineering, yet also known as operations management or management science. These techniques can be mathematical or organisational in nature. For example, linear programming algorithms can help optimise logistical problems through integrative mathematical calculation. Organisational improvement tools such as Reengineering, Activity Based Costing (ABC), or the Theory of Constraints (TOC) can improve the management systems of organisations so that the systems, processes, activities, or tasks are improved. Successful modern management techniques developed for and by other industries, may not be applicable to mining due to technical or cultural differences. The ability for mine management to control and improve the system through modern management techniques would be achieved if these techniques were applicable to mining. The components of the TMMS proposed in this thesis allows for the application of modern management techniques.

Some modern management techniques such as ABC and reengineering are used in the methodology as discussed in the next chapter. ABC is a technique to calculate the total cost of producing a product. The total cost should include all raw material, labour, equipment, maintenance, and overhead costs. The inclusion of overhead and support costs is what distinguishes this method from the better known standard or unit cost. For example, these overhead and support costs can include the expense of delivering the raw materials and/or transporting workers to the workplace for a particular process/product. This type of accounting requires a significant amount of production and cost data so that the costs can be accurately distributed to the appropriate process and/or product.[4] ABC was feasible only once IT made cost aggregation affordable. Another modern management technique that is enabled by IT is reengineering.[5] Reengineering is an organisational design methodology that uses a team of experts within an organisation to aggressively redesign the processes to conform to the strategic goals. This method advocates the use of IT in automating clerical work and improving service functions.[6]

Appendix G provides descriptions and hypothetical examples of the types of management tools used in the development of a TMMS. This management system is designed to establish the information and management infrastructure required to use modern management technique to improve the production system of a mine. Therefore, modern management is used in both the development and use of a TMMS.

2.1.6 *Synopsis of Limiting the Scope*

In summary, this work is limited to the establishment of a methodology for developing tactical management systems for underground hardrock mines. Limiting the scope in this manner allows a breadth of work sufficient for a single thesis. Ample scope exists for similar analyses of surface and/or softrock tactical mine management systems.

2.2 Uniqueness of the Mining Industry

The key reason modern management techniques remain unused in mines is the differences that exist between mining and those industries where the techniques were developed. Most modern operations management techniques were developed in the manufacturing or service industries. Differences between mines and factories, or other businesses, can be compensated by recognising then circumventing or accommodating those differences. The differences between mining and other industries are discussed in the following section. The purpose of this discussion is to determine how these differences would impact the utilisation of the techniques.

2.2.1 Construction Project or Factory?

The mining production system has a dual nature because it is somewhere between an ongoing construction project and a hybrid batch-continuous manufacturing system. Mines are similar to construction projects as most headings and stopes are interrelated according to a planned schedule. For example, a ramp must be developed in order to begin production mining by a certain date so that the monthly production quota is met, months, even years in the future. Another time-dependency example is where a large blasthole stope must be backfilled before the adjacent stope can be blasted. The production schedule is as important in a mine as it is for a construction project. Other factors which are common to both the mining and construction industry are:

- reliance on skilled workers for virtually every process;
- significant engineering design resources are needed on a daily basis;
- equipment mobility.

Factories do not require as much labour, daily design engineering resources or equipment mobility. Furthermore, a factory has far more flexibility in the assembly of a product. For example, raw material and work-in-process inventories can be stockpiled or purchased elsewhere in the event of a breakdown of a key process.

Mines are similar to factories in that mine processes are cyclical and the quality of work impacts on the costs and value of the final product. An example of the cyclical nature of mine processes is the series of activities within the development process, namely drill, blast, muck, support, which are repeated for years in the development of a ramp. The mucking cycle when mining a stope can last months, while the crushing process can remain unchanged throughout the life of the mine. Like a factory, these processes are designed to be repeatable without great variation. If the infrastructure, equipment, and procedures are maintained and are of good quality, then the processes should not vary to a significant degree, with the exception of workplace constraints. Therefore the manufacturing management techniques where workflow is studied and optimised, can be applied to mines. Techniques that focus on process integration, where the outputs of an upstream process are aligned with the inputs of a downstream process, are also extremely useful in mining.

Quality is not as great a concern in mining as it is in manufacturing. Most mines are equipped or designed to withstand outputs of poor quality. For example, many mines have secondary breaking mechanisms if blasting was of poor quality, or extra mucking horizons if an inexperienced equipment operator cannot achieve the required production from a particular stope. However, like manufacturing, these lapses in quality induce extra costs. For example, poor drilling frequently causes either blocky muck or dilution. Oversize muck increases mucking and crushing costs. Dilution reduces the value of the ore. Techniques where quality is closely measured may not be as useful in mining as in manufacturing but may still lead to significant improvements.

In conclusion, a mine can be seen as an on-going construction project that uses cyclical batch processes to create the infrastructure required for mini-factories (stopes) where hybrid batch-continuous materials handling networks move and process the product (ore) to the customer (mill).

2.2.2 *Workplace*

An important difference between mines and factories is the added complexity of the workplace, where the performance of identical processes in different workplaces (location) can vary significantly. For example, the mucking process at one draw-point may contend with different operating parameters than the mucking process in a different location such as added tram distance, road conditions, or muck size. Similarly, production drilling in one area of the orebody may be different from the production drilling in another part of the orebody where the rock may be harder or have many detrimental geological structures. Ground conditions can also close-down workplaces. Workplaces not only impact the process outputs but may also pose safety concerns. For example, some areas within deep underground mines have additional safety constraints where the procedures may be altered due to ground conditions. In comparison, in manufacturing, drilling a hole in a piece of metal with the same machine on one side of the factory can be compared to the performance of drilling the same size hole in a piece of metal on the other side of the factory. This component is a key added data element that should be monitored in a mine's production information system (IS). Many modern management techniques use comparisons between similar processes in order to track performance, or identify and plan improvements. The additional element of workplace would be required for the use of such techniques in the improvement of a mining system. Several aspects of the workplace would directly affect the managerial decisions and resulting performance including the mining procedures, timing, progress, quality, and maintenance costs. Information about these various aspects would be important in tactically managing the mine's various workplaces. The complexity of this information would necessitate the level of data integration found in many centralised information systems.

Most data elements in factories would be required for the management of mines, such as:

- Supplies / raw material and work in progress;
- Procedures / instructions;
- Machine / equipment availability;
- Manpower / labour.

2.2.3 Comparisons with Other industries

Construction and manufacturing are not the only industries from which new management techniques can be taken and modified for mining. Retail, engineering services, and agricultural industries all have management techniques that may be useful to mining. Retail industries are experts at ensuring that inventory is always on-site yet minimised. Minimisation and control of the inventory of raw material in mines would improve the bottom-line and relieve congestion at key bottlenecks. Mining requires continuous engineering to design the new workplaces, to track and control active workplaces, and to maintain the infrastructure (ground conditions, drainage, ventilation) in mined-out areas. Engineering firms have applied management techniques that ensure timely and high-quality design. The agriculture industry have expertise in land management and surface drainage from which mining may benefit. As the use and benefit of IT in other industries progresses, mine managers and researchers should keep abreast of developments for potential application and advantages.

2.2.4 Labour

Currently, mines require personnel for virtually every underground and surface mining process except hoisting and conveying in some mines. Researchers are in the process of automating the various processes that make up the production system, however, these systems are far from being widely available commercially. Increased automation would reduce the issues in today's mines that relate to workers. The discussion below highlights the factors within the mine that are affected or exacerbated by the intense use of labour. [7, 8, 9]

- **Dynamic working environment**: Decision making at lower levels of management have greater effect on workers. Mid-shift changes due to ground or equipment failures frequently change the daily plan, which can also affect the workers. For example, mid-shift line-up changes may cause reduced morale and productivity (through travel time) or injuries (because the operator is not familiar with the dangers in that workplace).
- **Cultural behaviour**: The degree to which the culture of the workplace affects productivity is increased with added dependence on labour. Cultural effects are discussed later in this chapter.
- **Incentive schemes**: Incentive schemes are used to control worker performance in operations. Unfortunately, many actions that are counter productive are rewarded by out-of-date or poorly designed incentive systems. Incentive systems are typically inflexible and difficult to alter.[10] For example, a development round requiring less holes but resulting in increased over-break and damage may be preferred by some miners as it would require less time to drill. The miner would attempt to reduce the total cycle time if the incentive systems rewarded workers exclusively for total footage driven, without reward for quality.
- **Human flexibility**: Active tactical management requires a flexible workplace. Humans are not as flexible to change work processes or rates as robots working in factories.
- **Human fallibility**: Much of the value of production information is at some point, influenced or processed by workers. Human involvement in data collection, process, or analysis can induce errors. Manufacturing uses Programmable Logic Controllers (PLCs) and networked sensors that provide the data far more accurately than the labour intensive data gathering used in mines.
- **Human variability**: Miners may execute their work tasks differently. For example, production drillers may set up their workplace prior to longhole drilling in a different way resulting in different production rates or levels of organisation.
- **Mechanised processes – human logistics**: In analysing the cycle time to advance a drift one complete round (development advance), more time is spent setting-up equipment, fetching raw material (such as bolts, steel, and explosives), and dismantling the set-up than the time spent drilling

or bolting.[11, 12] The efficiency of modern machines and increasingly effective operator-assist technologies have improved the core drilling and bolting tasks. The organisation and efficiency of setting-up workplaces, assembling the raw material, and timing of break periods (all logistical functions) remains the responsibility of the miners who have limited training in logistical optimisation.

These issues can be compensated by training a more flexible workforce and incentive system, education in logistics optimisation tools, deliberate and gradual implementation of better management systems, and/or increasing the level of automation. Management techniques developed in semi-automated factories will not be as applicable in a mining environment since the human induced variability will be more pronounced. For example, in the application of the Theory of Constraints, the standard deviation of the capacity of a process is an important parameter. A higher degree of variability will inevitably be introduced when humans are the key components of a process instead of a numerically controlled machine.

The impact of culture on a mine's productivity is amplified by the increased labour requirements. The cultural differences between mining and manufacturing transcend simply the impact of increased labour requirements, as the cultures themselves are different. Worker relations are deeply integrated with labour and cultural issues as the culture of management has a direct baring on the resulting attitude of the worker. An example of the effect of management culture on worker culture is discussed below, where disciplinary action was imposed on a worker who parked his vehicle 3 minutes before the end of the shift despite having worked through lunch. The workers were disaffected by this disciplinary action on their fellow worker and therefore unmotivated to contribute any extra effort for the company for several months following the incident. The reliance on miners for every process makes labour and the cultural interaction that governs its behaviour of utmost importance in the management of a mine. The importance of people is confirmed by Stanley: "You can have the most modern, technically sophisticated equipment in the world, but if it is run by an unmotivated, uncaring workforce, you won't be able to compete in today's world."[13]

2.2.5 *Cultural Differences*

As discussed earlier (chapter 1 and above), culture is a factor with potentially the greatest impact on productivity. It is also the most difficult to manage. The cultural differences between mining and manufacturing have a direct bearing on the implementation effectiveness of technology[14] and managerial techniques.[15] Many inter-related factors that generate a unique mining culture are rooted in the industry's long history, in particular (as discussed in Appendix E):

- union militancy;
- philosophical shifts in management thinking;
- world markets;
- miner de-skilling;
- safety issues;
- mining communities.

As many of these issues deal with historical events clouded by political/economic censorship and are more esoteric in nature, a specific scientific approach comparing mining and manufacturing culture is not feasible. However, a discussion on the workplace culture within mine operations is necessary and provided in the following sub-sections.

2.2.5.1 Mine Management

Runge has characterised mining culture as quiescent due to the successes of the past. He characterises mine management as acting on "gut feeling", relying more on experience than scientific analysis in making decisions, and using the rules of the past since they have proved successful. These characteristics are divergent from today's management business climate as: [16]

- A set of rules can be completely erroneous, endure for a long time and yet still yield excellent results for day-to-day application. Runge uses an analogy of how the Ptolemaic system (flat earth) continued to be used for navigation even after the Copernican system (round earth) was well accepted. Hence, as business conditions and precepts change, so should management.
- Experience is valuable only to the extent that the future conforms to a pattern of rules that have applied during the formulation of that experience. Therefore the expertise developed may no longer be applicable in an era where market conditions and business concepts are different.
- Current mining paradigms should be challenged. Mining companies typically use guidelines to keep innovation low (in-the-box) when hiring consultants. Innovation will therefore usually come from outside the industry.

Runge suggests that mine management and executives should consider challenging mining paradigms. In general, Runge is calling for more flexibility in mine management. The issue of mining's risk aversion to new technology prompt the common adage: "Miners like to be first to be second."[17] Investigations in Appendix C and above are interpreted characterisations from experts within the mining industry that may be perceived as critical. A more objective scientific assessment of mining culture is best undertaken using the specific science that analyses culture: anthropology.

2.2.5.2 Anthropological View

Anthropology is the study of cultures. Anthropologists undertake scientific comparative studies to determine how peoples of the world are similar and how they are different.[18] They are engaged in issues relating to contemporary society, such as health care, human rights, law, industry, urban development, environmental management, and global population. One of the few scientific studies of the cultural elements of a mining workplace that mentions productivity issues was undertaken by Rouse and Fleising[19], an anthropologist studying a British Columbia coal mine. The anthropologist spent several years living in the community of Elkford, working at the mine and at various other jobs, all in close contact with the mine employees. The overall conclusion reached by the ethnography (documented anthropological study) was that it would be difficult to find two more contrasting cultures, interacting in such close quarters, as the organisational cultures of management and workers in mines.[19] The degree to which the two cultures differ, yet must work together, create an environment possibly unique to mining.

The following discussion borrows heavily from the Rouse and Fleising study and anthropological theory. The goal of this discussion is to show the unique nature of the mining culture, but also to understand the cultural motivations in a mine so that appropriate managerial techniques can be instituted allowing for increased productivity. The discussion describes the management culture, the workforce culture, and then concludes by summarising the effect of the interaction between the two cultures. Rouse and Fleising uses a cultural model from Schien which postulates that culture has three levels: artefacts and creations, values, and basic assumptions.[20] Artefacts and creations refer to the physical and social environment including technology, art, behaviour and symbolism. Values are the groups' ideal state of being, their "should be" state. Basic assumptions are the non-conformable , non-deviable foundations of culture which "pre-consciously inform notions about the reality of time, space, human nature, activity, relationships and humankind's relationship to the environment."[20] The difficulty in change management is modifying these basic assumptions.

2.2.5.3 Management / Engineering.

Rouse and Fleising identified the top-down nature of the mine management hierarchy (is discussed in Appendix C) and the fact that the management culture in mining is really a manifestation of the culture of engineering, as most mine managers are engineers. The basic assumptions of engineers is summarised by the concept of order. Engineers impose order into potentially chaotic situations through a method described as "authoritarian rationale," they are inclined to closure, oriented to mastery, focused on facts, analytic, collegiate, structured and respectful of rules.[21] The respect for rules, authority, and structure manifest themselves in the penchant for engineers to document. Rouse and Fleising noticed that careful records are kept of activities, policies, and production with the intention of using that information for future improvements. Rouse and Fleising noted an example of the strict following of roles: when a truck operator suggested a solution to a problem, the foreman replied: "You are paid to drive, not think". Other elements of engineering culture noted by Rouse and Fleising include:[19]

- any activity, solution, or plan that appears to proceed without a set of clearly elucidated expert knowledge is met with suspicion;
- engineers require active intervention, where any decision is better than no decision;
- abilities necessary to facilitate the objectives of the organisation are highly valued. For example, the pit foremen with great tactical management skills were highly regarded;
- the relationship between engineers is characterised by a strong competitive nature. Rouse and Fleising noted how this competitive nature among the engineers at the mine grew to a point of dysfunction until a senior management intervention brought about a team-building program;
- a lack of trust toward the workers manifested itself by the assumption that the workers required constant supervision. This may also explain the popularity of incentive systems especially for underground mines. "The difficulty in supervising people in underground mines requires that they be given extra motivation to work hard."[22]

The overall cultural element among engineers was labelled as "order". Through the strict control of the environment, direct action, while following rules, the engineers are able to establish a sense of "order" on potentially chaotic environments.

2.2.5.4 Mine Workers

The central cultural element for mine workers is "security". Not to be confused with safety, security relates to the need for the stability of employment and the continuation of a lifestyle. This need for job security is a historical legacy prior to the labour movement where workers had little job protection. Rouse and Fleising notes that the job security enjoyed by today's workers have far more security and remuneration than their forefathers. From personal interaction, the anthropologist noticed a complex risk analysis undertaken by the workers when confronted with a potential conflict. Workers calculate factors such as their financial and social situation, general state of the economy and prospects for employment, strength of the union, and amount of support they can expect from other workers and the community.[23] The need for security also finds expression in resistance to change. Rouse and Fleising noticed that virtually any change introduced by management without in-depth consultation with the union is viewed with suspicion. This can be attributed to the history of the industry (discussed in Appendix E), where technological or world market changes had significant effect on employment stability.

Basic assumptions of trust, forgiveness, and solidarity are strong between workers. Anthropological comparisons with 'kin groups' is a characteristic of workers within a union. The observation that within the worker culture, 'kin groups', separated by job functions, is also evident as plant, maintenance, and mine workers have even closer ties with each other. Reciprocity also plays a major role within the basic assumptions of a worker, where increased work should result in rewards or forgiveness. Rouse and Fleising uses the example of a worker who cut his lunch-break in half to clean-up the turn-around area by a shovel (the area around a shovel where a haul truck would turn around can typically get littered with muck that falls off trucks during the loading process).[19] At the end of the shift, the operator who cut his lunch short, parked his vehicle 3 minutes prior to shift end, bringing condemnation and a documented disciplinary action by the foreman. The worker believed that he ought to have been forgiven for this minor infraction as he helped the mine during his lunch-break. For a period of time, few workers would provide any extra help for the company citing that particular incident.

2.2.5.5 Management-Worker Interaction

The difficulty of mine management becomes apparent considering the contrasting nature of these two cultures. The dependence on skilled operators in every mining process further compounds this issue. However, by acknowledging the necessity to maintain a sense of security for the workforce and a perceived state of order for management, management systems can be designed to address these cultural needs. The methodology for the development of a TMMS described in this thesis was written for management/engineers, thereby using documented and structured theories from experts and focuses on using past knowledge for future benefit. The obvious engineering nature of the thesis should not detract from the necessity to acknowledge that workers and functions which they complete will change as a result of the application of this methodology. Therefore worker representatives should be included in the activities of TMMS development.

Ethnography, the fundamental research method of cultural anthropology, has techniques that characterise culture. Some knowledge of ethnography would be useful for those designing a TMMS as cultural differences between mines vary and must be considered. The theory and application of ethnography was used in the development of the methodology and results presented in the next two chapters. The TMMS methodology was partly developed at operating mines where the workplace culture and dynamics between management and hourly workers varied significantly between mines.

Rouse and Fleising's model of the cultural conflict within mines is a common characteristic of the industry and can be used as a starting point for further cultural characterisation. Table 2-2 is a comparison between management and workforce culture. The methodology described in this thesis should only be implemented when taking the unique cultural situation in mining (the management-worker interaction) into account.

Table 2-2: Mine Management and Workforce Cultural Comparison.[19]

Cultural Domain	Management Culture	Workforce Culture
1. Identities and environments	Role based identities. Environments are those that have potential impact on the mine. Structural hierarchy	Identities based on friendship and work/community status. Environments based
2. Nature of reality: bases for decision making	Objectively determined reality. Potential impact requires decisions	Reality subjectively determined. Past impact warrants decisions
3. Nature of time	Present that facilitates the future	Past that informs the present
4. Nature of human nature	Hardworking, committed, individualistic, competitive	Hardworking generous, trusting, forgiving, communal (with each other)
5. Nature of human activity	Proactive, interventionist	Reactive
6. Nature of human relationships	Outside relations based on competition inside based on role-centred hierarchy and competition for promotion	Outside relations based on tradition, co-operation/ consensus. Inside based on friendship, consultation, participation. Reciprocity paramount
7. Central concept	Order	Security

Once these differences are taken into account, the following conclusions can be made:

- Proving that a particular plan will work by collecting data and undertaking calculations or simulations will be an effective mechanism to sell change to management but not to the workforce.
- Any endeavour that includes altering how the workers function should have direct involvement with the workforce;.
- The variables in the worker's "risk calculation" (financial and social situation, general state of the economy and prospects for employment, strength of the union, and amount of support they can expect from other workers) will have a direct bearing on the willingness of the miner to participate or submit to change. A management system should consider these needs within a TMMS;
- Reciprocity is extremely important as miners expect to be compensated for increased effort. This may be the cause for the prevalence of incentive (bonus) schemes. Rewards should also be considered if miners choose to participate in the development and application of improvement initiatives.

The next chapter describes ethnography and how it may be used in the development of a TMMS. Ethnography is also used to characterise in the field the culture of the workers and managers/engineers, as detailed in Chapter 4.

2.2.6 *Comparing Culture between Mining and Other Industries*

No published comparisons of mining and manufacturing workplace culture were found. However, in published reports of reengineering efforts in other companies, several examples comparing cultural flexibility were identified.[24] Increased cultural flexibility allowed greater benefit from modern management techniques.

The dual nature of mining may also be unique to mining. An important difference between mining workplace culture and that of other industries is the importance that culture has on the productivity of the overall system. Mines rely on human involvement for every process (an aspect shared with the construction industry) and therefore the workforce and its behaviour is a fundamental ingredient in improving the mine production performance.

2.2.7 *Information Availability*

Manufacturing, retail, and service industries are very familiar with the use of information. Being heavily automated, the manufacturing industry requires detailed information about the processes in the factory in order to control inventory, quality, and throughput. The widespread computerised control of many of the machines within a factory provide industrial engineers with the information and control needed to apply the management techniques. For example, the retail sector closely tracks buying behaviour and buyer statistics for marketing purposes and inventory control. Bar-coding and the computerised inventory ordering systems allow the retailers and manufactures to cut costs and offer their customers the lowest possible price. Service industries such as Engineering consultants can be networked allowing concurrent engineering, speedy communication and better technical service to their customers.

The availability and structure of the information is a critical difference between these industries and that of mining. IT is a central focus for many of these companies.[25] IT is not mentioned in modern mine management books[26] or in a mining company's mission statements (see infomine.com). According to the aforementioned RAND report (Chapter 1), mining leaders believe that mine operations are producing more data than ever before yet the data remain largely unused.[1] The missing element is effective knowledge management which is the ability to turn data into action. The same leaders believe that IT is one of the critical technologies for the future of mining. Considerable amounts of data in mines is available but the extent to which that data provides knowledge is limited. Knowledge management is a key aspect to modern management techniques which typically use IT and management procedures to improve the cycle time or quality of both processes and products.

As the importance of IT continues to grow in other industries, mines will continue to recognise IT's importance. The cost of collecting and processing data into information is quickly being reduced through computer networks, integrated databases, sensors on mobile equipment, and wireless communication technologies.

2.2.8 *Equipment Reliability*

Mining equipment has low reliability compared to the machines in manufacturing plants which can consistently produce quality products for months without requiring maintenance. Paraszczak *et. al.* insists that the reason for such low reliability is in the methods of maintenance records keeping, the abusive nature of mine processes on equipment and the mining environment. The author also discusses how the focus of management in mines is on very short term production targets, not managing maintenance for long term productivity. The authors list the differences between mining reliability and those of other industries:[27]

- Reliability is a relatively misunderstood concept;
- Unlike other industries, mining has no safety regulations stipulating a certain level of system reliability;
- Mine equipment manufacturers do not deliver large quantities of equipment so substantial testing is not affordable. Most mining equipment manufacturers also have little access to equipment maintenance records;
- No standard method of collecting maintenance data exists;
- Mines typically use measures that do not adequately reflect the necessary reliability statistic. For example, engine hours are used on LHDs where the real cost drivers of maintenance are tonnes-kilometres;

- The low profit margins and high equipment costs in mining companies necessitate the need for less equipment;
- Poorly structured mine costing systems rarely allow for the calculation of equipment costs.[28]

2.2.9 Natural Bottlenecks

Underground mines suffer additional bottleneck constraints such as a shaft or adit. Particularly for deep mines, the delivery of raw materials and the hoisting of ore and rock create difficult logistical constraints rarely experienced in manufacturing. Storage space underground is also expensive as voids to store inventory are expensive to construct and material is frequently damaged due to the harsh wet environment. Raw material delivery techniques such as JIT and MRP are therefore more challenging to implement.

2.2.10 Remote locations

Factories can be built in locations close to their suppliers or customers whereas mines must be built where the deposits were formed. There are several practical and cultural issues related to remote locations. An example of a practical issue is that additional costs must be incurred through long distance transportation of the bulky raw materials and product. A cultural challenge induced by remote location is the difficulty of finding and keeping a well-educated and diverse group of experts.

2.2.11 Synthesis of Uniqueness of Mining Systems

The above discussion highlighted some of the most important elements that make mining unique and create complications when implementing best practice production management techniques. The most important characteristics include:

- Lack of information infrastructure;
- Importance of acknowledging the influence of workplace;

- Skilled labour and relatively small monitoring ability;
- Unique dual culture of engineering/management and workers;
- Poor equipment reliability, bottlenecks from constrained workplaces, and remote locations;
- Similarities with both the construction (scheduling importance) and manufacturing (repetitive processes);

The above characteristics should be considered in designing a TMMS for mining based on production management techniques developed in other industries. The methodology presented in the remainder of this thesis aims to incorporate the unique aspects of the mining system into the core components of a TMMS.

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Chapter 3 Mechanics of the Tactical Mine Management Methodology

The previous chapter reviewed the key differences between mining and other industries. The research used to justify and develop the TMMS methodology is documented in the appendices and chapter 2. These investigations include a description of the historical and technical development of production management. Production management in mining is reviewed separately because the operational constraints, goals, and culture are different. Information technology is identified as a management tool that has been well exploited by other industries and could potentially benefit mining.

This chapter reviews the theory, reasoning, and procedure of the methodology. The methodology aims to use IT, modern management techniques, and incorporate cultural issues. The resulting TMMS should be flexible and increase management's control of the production system. It should also identify areas in which tactical managers should receive training. The methodology is organised into five distinct phases:

- **Scope/systems planning**: this phase ensures that the system is adaptable for the future by laying out a preliminary design of the future management system taking into account anticipated technology and corporate goals. Constraints that could be built into the management system can be avoided by envisioning the long-term evolution of IT and management systems;
- **Build data infrastructure**: the application of data modelling is used in this phase organise the various data sources, once identified;
- **Determine measures**: Measures are the key to good performance management and the building block for information used in operations management techniques. Accountability measures induce the need to improve resulting in improvement initiatives. This phase develops these measures and accountabilities;
- **Build management infrastructure**: The use and maintenance of any management system requires organisational design. This phase designs and implements appropriate procedural mechanisms to ensure the effective management of the system;

- **Using the system**: Findings on how to use, maintain, and further evolve the system together with hypothetical examples are addressed in this phase;

Figure 3-1 shows the structure of this chapter (the same structure is followed for chapter 4 and in Appendix G). As can be seen, each phase is discussed separately. This chapter presents the theory for each phase. These concepts can be perceived as a general guideline, procedures, and methodology for tactical mine managers interested in creating the core components of a TMMS.

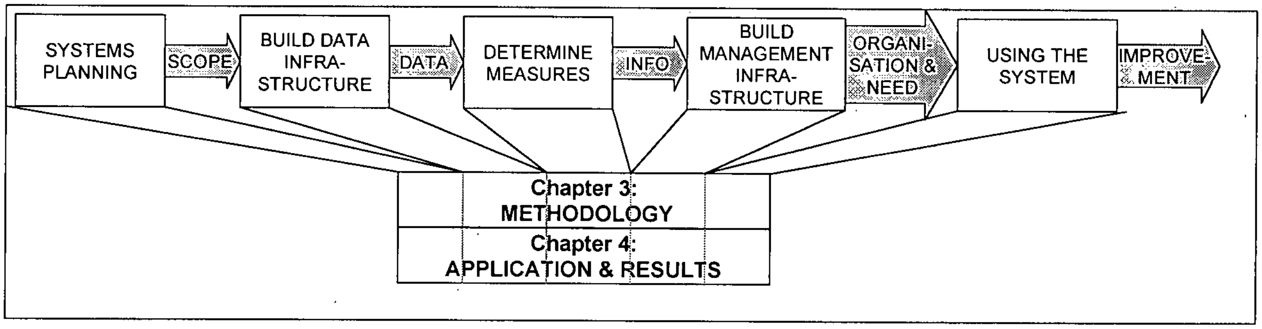


Figure 3-1: Five Phases of the TMMS Methodology.

3.1 Systems Planning Phase

A strategic plan for the evolution of technology and management systems is of key importance to the long-term effectiveness of these systems.[1] The establishment of a TMMS includes a systems planning component. Figure 3-2 shows the difference between classic and modern systems life cycles, from current systems theory.[2] The additional step of systems planning is required due to the intense complexity of IT and business issues. Systems pass through this life cycle from top to bottom where the basic building blocks at each level are people, data, activities, networks, and technology. As the business issues are defined and developed into a technically functional system, the system becomes increasingly more detailed. As the purpose of this work is to define a new tactical mine management system, planning the evolutionary life of the system is important.

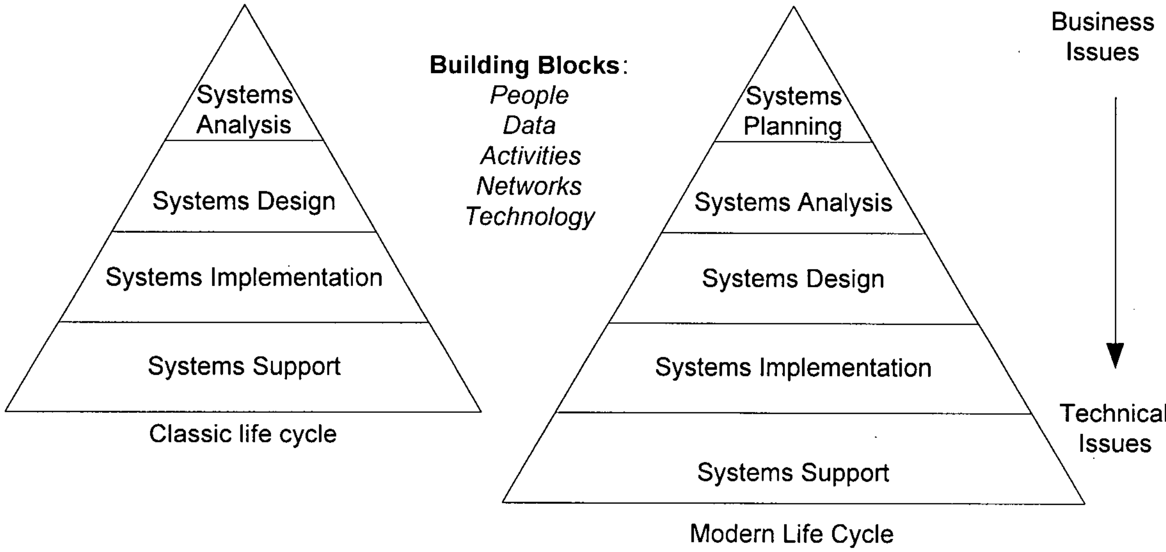


Figure 3-2: Classic versus Modern Systems Development Life Cycle[2]

The purpose of the systems planning exercise is to envision a management system of a mine that automatically induces the need to improve the operational processes. Therefore the intended "end-in-mind" is to produce procedures, IT infrastructures, measures, and accountability that would institutionalise and facilitate improving operational and managerial processes. The TMMS is a process of evolving management systems into an increasingly more powerful tool for positive change. In order to initiate such an evolution, the general path of growth for the system must be envisioned. The ensuing discussion relates how to reach achieve a vision, the tools that can help, what to do with the output, and examples of such visions.

3.1.1 Preparation

The preparation process should not take longer than a few weeks. The most difficult step is the inspiration step as front-line and service managers will be asked to abandon management systems that mask mistakes and accountability to a system of clear accountabilities and increased management participation within the production system. It should be mentioned that absolute unconditional support from team participants is not a prerequisite. Management systems which evolve over time and that are not too intrusive at the outset, can gain acceptance over time. The most time consuming step will be training since some managers may be unfamiliar with modern management techniques.

3.1.1.1 Team forming

Management should always be a team effort, even when redesigning management systems. The redesign team is usually made up of experts within the various core functions or processes. [3] A typical redesign team would have the following members:

- **Operations**: exemplary foremen, and the supervisor of the foremen, sometimes known as general foremen, mine captains, or shift-bosses. Some outstanding operators may also be included.
- **Engineering**: chief engineers or engineering supervisors that deal directly with the operations personnel.
- **Maintenance**: central managers of maintenance.
- **Mill**: these are usually the customers and may have input constraints that should be considered.
- **IT department**: a representative from the IT department is a key yet often overlooked participant on reengineering teams. They can provide expertise on the capabilities and limits of IT.[4]
- **Outsider**: consultant, researcher, or academic, that is not part of the culture of the operation, yet can provide fresh perspective or management expertise.

3.1.1.2 Education

Once the team has been formed, the participants are educated in IT and best practice management techniques. An in-depth literature review, as undertaken for this thesis is not necessary; a simple cross-section of some of the key papers listed in the endnotes would suffice.

3.1.1.3 Inspiration

During team formation and the education process, the team leader, preferably the most senior team member, should communicate the benefits of undertaking such a process. These are Change Management issues that are important but too large to be covered in the scope of this work.[5]

3.1.2 Visualisation

Once the preparation steps are complete, the current and future mining and management systems must be visualised. The challenge of visualisation is to be able to not only mentally formulate a future end-state system, but to create one that can be communicated to current and future management. The visualisation process begins by establishing a common vision of the required management inputs for the operation. As these needs would differ between operations, a general guideline on visualising is discussed in this subsection. Visualisation is aided by tools that pictographically represent system components and their inter-connectivity.

3.1.2.1 Visualisation Tools

The communication method used is not as important as the ability to efficiently represent processes in the mining system. Various process description techniques exist, including:

- Flowcharting;
- Process mapping;[6]
- Cross-Functional mapping;[7]
- Soft Systems Methodology (SSM);[8]
- Structured Analysis and Design Technique (SADT)[9];
- Scenario analysis;[10]
- Systems thinking (Senge's);[11]
- Brainstorming[12].

These tools should be used to roughly map out the current processes within operational and service systems. In mining, the likely lack of familiarity of these tools would necessitate the use of the simplest methods such as process mapping and flowcharting. SADT is one of the most complete and structured tools but may be unfamiliar with mine employees. These methods are described in Appendix G.

3.1.2.2 Understanding the Current and Required Management System Components.

Graphical representation of the system aids in understanding how it functions. In building a common understanding of the current and needed management systems a consensus must be reached among the team designing the TMMS. A series of group meetings where the reengineering team seeks to understand and characterise the mining system is undertaken in this phase. A further benefit of increased understanding and documentation of the system is risk mitigation. Through increased understanding of the constraints and behaviour of the system, managers would better understand how to deal with random obstacles to production goals. Once a consensus is reached, the technical and social systems in the mine should be documented using the visualisation tools. The list of questions below can be used as topics of discussion to uncover the key systems and mining processes in group discussion. The first series of discussions should be directed toward understanding the technical and social goals of the organisation (and how a TMMS can help accomplish those goals) :

- How does the mine control the social/labour component of the operation?
- What do the internal and external customers want – what and how do they measure their inputs?
- What are the core processes in the mine (what is the value chain of the operation[13])?
- How are the strategic directives interpreted into action?
- How effective are the mine's supervisors?
- Are the accountabilities within the management structure clearly defined and understood?
- What are the key positive and negative characteristics of the organisation's culture?
- What is the return on equity and unit cost?[14]

- What foreseeable technological developments will occur over the next ten years in both mining methods and supporting technology and how would they be managed?
- Are the existing systems designed or did they evolve without a clear path?

Once the long term objectives have been established by answering the questions above, a more proactive approach can be taken. The initial key aspects that must be analysed to design a tactical management system are:

- Understand and measure the inputs and outputs of the operational and managerial processes;
- Understand the needs of workers in terms of supervision, motivation, and participation;
- Understand the current workplace culture and the management systems that would be required to achieve the desired workplace culture;
- Understand the influence of managerial structure on the quality and effectiveness of the various functional departments;
- Understand the inputs and outputs of the strategic management systems.

3.1.2.3 Final Product: the Evolutionary Plan of the TMMS.

The output of the visualisation is a general plan of the evolution of the management system. Once the long-term and key tactical management requirements are identified, a plan to implement specific management components is laid-out. The core component requirements of any TMMS remains the four components as described in this chapter (a plan, data, measures, and management infrastructure), however, the specific mechanisms that achieve the results vary by mine. Table 3-1 suggests some possible mechanisms by which the core of a TMMS is established. Note that some of these components may already exist to some degree in an operation. As each component is developed, the necessary management infrastructure is established so that the TMMS is immediately functional. The issue of fully implementing each component independently, is clarified in section 3.4.

Table 3-1: Potential TMMS Components

TMMS Component	Development phase	Description
Auditing tool	Data Infrastructure	A mechanism to easily diagnose the validity and accuracy of the core data is necessary since sensor data or to a greater degree, key punch data, may have incurred errors. The ability to easily correct faulty data is also important.
Unitised costing	Data Infrastructure / Performance Measures	Ability to link the unit of output with the inputs which it consumed. Basically, integrating all data through database links.
Informed Process Based Budget	Performance Measures	Typically used to determine a high-level tactical manager's performance targets. Corporate strategic planing usually requires a mine to forecasts its costs and production on an annual basis in some detail. This information is then passed upward for corporate strategic planning. The strategic managers can then use the budget as the performance measures for the high level tactical managers (superintendents)
Capacity Analysis	Performance Measures	Ability to calculate the capacities of the activities, processes, or system. For example, analysing productivity by workplace location, worker, piece of equipment, etc....
Process Production Monitoring	Performance Measures	If planning and control functions are managed by process, information related to day-to-day progress according to plan should be collected for the key processes. These numbers can be aggregated for accountabilities at higher management levels.
Unit Process Control	Performance Measures	Unit process control technology can provide log data that acts as raw data. As a management system, these unit control tools such as PLCs are more automated and technical in nature.
Real-time Optimisation	Using the System	These systems are typically automated and therefore infrequently require additional input other than design constraints. However, if specific goals such as blending or asset optimisation algorithms are available, additional information and management systems may be required. Similarly, if operators are not following orders, disciplinary intervention may be required. Therefore real-time optimisation is a management system whereby pertinent information is delivered to the front-line supervisor in real time.
Process Optimisation	Using the System	Optimisation using algorithms frequently require statistical information. For example, when analysing mechanical performance, mean time between failure (MTBF) and mean time to repair (MTR) are common variables used for optimisation.
Equipment Rationalisation	Using the System	Determining the costs of a piece of equipment (repair, lease/depreciation) as a factor of its productive units (Example: $/bolt installed). This can be used to help equipment acquisition or retirement decisions.

3.1.2.4 Systems Plan Examples

Note that many of the management systems discussed above are evolutionary in that they use output derived from other management systems. The systems plan is intended to map out the general evolution of the various components of the TMMS. Figure 3-3 is an example of the evolution of a TMMS.

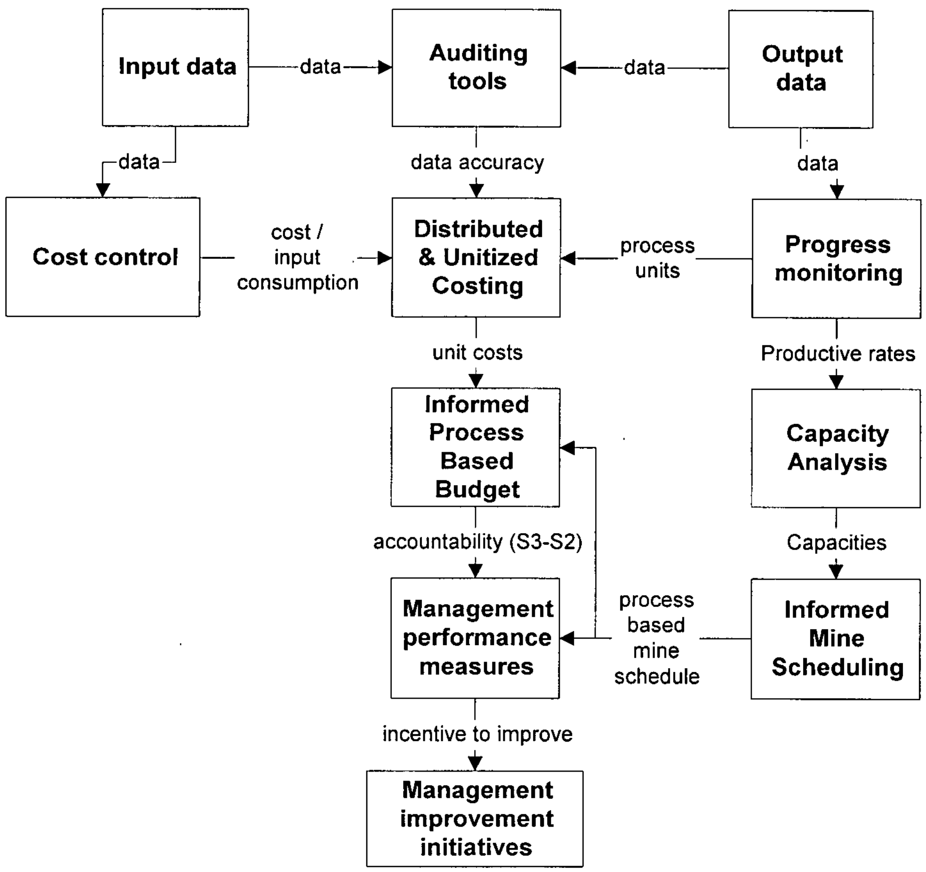


Figure 3-3: Possible Systems Plan, showing a Tactical Mine Management System Evolution.

It must be reiterated here that the management system and evolution proposed above is not applicable to every mine. The above is simply a suggested TMMS evolution. Different mines may formulate different evolutionary paths because mines cany vary by equipment, methods, cultures, and various other important factors. The systems plan developed for INCO Ontario Division West Mines is presented as an example in Chapter 4. Other systems plans exist and are being promoted from IT providers such as SAP.[15]

3.1.3 *Synthesis of Systems Planning*

The systems planning phase is simply the process of mapping out the development of a TMMS. Mine personnel would likely be unfamiliar with this 'reengineering' type process and the process mapping tools needed. Therefore a process of preparation is required where the appropriate TMMS design team is selected and educated. This is followed by a visualisation process whereby the goals and evolution of such a system are defined and documented. Figure 3-4 shows that the systems planning phase outputs or defines the scope of a TMMS so that the design team and IT suppliers can forecast future data needs and management resources. The next step involves building the data infrastructure component needed for a TMMS.

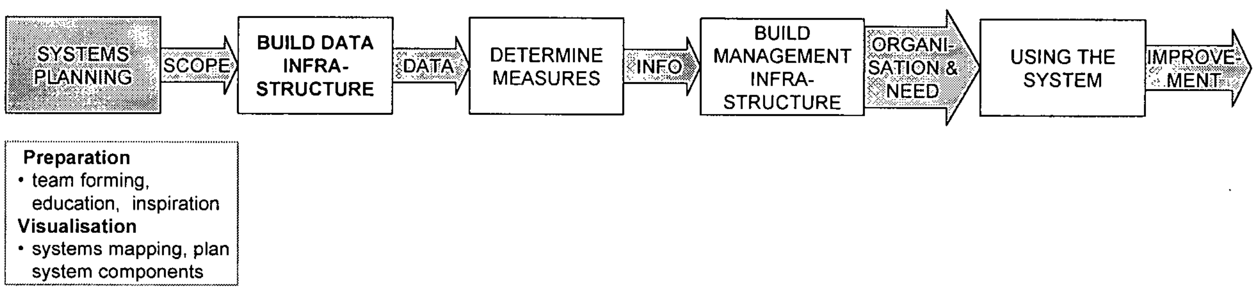


Figure 3-4: Systems Planning Phase Complete

3.2 Build Data Infrastructure Phase

When establishing data infrastructure a distinction should be made between the tasks which mine management is expected to undertake and those that an IT supplier (internal or external) should undertake. Once again consider Figure 3-2: Classic versus Modern Systems Development Life Cycle. The phases at the upper levels of the triangle are the responsibility of the mine operation. IT network and service providers should not be expected to develop the business plan. Neither should mine managers be concerned with the design and construction of databases. However, mine managers should be aware that data collection within the production and service processes is a key concern. IT management and maintenance is an entire field of study best left to experts but collecting the data and choosing what data to collect is the responsibility of the mine employees. When IT suppliers help the operation implement the system, education on how to maintain the information should also be provided.

Managers should be aware of some data modelling theories so that the appropriate core data is collected in a format that can be used in relational databases. Therefore a brief review of relational databases is required. Types of IT and suppliers are briefly discussed in this section. The suggested data required to populate the selected database will also be listed.

3.2.1 *Relational Database*

A data model is used to select data appropriate for a relational database with the flexibility to supply information to the planned management systems. Relational database theory provides a mechanism for describing data. Mine managers do not need to be experts in database design, however, by understanding the basics of database design, deficiencies in the database can be avoided. The basic concepts of data modelling are provided in the following subsections.

3.2.1.1 Basic Nomenclature of Data

Data is described within the database design, on three different levels of abstraction: reality (real world), metadata (information about data) and actual data. [16] Reality is the organisation itself, typically a collection of people, facilities, objects, and procedures that are organised to satisfy particular goals. An entity is an individual object, concept, or event that the organisation wishes to collect data about. An entity class, also known as entity sets or types, is a collection of entities sharing common characteristics. An attribute is a feature of an entity that is desirable to record. Each entity must have a unique property called an identifier. An association is a relationship between other entities within the same class or that span classes. Figure 3-5 provides a diagrammatic example of data within the realm of reality. The figure shows how an entity class could be a group of people who are all employed by the same company.

Entities within that company may be employees. To identify a particular employee a name would be used as an identifier. Several employees may have an association to each other such as their common position as supervisors.

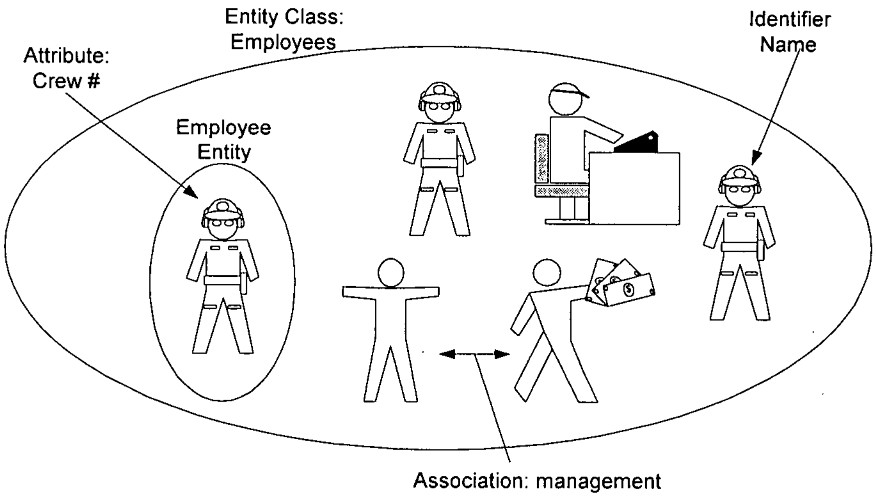


Figure 3-5: Reality Data Nomenclature

Metadata is information about the data being collected. Metadata is stored in the organisation's data dictionary or repository. For each entity class in the real world, there is usually one record type defined in the metadata realm. A data item is the smallest named unit of data in a database with meaning to the user. An example of a data item would be Employee-Name or Employee-Number. The synonyms used within the company are located in the data dictionary (e.g.e: LHD, scoop, scooptram, loader, are all used to describe a load-haul-dump machine). A data aggregate is a collection of data items that have associations. For example, Last-Name and First-Name, are both data items that can be aggregated. A record is a collection of data items and/or data aggregates. For example, for an entity class called Scooptram, one might choose to define a record type called Scooptram Record. A key is a data item used to select one or more records. A primary key is a data item that uniquely identifies a record and is equivalent to the identifier in the realm of reality. A secondary key is a data item that identifies several records that share the same property.

Within the data realm, data occurrences are records that contain data item values, describing a particular entity. For example, within a particular mine, there are 200 mobile machines in the mobile machine entity class, meaning there are 200 mobile machine record occurrences in the database, yet only one definition for this record type in the metadata (only one definition of mobile machine). A file is a named collection of all occurrences of a given record type, for example, the mobile machine file at a mine consists of 200 mobile machine records. A file can be visualised as a table as seen in Figure 3-6, also known as a flat file.

Data Items

Data Item Names

Equip No	Equipment Name	Equipment Description	Equip Type
18411	Locomotive	LOCOMOTIVE DIESEL 337 SURFACE (SCRAPPED)	LC
18917	Longholedrill	ITH BOOSTER COMPRESSOR #405 7000L	CP
19016	Jumbo	JUMBO CMS CJ-2H #551 2BOOM (OOS) 3400L	DR
19183	Boomtruck	BOOM TRUCK, RBL #208 (SEE EXTENDED TEXT)	TR
19199	Boomtruck	SCISSOR BULK LOADER #558 7200 LEVEL	AM
19202	Fueltruck	FUEL TRUCK #469 - 3 SHAFT (OOS)	TR
19279	Compressor	COMPRESSOR TWISTAIR AUX.HST 9SHFT (OOS)	CP
20901	Compressor	BOOST AIR COMPRESSOR #394 7200L	CP

Records

Primary Key

Secondary Key

Figure 3-6: Flat File Using Partial File Record of Equipment List, Example from the Creighton mine.

An association is a relationship between two data entities in a model. The various types of associations include:

One-to-one association: For any point in time, each value of data item A is associated with zero or exactly one value of data item B. For example, for every employee (serial) number, exactly one miner's name is associated to it.

One-to-many association: For any point in time, each value of data item A is associated with none, or many values of data item B. For example, for every miner's employee number, none, or several incentive contract numbers can be linked.

Many to many association: For any point in time, each value of data item A can be associated with many values of data item B and vice-versa. For example, several crews can be under various incentive contracts simultaneously.

3.2.1.2 Data Models

It is important to make a distinction between data models and data flows. Data models depict the internal, logical relationships between the data regardless of who is handling the data or what is being done to it. Data flow shows how the data is handled within the organisation such as who handles the data, where it is being stored, and how it is being manipulated.[17]

Pictographic nomenclatures are used to represent data models. Many were developed as computer assisted software engineering (CASE) tools. Figure 3-7 shows the main components of a simple data model representation scheme called Entity-Relationship (E-R). This is presented so that an example of a mining data model can be understood. E-R diagrams will be used to show how data can be integrated into forming information. Figure 3-8 is a mining data model showing how the incentive contracts are linked in a possible database with the productive units that would be used in the calculation of a bonus incentive. From the E-R diagram, it can be seen that the production records record units produced and where those units were produced. The amount of production that is allocated to an operator is calculated by linking to the production record to the workplace where the work was undertaken and equipment that the operator used to produce the unit. As can be seen, entities can be associated through common data items or relationships.

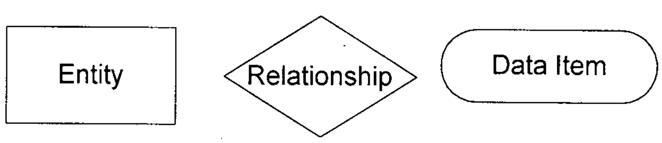


Figure 3-7: Basic Pictographic Components of the 'E-R' Data Modelling Method.

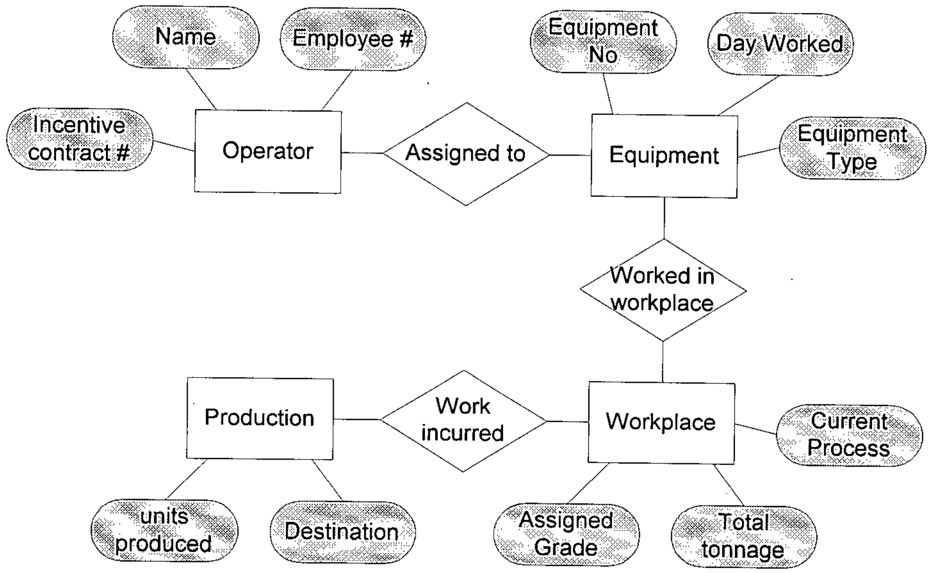


Figure 3-8: Data Model of Link between Incentive Contracts and Productive Units

There are considerably more theoretical aspects to database design, construction, and management than those presented above. Hierarchical and network databases are also widely used and relational database theory is far more complex than described here. This discussion is intended to show how data inputs need to be identified by both mine management and database designers. It is important to understand that computer database specialists should not be expected to be experts in mining while mine managers should not be expected to be experts in databases.

3.2.1.3 Relational Productive Process Database as Critical Infrastructure

In the construction of a relational database, data models are created. Brown-field (already opened and operating) mine sites will already have databases that were developed for particular functions such as:

- Maintenance work-order records;
- Purchasing records;
- Production records;
- Accounting transactions;
- Geographic/Geological Information System;
- Personnel records / training.

These databases were designed for their intended users. Data models were constructed using a systems plan that did not include the TMMS. Their data models are appropriate for their intended applications. For example, purchasing records are archived in databases to undertake monthly cost summaries and GIS is used to formulate strategic plans. It would be difficult, in most current mining operations, to associate a particular production record with the accounting transactions that paid for the work done.

Few mines have designed and implemented a production database. Production information is typically collected using a file processing mechanism where one or more technical staff collect statistics on daily or weekly production performance. This information is input into spreadsheets. Various calculations, usually left to the discretion of the technician, are made for incentive purposes and for tracking the progress of the mine plan. Off-the-shelf, mining-specific production and cost database tools do not exist. Hence, most mines would require a production and cost database to be constructed. Cost databases derived from accounting software may already exist; however, relational links to the unit of production which consumed the cost rarely exists. Figure 3-9 provides an example of a cost data model. When the cost data model in Figure 3-9 is seen alongside Figure 3-8, it would be difficult to directly link the costs of the unit of work produced. The only common data item is the DATE and the only common entity is OPERATOR. Additional data items need to be added to either the cost data model or the production data model so that a closer link can be made. For example, if the supplies ordered are attributed to the CURRENT PROCESS data item in the production data model, a more direct link is created between the costs of those supplies and units of production that were output from the process.

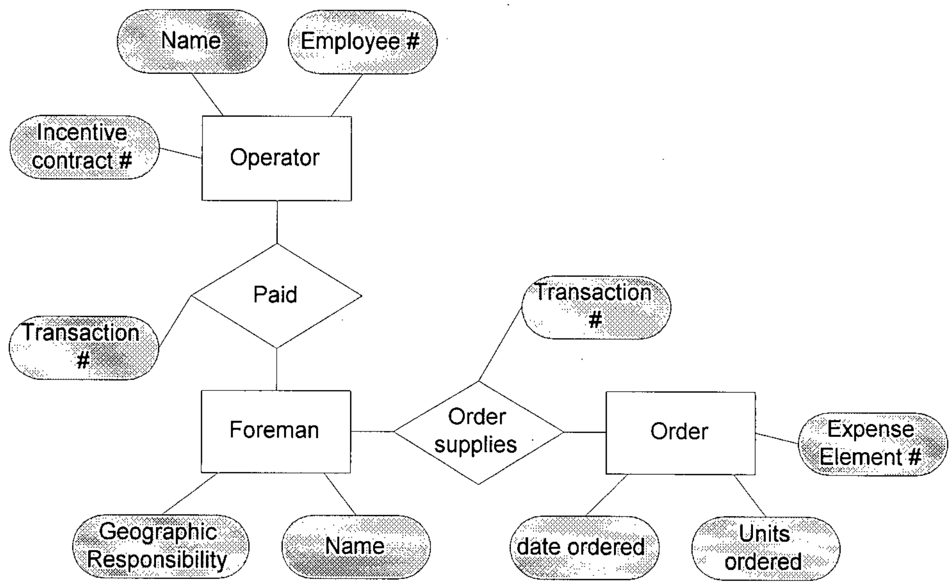


Figure 3-9: E-R Cost Data Model .

Although rare in mining, centralised production databases may exist where automated monitoring and control technology (example: mine dispatch systems) has been implemented. Mines frequently keep records of production but infrequently design the production data as needed for a relational database.[18] This lack of standard results in data measures that vary over time and is therefore not trustworthy. This tendency is understandable since, as discussed in Appendix C, detailed production records have no formalised use in mine management. Therefore a core component to a TMMS is a process based production statistics database. The process based production database should be designed using the basic relational database theory discussed previously. As each mine is unique and mine nomenclature varies, a specific production database may be created for each mine. Speculatively, as production databases become more important in mining operations, a standard measure may be created in the future. This would benefit mines as processes and productivity statistics could be effectively compared between mines. IT suppliers will also begin to provide off-the-shelf IT infrastructure more amenable to TMMS.

By designing the database using data definitions, similar or identical data items can be linked between disparate databases. Equating similar data items from various sources would allow the integration of data between systems such as accounting, personnel, and maintenance. Through closely linked process inputs such as accounting and maintenance, to the process outputs such as tons or footage advance (development output), a process based relational database is created. Figure 3-10 shows how the process based relational database is created by integrating output data with input data. Linking costs to production has been traditionally undertaken at a high-level where absolute outputs such as total tons produced at the mine is compared with absolute inputs such as total dollars spent. The ability to link outputs to inputs at a lower level allows far greater flexibility in analysis and visibility of the efficiency of the processes.

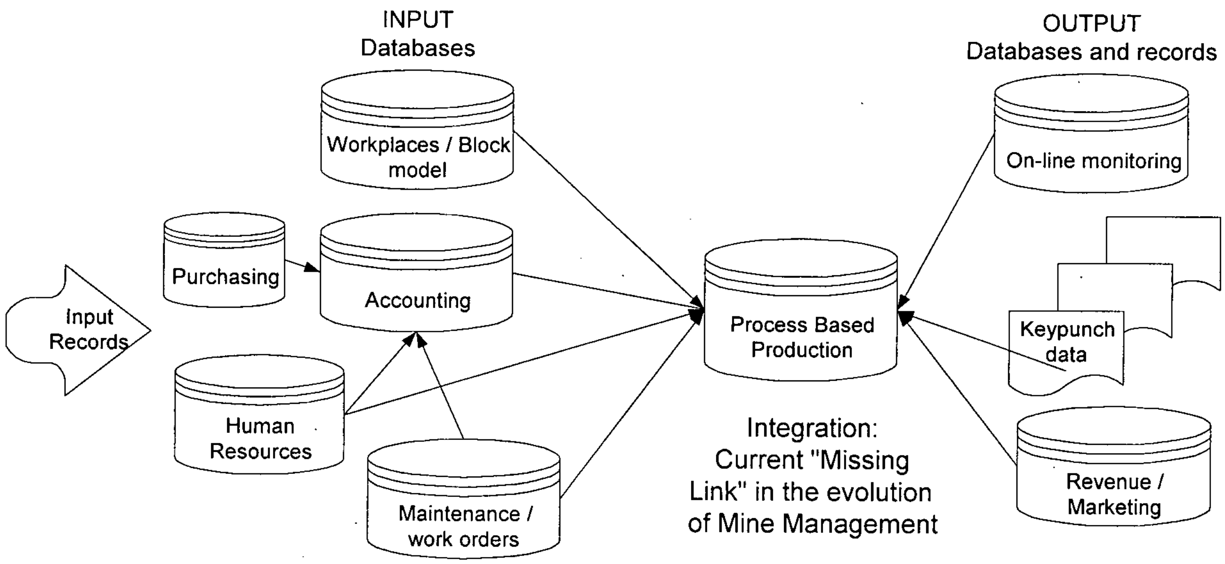


Figure 3-10: Linking Inputs and Outputs by Process

Integration can occur during the design phase of the production database. By ensuring that entities can be appropriately linked, various facets of process inputs and outputs can be analysed. For example, equipment costs can be linked to a piece of equipment. Equipment in turn can be linked to a particular amount of production. Therefore, the equipment cost component of producing a unit of production can be determined. This unit equipment costs per unit of output measure was used at the INCO Ontario Division as discussed in chapter 4. From a database linked in this manner, the productive output by piece of equipment can be compared to its maintenance costs. This comparison is far more accurate and simple when the information is linked in a database than when individual spreadsheets are combined every time the analysis is needed.

3.2.1.4 Flexibility

An integrated relational database would be capable of integrating the appropriate data for any analysis if a well defined systems plan was formulated. However, some changes may be identified that could improve the database. Therefore a key advantage would be the ability to easily change the data definitions and data models so that new data items can be added allowing more options for management systems. For example, consider a group of managers that would like to compare the life of the tires of scoops operating in a particular area with the number of hours grading that particular area. A missing data element may be needed such as the location of where the grader operates. A flexible system should allow the easy creation of a data item called hours and area graded in the records for the grader reports. Unfortunately, some databases are proprietary or difficult to edit in such a manner. Furthermore, brown-field mine sites typically have IT infrastructure for geological and accounting data from off-the-shelf application providers without the capability of sharing between applications. The issue of IT providers is important as much of the technical expertise in building IT infrastructure should be provided by in-house or contracted experts.

3.2.2 IT Providers

IT providers can be loosely classified into 3 types. Table 3-2 provides comparisons between the subjective classification. Note that the best IT supplier with a reliable product will still fail if the mine and its management is not willing to undertake the considerable changes typically needed to gain value from IT.

Table 3-2: Characterisation of IT Providers

Characterisation	Advantages	Disadvantages	Examples
Off the shelf	• Simple & cheap • Frequently without programming bugs	• Too general • No mining specific support • Will require substantial effort from the operation and consultants to construct the infrastructure	Microsoft Access™
Modular	• Option to purchase only those modules that are deemed useful • Mining specific available • Proven in industry	• Modules may not easily integrate • Difficult to learn • Expensive, limited support • Good for large companies • Difficult to implement	MINCOM™
Full System	• Those that can offer such systems are experienced • Usually can be integrated throughout organisation	• Integration efforts must continue and be maintained • Bug prone • Very expensive & complex • Difficult to implement as major operating and management changes are required • Often beyond the scope of understanding	SAP™

3.2.3 *Suggested Data to Collect*

As mentioned previously, a systems plan and a detailed process map are the key requirements needed to determine what data is needed and therefore included in the IT infrastructure. Since each mine is different and systems plans can vary, not all data items are required or available. Similarly, not every process map is identical. The theory and practice of process mapping is discussed in Appendix G; however, a process map is presented here to show how the inputs and outputs for the data infrastructure can be identified. This subsection then lists some suggested data items that would be needed.

3.2.3.1 Process Map

A process map can help identify the workflow, the input and output components, and interaction between the processes. As each mine is different, no generic mining process map would be applicable to every operation. Figure 3-11 is a generic process map for underground hardrock operations. These are the core processes in an underground mine that are managed for maximum efficiency. Therefore information about these processes will be required. Note that a far more detailed process map would be needed to identify the inputs and outputs from key processes. Capacity maps can also help identify data items that may be important to track in order to manage capacity as called for in the systems plan in Figure 3-3 (capacity analysis listed as one of the components in the evolution).

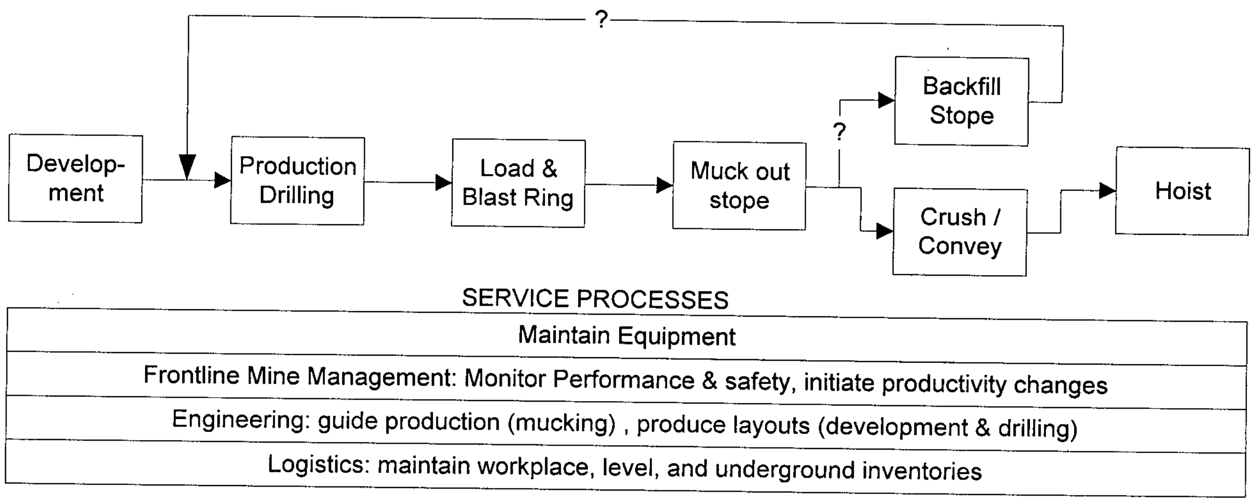


Figure 3-11: Simplified Proposed Process Map for an Underground Hardrock Mine

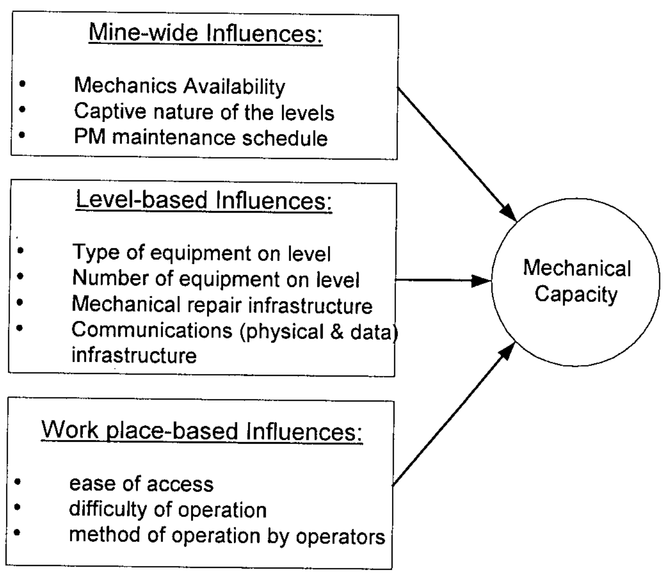


Figure 3-12: Possible Capacity Elements for Mechanical Capacity.

Figure 3-12 shows how entity relationships between equipment and aspects such as maintenance schedules, workplaces, and levels can be created. Linking entities such as a piece of equipment and the captive level may be deemed important if the database is used to calculate the productive capacity of levels. The aspect of location as an entity in mine databases is an important distinction that should be discussed further.

Figure 3-13 shows how the capacity of inputs such as equipment (mechanical capacity), raw materials (supplies capacity), and labour (manpower capacity) affect the output of a particular workplace. Cumulative workplace capacities have influence on the levels on which they are located. As discussed in chapter 2, tracking the workplace is unique and extremely important in mining. Different workplaces within mines have varying constraints such as ground conditions, or values, such as grade. Therefore the production databases must include data items related to workplace. It can also be seen that the output of one process, such as development, is a workplace. Therefore in order for a particular stope to be mined, a workplace must be created, then the drilling and mucking processes must mine that stope. The costs of mining that stope and the costs related to producing that workplace could be calculated if:

- A relationship is defined in the data model between different workplaces;
- A relationship is defined in the data model between the workplace and the processes which consume or are undertaken in the workplace. For example, a particular sill drift could be consumed by a particular stope once the production drilling has finished. The costs to produce that sill pillar should then be associated to that stope;
- Records of the inputs, and outputs of the processes are entered into the database.

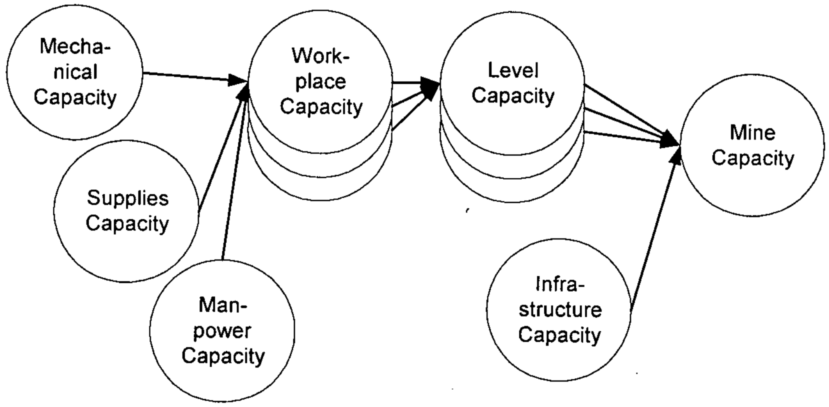


Figure 3-13: Hierarchy of Capacities

3.2.3.2 Proposed Data Items

Some information is traditionally already integrated to some degree. For example, productive units are often associated with a particular date. Knowing the date and the number of men employed on that date, the accounting transactions that paid those miners on that day can be known. Therefore the number of labour hours roughly needed to produce that unit of production can be calculated for that date. Unfortunately, this level of information is far too general to provide information on a process level. Therefore process-level measures need to be collected and the data inputs and outputs need enough detail to be associated with each other. This will result in an IT infrastructure suitable for a modern mine management system. It is suggested that a common data item such as process and date be used to integrate data between and among inputs and outputs.

Table 3-3 provides suggestions for various input data items that would be useful to collect and Table 3-4 provides useful output data items. Many of these were noted to be important during the on-site construction of an IT infrastructure at the Crean Hill mine, as discussed in chapter 4. Note that the common data items are dates and process. Many of these data items may already be collected in some mines. The systems plan and process map in mind can be used to identify missing data. These missing elements will complete the data infrastructure required. Automated data collection technologies are an important consideration as increased monitoring options are becoming available.[19] However, considering the innumerable options available to mines presently, a discussion of the technology or supplier options is beyond the scope of this work. Similarly, descriptions of specific tools that can be used to identify data requirements is not within the scope of this discussion but literature on the topic is available.[20]

Table 3-3: General Input Data

Classification	Description/Concerns	Possible Data Items
Cost Transactions	Typically, data on cost transactions are collected by the accounting department for every item paid for. Each transaction will require one or more relationships to other entities, for example based on process, piece of equipment and/or worker.	• Amount paid • Person ordered • Process to be charged • Expense element type • Supplier information
Labour Input	Some statistics on labour are already recorded for incentive purposes. However, these should be linked more directly to actual outputs thereby requiring data items such as workplace and process (for a particular date). Tracking more information on labour will also facilitate supervision as manpower and equipment damage analyses can be made.	• Data about operator • Hours worked • Hours of delay at face • Date worked • Process and workplace on date • Incentive contract #'s
Maintenance	Maintenance systems are already well established in the mining industry. What remains are data items that link the pieces of equipment with what was produced and who operated it.	• Equipment # • Work-order # • Processes linked by date • Date of work-order
Engineering Input	Keeping track of engineering time and effort is rarely undertaken in operating mines. However, consulting companies however, require engineers to closely track their time.	• Engineer name • Time spent on process • Outputs
Workplace	Linking workplaces is standard within mine plans. For example, a haulage drift has to be developed prior to a crosscut. Additional data items that link workplaces together would be beneficial such as, the dates when the workplace was worked on and the processes undertaken would allow the sunk costs of a particular workplace to be calculated. Furthermore, logistics processes can also be linked to workplaces and levels. For example, maintenance costs on the bottom of the ramp can be directly attributed only to the workplaces that would use that section of the ramp.	• Date • Process • Mine plan data • Logistics information

Table 3-4: General Suggested Outputs Data

Classification	Description/Concerns	Possible Data Items
Operating Processes	Operating processes are already measured to some degree. Workplace location and specific measures of the types of supplies used, and delays and conditions encountered would enrich process outputs.	• Date • Process • Material consumed • Workplace location • Delays • Productive units • Time consumed
Support Processes	Support processes such as engineering or logistics are difficult to track in terms of both inputs and outputs. Specific outputs such as number of drifts surveyed may not be useful to collect and micromanage. Furthermore, recording engineering output may be an intemperate cultural shift as managers are typically former engineers and would be disdainful of measurement.	• Date • Process • Units produced?
Strategic Outputs	Revenue information, cost of capital, ore impurities, and environmental costs may be related back to processes or system that produce them. For example, consider a particular mine within a multiple mine, single mill network. The value of the ore shipped to the mill may be awarded back to the mine as a measure of its value generated which would be affected by the processing costs.	• Time period of revenue • Mine-attributed value • Environmental discharge

3.2.3.3 Identified Data Sources

Once the data requirements have been identified, the sources of data can be sought-out. It is preferable for all raw data to be immediately entered into the database and in the appropriate relational structure. Many mines already have multiple data sources, some for single purposes. For example, in the INCO Crean Hill experience, drilling data was used exclusively for the calculation of incentives. When planning personnel wanted to know the amount of drilling that remained in a workplace, they would ask the operator, who would count the remaining holes and feet on the printed layout design while underground. A common data source would eliminate the discrepancies between these two systems. Typical data sources should include:

- Financial transactions;
- Bills of lading;

- Invoices;
- Mill reports;
- PLC data;
- On-line monitoring;
- Operator slips/reports.

3.2.3.4 Design Data Entry Mechanism

Once the database has been designed, data models defined, and various data sources identified, a mechanism is designed that ensures the information is entered accurately and on-time. If the data is entered into the system using sensors, wireless communications, or computer systems, mines will require electrical/electronic engineers and IT professionals. IT suppliers such as Modular Mining have underground equipment monitoring technology, pre-programmed to provide productivity data.[21] A formal mechanism that ensures that the data is collected is required if hand-written slips are used. It was evident from the field studies at INCO that such a mechanism would require the following components:

- Training operators on how to fill-out the slips correctly;
- Collecting the slips;
- Auditing the information;
- Entering the information into the system on time and accurately.

3.2.4 Final considerations for Data Infrastructure

As is discussed above, it is important to collect and integrate as much information as possible for maximum flexibility for the long term.[22] Determining the data sources then altering the output to conform to the design of a relational database is a key step toward establishing a data infrastructure. Ensuring the data is entered on time, accurately, and in the correct format are operational issues for which change management are needed. From the research at INCO these were found to be the most important issues in building a data infrastructure. The efficiency and effectiveness of the data is dependent on the data definitions and faithfulness to which the data conforms to the data model. What has yet to be discussed is the cost of collecting that data. Looking for inexpensive data alternatives is important when developing IT infrastructure. For example, the cost of directly tracking the actions of each miner would be far more complex than monitoring the activities of a piece of equipment equipped with sensors and wireless communication. The political and cultural considerations of closely tracking the activities of individuals may also be detrimental. Trade-offs between data reliability, accuracy, cost, and workforce stability will undoubtedly be made.

The data integration is the key to modern IS . Data models and process maps are tools that allow IT infrastructure designers to ensure that the data is integrated. The complexity of these systems increases the importance of training employees on how to provide, manipulate, and use the data. True benefits of IT can emerge only if considerable investment in training is made.[23] A clear set of standards is also important for training and integration purposes as these systems will require maintenance and growth with time.[24] These and other issues are discussed by Pervan in considering mine IT requirements:[25]

- Management and workers are busy so the time it takes to collect, input, and process data should be minimised;
- Data output (not input) should be tailored to fit individual users;
- The ability to extract, filter, compress, and track critical data is important;
- The system should provide on-line status access, trend analysis, exception reporting and "drill-down" abilities;
- User friendliness;
- Graphical, tabular and textual data presentation;
- More research on IS in mining, less on specific applications.

Trend analysis, data compression, managerial time, and process outputs are mentioned above. Reviewing raw data is time consuming and frequently ineffective. Throughout this subsection, the importance of integrating data through relationship was stressed. The use and presentation of integrated data becomes powerful when measures are tailored for managerial accountability and when the data is manipulated into information that can be understood and acted upon. The process of determining specific measures is discussed next, as seen in Figure 3-14.

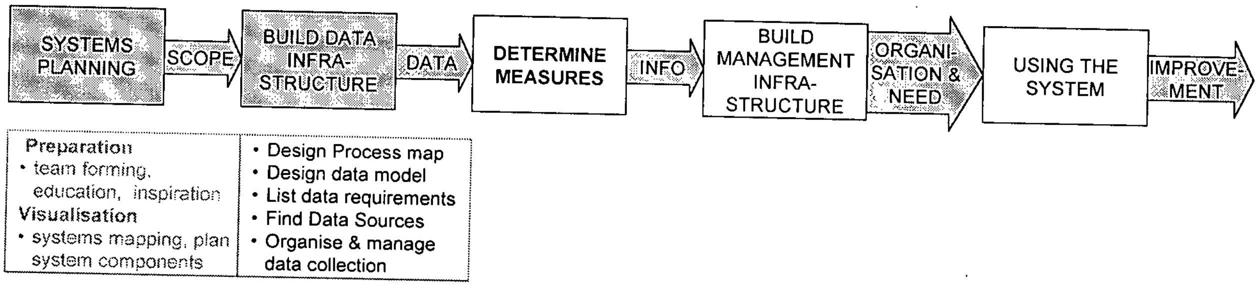


Figure 3-14: Data Infrastructure Complete.

The 'build a data infrastructure' phase includes several steps where the processes are mapped, a data model is created, data requirements uncovered, and data sources are organised and managed. A process map is used to determine the data requirements and define the data dictionary from which the data models can be built. Once the data requirements are known, the data sources can be found. Then the mechanisms needed to collect the data and populate the database are designed and managed. The costs of maintaining the infrastructure should be considered. For example, if it is far cheaper to have operators fill-out slips by hand than instrument all pieces of equipment with sensors, then perhaps the loss of accuracy in human-data entry can be tolerated.

3.3 Determine Measures Phase

Designing the measures for a tactical mine management system first requires a system plan and an IT infrastructure. The system plan guides the types of measures to produce and the IT infrastructure provides the basic data to calculate the measures. The determine measures phase of the methodology provides the guidance and theory necessary to establish the measures needed for the TMMS. The three types of measures required in the development of a TMMS include:

- performance measures linked to management accountability;

- diagnostic measures that can identify sub-optimal processes;
- measures that are developed specifically for improvement initiatives.

Activity based costing (ABC) measures are basic process measures that are derived from the process based IT infrastructure. The TMMS data infrastructure phase discussed previously recommends the creation of an IS that integrates process inputs with process outputs. This is similar to ABC where inputs are directly attributed to process outputs. ABC measures are used as the most basic measure from which most performance measures are derived. Issues of design, theory, and application of ABC and the other three types of measures are detailed in this section. How the information is compiled and processed is as important as how it is presented. When reporting on processes, it is important to present the information in a clear, simple, and consistent manner and to have comparatives.[26]

Measures are designed with a specific intent. Understanding the audience and their goals is a good first step. The measures pertinent to one set of managers or application may not be applicable to another set of managers or in a different application. For example, the performance measures of superintendents would be different from those of a front-line foreman. Similarly, historical cycle-time information may be useful in the simulation of processes but not useful in developing improved logistical procedures. Therefore measures are designed for both a specific audience and intent.

The following subsection will discuss these issues within the context of ABC, diagnostic measures, performance management, and effective measurement communication strategies.

3.3.1 *Activity Based Costing*

ABC is frequently incorrectly referred to as a tool to aid pricing products for manufacturers with multiple product lines.[27] Further in its development, management experts identified that ABC can be used for process management and accurate budgeting. ABC is now recognised as a tool for measuring performance, diagnosing sub-optimal processes, and in decision making.[28]

Activity based costing (ABC) is a management technique that organises costs according to the processes in which the costs were consumed. In ABC, costs traditionally lumped together as 'overhead' are distributed to operational processes according to cost drivers that correlate to how those processes consume the overheads. For example, in the design of a large production blast in a Vertical Retreat Mining (VRM) stope, several days of a planning is required, whereas in a narrow vein cut and fill stope, no direct engineering intervention is required. The added engineering requirements for the VRM workplaces could be added in an ABC measurement system.

A substantial IT infrastructure is required to develop an activity based cost system. Information about costs and the processes that consumed them have to be directly linked. The previous section reviewed how process outputs can be linked with process inputs through data modelling and relational databases. The 'Build IT Infrastructure Phase' also discussed the importance of tracking the workplace. The TMMS IT infrastructure should be designed to facilitate the creation of ABC for mining systems.

It may be important to mention the difference between process and activities as discussed in Chapter 2 (and in Appendix B) and as represented in Figure 3-15 and Figure 3-16. Note that processes are a conglomeration of activities. Manufacturers, with considerable IT infrastructure and experience at implementing such advanced management tools, have the capability to track at the activity level. Mining does not yet have the ability to track at the activity level, hence, for the time being, mine measurement systems will be constrained to process based costing. Although, in an effort to avoid confusion, process-based costing for mining will continue to be referred to as ABC.

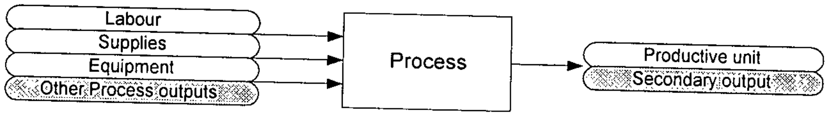


Figure 3-15: Generic Process Inputs and Outputs

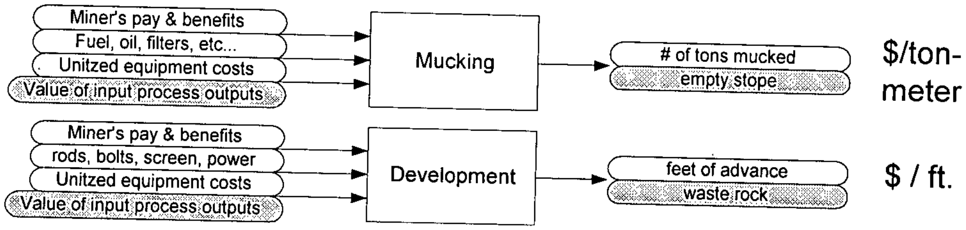


Figure 3-16 Mining Example of Process Inputs and Outputs.

ABC is described in Appendix G along with other important management techniques. This subsection simply suggests that a key measure is the unit cost of key processes, suggesting that outputs and costs should be organised according by process. Many mines can already track their unit costs for some key processes such as dollars spent on haulage or drilling. Few are capable of tracking according to workplace, equipment, specific date, or operator in a consistent and automated fashion. Adding the costs of support processes and overhead would also be difficult using current IS design. Costs can be effectively investigated when unit measures are developed using the IT infrastructure suggested in the TMMS methodology.

Figure 3-15 shows the integration of mine inputs and outputs from an operational process. The greyed outputs and inputs are measures typically unfamiliar to mining. Compiling the value of other processes including traditionally 'overhead' type costs such as engineering inputs, secondary blasting, reconditioning, and depreciation[29] is not traditionally included in mine costs. Secondary outputs, are also rarely tracked. An example of secondary output is the rock resulting from drift development. The rock can be considered a benefit in mines requiring rockfill, or as a cost in mines that must hoist rock.

Figure 3-16 shows the same diagram using mining specific examples. These basic measures assume that all costs and productive units for a specific process are measurable and tracked. These costs may be directly proportional to a particular unit of production such as feet drilled, tons hauled, or skips hoisted. However, some costs may not be proportional to the productive unit traditionally measured. For example, a mine may measure the productive unit from the mucking process using 'tons delivered' as the cost driver. However, upon closer analysis it becomes evident that mucking costs are a factor of both tons and distance hauled. Furthermore, mine process outputs vary dramatically. Drift development costs vary according to design and support requirements. Haulage costs vary according to distance, grade (on ramp), weight, and other operating conditions. The flexibility of investigating factors such as location, material type (ore or rock), or operator are key to the successful use of ABC in mining. This flexibility is available using the TMMS IT infrastructure.

ABC is far more simple in manufacturing. Manufacturers assemble standard products and need identical outputs, therefore identical products would have the same cost. Manufacturers do not require the added information of location, equipment capabilities (if equipment varies within the same fleet), ground conditions, etc...

Mining's inherent variability due to factors such as location or geology raises further concerns with tools which were developed by and for the manufacturing industry, namely diagnostic tools, used to identify sub-optimal processes by statistical analysis (example: statistical process control). Comparing performance is also complicated by the inherent variability in mining processes as target (goals) must be carefully chosen for managers within the same mine but operating in different areas. Furthermore, unitised costs alone cannot be used as a measure as production targets are central to the performance of a mine. For example a mine may have the lowest cost per foot drilled yet only have drilled 10 feet per month. Therefore volumetric measures are still needed. Despite these numerous limitations, ABC and process-based IT infrastructure can still be used as building blocks for measures that are informative, compelling, and functional. The issues of diagnostic, performance, and solution-resolving measures are discussed next.

3.3.2 Diagnostic

Within the context of this work, diagnostic measures are tools which can be used to determine if a process is operating sub-optimally. Mathematical tools, such as statistical process control, are used to determine the stability and consistency of processes. The highly variable nature of mining systems reduces the effectiveness of these tools however, using more detailed process information, the effectiveness can be improved. Process indicators are similar diagnostic measures as they monitor key input variables that impact on downstream processes. By monitoring these indicators, remedial action can be taken to optimise the upstream or downstream process. The use of mathematical diagnostic tools and process indicators are discussed in this subsection.

3.3.2.1 Mathematical Diagnostic Techniques

Roberts suggests the use of statistical process control (SPC) tools for mining, as used in the manufacturing industries.[30] These tools are only applicable to mining processes which mimic manufacturing processes: where a consistent product is produced over an extended period of time. SPC requires a statistically significant number of data points in order to ascertain the level of stability in a process. For example, a process such as conveying, or crushing, with a constant source of feed, could be analysed using SPC. The productivity at a particular heading may not be analysed using SPC as work at a heading strongly depends on varying factors such as the daily mine priorities, geology, distance from shaft, and equipment type.

For mining, measuring the consistency and quality of output could be used as a diagnostic tool. Measuring the variability in fragmentation may be indicative of sub-optimal drilling or blasting practices.[31] Slump test can be used as an indicator of sand/pastefill quality. These measurement tests may already be used in mine operations. The inclusion of the raw data or results of these tests in the IT infrastructure would ensure consistency and records that could be used for further analyses.

3.3.2.2 Process Indicators

Process indicators are diagnostic measures that are used to optimise processes downstream or preventatively, upstream. For example, fragmentation analysis at a crusher would be a process indicator that would allow a SAG mill operator to adjust operating conditions for optimal milling, resulting in a downstream solution. Feedback from the same process indicator would allow the blast designer to vary the design upstream.

Automated technology has been developed which can sense variability in operating conditions of mining processes and suggest changes to optimise output. For example, in surface mines, sensors on rotary blasthole drills can provide information about the material being drilled, such as spacial location, hardness, and geological structure. This information can then be used to optimise blast design or mill recovery. More research is needed to develop indicators that can identify processes in difficulty, especially underground.[32] Measuring a process without understanding what an 'optimal' measure should resemble is useless. Therefore targets or accountabilities must be established. The science of performance management can help design the targets for which management can use to improve performance.

3.3.3 Performance Management

Performance management has been described as "the often-overlooked key to organisational success."[33] Performance management must have carefully designed goals, frequent reviews, respected rewards, and measures that vary between manager type and managerial level. Performance management is the area where organisational workplace culture can be modified to improve the overall system performance. Foote[52] uses an analogy to show the importance of several aspects of performance management. He compares two workers performing somewhat similar tasks. One worker, 'Jim' , must remove items from a conveyor using a forklift, which requires some skill. Although the pay and benefits are good, it has become mundane. When Bob's performance is evaluated quarterly and falls below company standards, he is reprimanded and asked how he will improve performance. When performance is above, the supervisors tell him to "keep it up". Foote[52] then compares Jim's work environment with Bob's, whose task is to put items into a basket for a different company. Bob's job is much more difficult as the basket is small and elevated ten feet off the floor. However, when an item is placed into the basket, a point is put on a board where everyone can see it. When Bob's performance falls below standard, his boss provides information and training to help him improve. His boss also provides rewards such as metals and trophies when performance excels. Bob is not even paid for his efforts and undertakes the physically strenuous work happily.

This analogy is comparing the similarities and reward mechanisms between sport and work. Elements that make sports appealing are clearly defined rules, immediate feedback on good performance, and help when performance falls below standard. Performance management is the technique used to organise and implement mechanisms which use these elements to improve. It is often a systematic, data oriented approach to managing people that clarifies rules, provides feedback, issues adequate training and steers results toward organisational needs.

3.3.3.1 Activity Based Performance Management

The first step in developing performance measures is to define the rules and objectives. The link between corporate mission statements such as "Copper company XYZ will be the lowest cost copper cathode producer, with the highest return on equity..." and front-line management is unclear and ambiguous. Measuring the successes of management at the front-line based on final products or corporate objectives is ineffective as there are no identifiable links between action at the face and copper cathodes. By linking output performance measures, also known as metrics, with activity based costing, a front-line manager would be able to definitively point to performance through productivity analysis, profitability analysis, trade-offs, and decisions.

Traditional organisations are misled from knowing their true product profit margins due to mis-allocations of direct and indirect costs.[34] Corkins claims that activity based costing or activity based management (ABM) increases the visibility of measurement systems and can help organisation remove waste, engender a sense of profit, and align capacities. Therefore ABC is a key component to any performance measurement system for management. However, as the responsibilities of managers vary, so should the process measures assigned to a particular manager. Therefore those managers who are responsible for the outcomes of particular processes should be measured on those processes. Accountability is defined as being responsible for someone or some process.[35]

3.3.3.2 Understanding and Controlling Culture

It is suggested that some basic understanding of the workplace culture should be characterised during the systems planning phase. However, a more detailed analysis is required to build systems that would direct changes to the culture. The two core components of the TMMS that control culture are the performance measures and management systems. Accepted strategies that steer (control) culture suggest the creation of a clear set of organisational accountabilities, performance measures, education, and formal yet flexible management infrastructure. Prior to the selection of specific techniques for control, a basic understanding of the current workplace culture should be established. The following discussion describes some techniques for the characterisation and strategies for control.

Anthropology is the science that seeks to understand and characterise culture. Behaviour of individuals is a product of both psychology and organisational culture. Management systems seek to steer a worker's behaviour toward the organisation's goals. Therefore anthropology is intimately linked to creating effective management systems. Psychology is too individualistic to be an effective tool in the design of management systems in mines that have many employees.

Ethnography is the technique that anthropologists rely upon for the most accurate characterisations of culture.[36] Ethnographers participate in the cultures under investigation in order to gain insight into cultural practices and phenomena. Useful and reliable notes documented throughout this research process typically constitutes the major part of the data on which later conclusions will be derived. Other data sources include site documents and interviews.[37] Questionnaires and surveys are considered to be highly unreliable as the covert aspects of the culture are frequently omitted. Ethnography is explained in more detail in Appendix G. In general, this is simply a tool from which to uncover the nature of the organisation so that systems and/or action can be implemented to mitigate the negative while promoting the positive.

The following concepts of culture illustrate the complex dual nature of organisational dynamics that complicate efforts to characterise and manage organisations:[38]

- Culture contains both conscious and unconscious patters of shared, learned behaviour acquired by experiences;
- Culture has both overt (obvious, visible customs) and covert (less obvious, hidden) ways of behaving;
- The two sets of expectations are the ideal (expected) and real (actual) behaviours;
- Cultures can have different viewpoints from an insider and outsider;
- Culture forms and constrains sets of adaptive and resistance strategies.

Understanding the contrasting elements of organisational culture listed above are a key first step to changing or taking advantage of culture. These contrasting elements can be determined using a variety of cultural assessment models. For example, Ibarra suggests using the following model to analyse organisational culture:[38]

- **Organisational Heritage**: determine the major events in the organisation's history that have had influence on the present;
- **Organisational Structure**: analyse both formal and information organisational structures and groups;

- **Political System**: identify the critical path of decision making, strategic planning and power both real and ideal;
- **Environment**: analyse the physical arrangement, design, community location, and regional/national influences;
- **Communication/language**: analyse how culture is transmitted through symbolic or linguistic systems;
- **Demographics**: examine the human components of organisational culture;
- **Subculture Types**: analyse and categorise subcultures as identified by insiders;
- **Change Systems**: review adaptive strategies for change and adversity and to seek out the formal and informal innovators and entrepreneurs in the organisation.

Note that several of these elements can be directly controlled. Organisational structure, the political system, and some aspects of the environment, demographics, language, and change systems can be modified by changing the management systems. Other aspects such as organisational heritage and communication cannot be directly affected by changing the management system. In designing a management system, the elements of culture should be understood and characterised for the company so that the appropriate control strategy is applied.

Many strategies to control culture exist and are used throughout all industries. Senge suggests using a process of identifying key leverage points that act as catalysts of behaviour.[39] Through education or incentive systems, these catalysts are removed (in negative behaviour) or promoted (for positive behaviour). This rich and complex method is called "Systems Thinking," and is further described in Appendix G.[39] Blanchard and Bowles suggest a three-part strategy for boosting morale, clear accountability, and rewards, in a change management technique called "Gung-Ho!"[40] Cooper and Markus suggest abandoning expensive training and education programs that are not directly applicable to the structure management system.[41] Instead, Cooper and Markus suggest using five techniques that include group meetings, role-playing, and hypothetical redesign of the production system.

There are many strategies available yet the most effective strategies typically have the following key aspects:

- Clear accountabilities, performance targets, and rewards
- Unambiguous measurement
- Education/training
- Morale boosting, coaching, team-participation
- Formal and informal flexible management structure[42]
- Characterisation and comprehension of the actual and ideal organisational culture

From the general characterisation of mining culture in chapter 2, it can be seen that the accountabilities and performance measures for management and workers would differ due to their contrasting nature. For example, the engineers require order while the workers require security. Clear accountabilities and management structure provides order. From Table 2-2: Mine Management and Workforce Cultural Comparison.[19], it can also be seen that engineers/managers have an "objectively determined reality" meaning that unambiguous measurement would be welcome. These measurements can be used proactively to improve performance. Managers are considered to have a "competitive" and "individualistic nature, therefore, team-building training and measures that would not result in destructive competition may be areas of interest in mine management systems. However, in spirit of competition, managers of equal managerial level could have a common measure from which their performances can be ranked. In conclusion, a TMMS design should incorporate cultural issues specific to a particular company or mine.

3.3.3.3 Accountabilities

Accountability is the most important issue in the design of performance measures. The formal management hierarchy and responsibilities are the key building blocks from which accountability can be designed. The time-frame of management decisions and volume requirements also vary according to the management hierarchy. The issues and methodology for designing accountabilities are described in this subsection.

PROCESS BASED MANAGEMENT STRUCTURE

Traditional hierarchical (vertical) management structure usually does not allow clear accountability for processes, as discussed in Appendix C. For example, the managers of operations and maintenance are typically at odds as operations are directed to produce ore while the goal of maintenance is to provide availability and reliability. These are often competing objectives. Horizontal organisations have managers that would be responsible for an entire process and all its support activities. For example, at the INCO test sites, operations managers directly supervise short-term planning engineering staff and technicians. This allows engineering services to be completed to the specifications and schedule needed by operations. Modern management techniques usually suggest this horizontal type of organisation, where single managers are responsible for a single core process.[43]

FRONT-LINE SUPERVISION – ORGANISED BY WORKPLACE

Process management may not be facilitated in mining due to its dispersed workplaces. It may be difficult for a front-line supervisor to be the manager of the "drilling" process as the headings undergoing drilling may be geographically dispersed throughout the mine. If supervisors were accountable for specific processes, the majority of their time would be spent travelling between headings. This is why front-line supervision in mines should continue to be organised according to geographical areas.

ACCOUNTABILITY AND FUNCTION ARE NOT NECESSARILY COMPLEMENTARY

Management structure and accountability structure does not always have to be identical. For example, the Musselwhite Mine uses an accountability structure that is process based while the functional structure is organised according to functional departments. [44] Clear accountabilities, goals, measurement, communication and training are all stalwarts of Musselwhite and good accountability management.

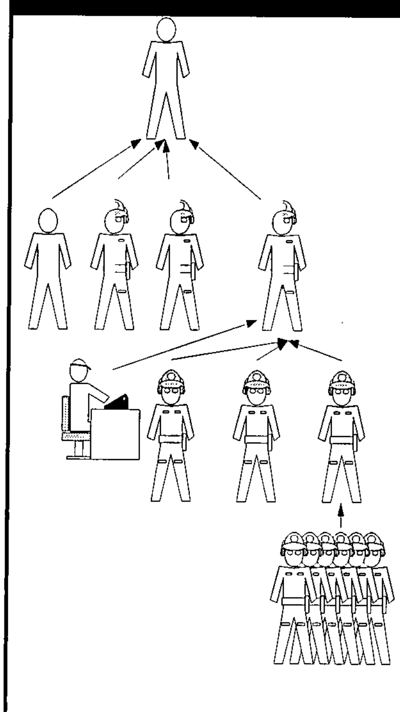
DEFINING ACCOUNTABILITIES

Well defined accountabilities are essential. If there is confusion among front-line supervisor accountability, variance in decision making between cross-shifts or within different areas of the mine will induce waste. Figure 3-17 proposes a possible accountability structure for the various managerial levels. Note that accountabilities can be clarified using:

- Job descriptions;
- By setting goals on a process level;
- Training.

SUGGESTED ACCOUNTABILITY STRUCTURE

It is beyond the scope of this work to design a standard accountability structure as each mine will tend to have a unique culture and operational parameters. Job descriptions can be designed to suit required accountabilities and needs. This task is facilitated using organisational design. This discussion simply emphasises the importance of clear accountabilities of managers within a tactical system.



Position	Accountabilities
Super-intendent	• Mine ($/unit output) for entire mine • Responsible for $/unit of final product • Responsible for those below • Accountable for integrating strategy with tactical imperatives.
General Foreman Engineering – tactical support	• Unitised process level ($/unit output) • Engineering: Providing technical support in planning and improvement initiatives • Accountable to individuals above • Responsible for those below
Front-line (foreman) Engineering – tactical outputs	• Activity-level and process level ($/unit output for crew) • Engineering: Providing tactical technical outputs (example: layouts) • Accountable to individuals above • Responsible for those below
Miner	• Task-level work • Accountable to individuals above • Responsible for providing accurate information

Figure 3-17: Possible mine tactical accountability structure

Figure 3-17 shows how the front-line supervisor would be accountable for optimising activity and process level work. For example increasing mucking rates in his area by having the road graded. The foreman would be measured on the productivity of the crew he/she is supervising. These measures would be easily tracked using the IT infrastructure proposed in previous sections. Foremen are responsible for a work area and a particular crew. Several foremen may be accountable for the same area but on cross shifts. Similarly, foremen can be on the same shift yet in different areas. Crew reporting is well established in mining as incentive systems are typically organised by work crew. The responsibility to ensure co-ordination between cross shifts and over a geographic area would fall on the second-line supervisor, also known as the general foreman or mine captain. This individual will also be the first manager accountable for costs. Foremen usually use the same equipment and draw supplies from the same inventory. This common resource pool makes it almost impossible to track inputs on a crew by crew basis as technology does not yet exist to record specific consumption of raw material, equipment availability, or labour by workplace and time. Geographical regions within a mine may have captive equipment, local inventories, and control points where inputs and outputs can be monitored with accuracy. These second-line managers are therefore the individual that issue the orders coming from the tactical engineering outputs, namely the blast and drift layouts. Technical support for process improvements, may also be supported by engineering technicians. These second level tactical managers are therefore responsible for:

- Co-ordination between cross-shifts;
- Co-ordination between crews of different regions;
- Cost control at a local level;
- Implementing engineering schedules.

The second level managers (general foremen) are accountable to the next and final level of tactical management. The final level of tactical management is the superintendent, also known as mine manager. These individuals must co-ordinate the activities of the various general foremen so that the mine's production is predictable, and within budget. This individual must interpret strategic goals into tactical goals and action. This is the last level of tactical management and the longest time-frame for tactical decisions.

MANAGEMENT ACCOUNTABILITY TIME FRAMES.

Each level of management has different time-scopes. Table 3-5 provides the approximate time-frames for each management level. Performance feedback should be provided according to the time-frame of the management level. For example, the time-frame for the second level of management is a week to a month; process unit costs should be reported once a month. A monthly report of key unitised process costs can be issued to this level of management showing the effectiveness of co-ordinating the work between crews. For cost control purposes, a weekly review of supplies ordered or equipment repairs can be provided. A weekly summary of the output of key processes can also be provided indicating where management efforts should be focused to meet the monthly quotas.

Table 3-5: Time-frame for Decisions at Different Management Levels

Management Level	Typical names	Examples	Workflow Level	Time-frame
3	• Superintendent • Mine manager	• $/ton shipped • total costs • total revenue • mine safety	• System	Month to Year
2	• General Foreman • Mine Captain • Second-line supervisor	• $/ton of area • $ / ft drilled area • tons / man-hour • % index planned	• System • Process	Month to Week
1	• Foreman • Shift-boss • Front-line supervisor	• Drill ft. / day crew • Tons mucked by man • Workplace utilisation	• Process • Activity	Week to Day
Base employee	• Miner • Operator • Worker	• Ft / day • Tons mucked / hour • % re-muck	• Activity • Task	Daily

INFORMATION VOLUME.

The information volume requirements vary according to management level. On a daily basis, miners require only the production and workplace objectives (called a line-up). Foremen require more information as they must allocate miners to specific work areas, compare miner and crew productivity, and determine supplies ordering requirements. General foremen and superintendents require far more information than any other manager as they must optimise the processes and all their inputs and outputs. As management level continues to increase into strategic areas, information requirements begin to reduce. Senior executives require only aggregated information such as mine profitability and market projections. Figure 3-18 shows how information volume would vary between management level (developed from conversation with Bill Stanley, July 21st, 2001).

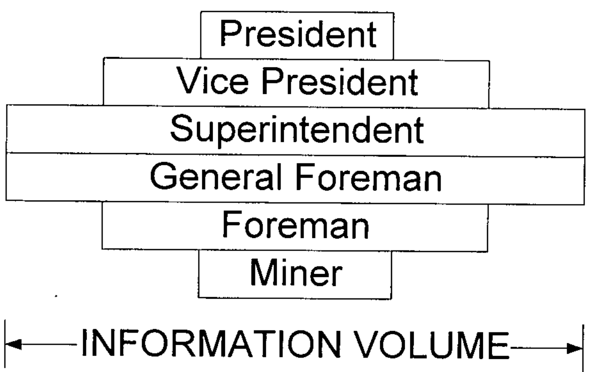


Figure 3-18: Information Volume in proportion to Management Level

SYNOPSIS OF ACCOUNTABILITIES

Training in accountabilities and developing clear job descriptions is vital. A miner must be trained for the various equipment he is expected to use throughout the shift for both safety and efficiency reasons. Similarly, management must be trained on the various tools that will be applied throughout the day for both safety and productivity management. Training in management, especially at the tactical level is rare in many mines.[45, 46] While job descriptions provide clear guidance on job responsibilities, quantitative measurement also plays a key role in establishing accountability.[47] By providing quantifiable feedback, managers can know how effective they are. The measures must also conform to the time-frame for which the manager is responsible. The feedback should include targets, also known as comparatives so that managers understand the level of effort that is required for each area of accountability.

3.3.3.4 Comparatives, Targets, and Goals

A key aspect to effective use of measures are targets or goals. Accountabilities provide what should be measured while setting targets ensures that the efforts are in the right direction. In-depth studies of the social and industrial-psychological value of goals are numerous.[48] Setting process based targets for managers should be a key step in developing performance measures for a TMMS. For example, the goal for a general foreman may be to reduce his production drilling process by ten percent from the cumulative average of the past 6 months. Since the measures are based on accountability, the goals should also be within the sphere of accountability of the manager. For example, a foreman supervising a crew of miners should not be measured on the effectiveness of maintenance. However, the number of repairs due to operator abuse can be measured for the foreman, along with a goal to reduce the amount of 'damage' maintenance work orders. Therefore a manager's goals should be aligned with his accountabilities and area of influence (a manager should only be measured or asked to improve what he controls).

Goals alone do not improve performance. "The most important reason for setting goals is to create additional opportunities for reinforcement. Having a common goal gives a team a common purpose".[49] Other benefits include improved communication and enforced data collection.

Several management techniques can be used to determine appropriate goals.[50] Regardless of the tool used, setting behaviour goals or action focused goals are still governed by two important considerations: making goals challenging and attainable. Goals should be challenging since individuals have been observed to slow or stop performing when they reach their goal.[51] Setting the goal unattainably high results in negative reinforcement and decreased motivation for the future performance. Finally, each level of the organisation should be responsible for setting its goals and objectives (with consultation with the immediately superior level).[52,53] Sources of information for setting goals can include:

- Performer's past history;
- Performance of peers;
- Industrial engineered standards;
- Budget;
- Participation by the performers (setting their own goals).

3.3.3.5 Rewards

As mentioned previously, feedback, rewards, or reinforcement is a key element in setting goals and performance measurement.[54] There are generally two types of rewards: extrinsic and intrinsic. Extrinsic rewards are money, promotion, or fringe benefits. Mining is very familiar with extrinsic rewards as incentive systems are commonplace. Intrinsic rewards are when employees experience a state of internal motivation, and self-fulfilment through work.[55] Motivational theories all recognise the benefits of rewards.[56]

3.3.3.6 Performance Measurement Management Techniques

Some modern management techniques aid in the design of performance measurement systems. The Balanced Scorecard is a modern management technique that involves several types of measures including: financial, customer, internal business process, learning and growth. These measures are derived from the vision and strategy of the company.[57] This tool is a highly evolved system that may be too complex for the current state of mine management as the IT infrastructure and ideals of customer measures, and other 'soft' issues are not yet well established in most mines. Appendix G describes this performance measurement management technique.

3.3.3.7 Synopsis of Performance Management

The analogy comparing the performance management systems of sport and businesses at the beginning of this subsection highlighted the importance of clearly defined rules, immediate feedback on good performance, and help when performance falls below standard. Clearly defined rules for production systems are identified by analysing the cultural requirements for motivating the employees, and educating and setting targets for each manager's set of accountabilities. Immediate feedback is provided by measuring the manager according to his/her accountabilities. Both extrinsic and intrinsic rewards should be awarded when goals are met. Training requirements, additional resources, or improvement initiatives would be identified depending on where the manager fails to achieve the specific targets.

3.3.4 *Solution Resolving Measures*

Solution resolving measures are the calculations and analyses of the raw data within the IT infrastructure that are subsequently used in management techniques in improvement initiatives. For example, consider a manager that would like to improve the materials delivery system underground by instigating a just-in-time (JIT) initiative. In this case, solution resolving measures would be material consumption rates in underground headings, delivery times, and delivery capacities. These measures are to be calculated from the data infrastructure. These measures are also only undertaken in an as-needed basis. Skills at database querying languages and a well organised and well understood IT infrastructure are necessary to produce these types of measures. Technical staff will need to be become familiar with the types of improvement initiatives available, their information requirements, and the tools used to extract such information from the IT infrastructure. Internal or external industrial engineering experts and management consultants may be required for some improvement initiatives. Appendix G provides a list of management techniques that could be applied to processes as improvement initiatives.

3.3.5 *Presentation of the Measures*

An issue common to all these measures is how the measures are presented. Information presented as trends over time, Pareto charts, and bar-graphs are some of the most effective, simple, and common presentation formats. The presentation should be clear, simple, unambiguous, and have easy drill-down ability (where more detailed information about a displayed item can be readily summoned).

Without proper presentation formats and adequate simplicity, confusion leading to frustration and eventual abandonment of a measurement based tactical management system will occur. There are several examples of performance reporting tools being abandoned due to inappropriate and user-unfriendly reporting mechanisms at the INCO Limited test sites, as is discussed in Chapter 4 and Appendix C.

The scientific study of human factors is a field of research encompassing sensation, perception, systems design, engineering anthropology, bio-mechanics, human reliability and communication.[58] Coe presents a thorough yet simple review of human factors in technical communications that would be helpful for those responsible for building the Graphical User Interface (GUI), applications, and reports.[59]

3.3.6 *Final Considerations for the Determining Measures Phase*

ABC measures are the first to establish when developing a TMMS. If the IT infrastructure is organised according to process, this is a relatively simple task. Performance management is the most important and direct use of measures. Devising a performance management system using organisation theory would immediately follow the creation of an ABC measurement system. ABC is an acknowledged ideal source of measures. Managers are capable of being true 'business managers' as a sense of profit can be engendered by measuring outputs alongside inputs. Devising a performance management system based on processes would also provide an opportunity to clearly align accountabilities to processes. Accountability provides the framework for the performance measures for all types and levels of management. A suggested accountability model presented in this section (Figure 3-17) identified second-line managers, those responsible for optimising mine processes, as the primary tactical manager with direct accountability for costs. Unit costs should be reported alongside production volume measures. Budgeted amounts of production allow the manager to fulfil the required quotas while unit costs ensure that the work is done efficiently. Other measures may be developed if quality issues are deemed important. For example, drill-hole surveys or secondary blasting costs and frequencies may be measures of the drilling and blasting performance.

Goals can be used to direct action but are primarily used as enforcers of positive behaviour. Making goals challenging and achievable provide employees with the psychological need of challenge and success. Rewards are also effective positive enforcers that are part of successful performance management systems. Entire disciplines are dedicated to the study of performance management. Mine managers should be aware of at least the basic issues related to employee motivation and performance management, especially when designing measures for a tactical management system.

Performance measures and targets should induce the need to improve, resulting in improvement initiatives. The last type of measures discussed in this section are solution resolving measures, which are those constructed on an as-needed basis in improvement initiatives. These are short term analyses using either pre-constructed performance measures such as unit costs (ABC), or core data within the IT infrastructure.

In summary, Figure 3-19 shows the proposed procedure that should be followed when determining and developing measures. The ABC measures are used as a base from which to build performance management, diagnostic, and solution specific measures. Performance management measures are based on the job responsibilities and confirm accountability of managers at various levels of work. Targets are set to motivate these managers to improve their performance and rewards lauded on those that do. As discussed, there are several purposes for developing these measures:

- Motivates improvements (through setting goals, measuring performance, and holding people accountable);
- Helps managers understand their accountabilities and processes (by reviewing performance information and setting goals);
- Identifies sub-optimal processes (through trend analysis and diagnostic tools);

- Facilitates improvement initiatives (by measuring aspects of the system that may be causing harm).

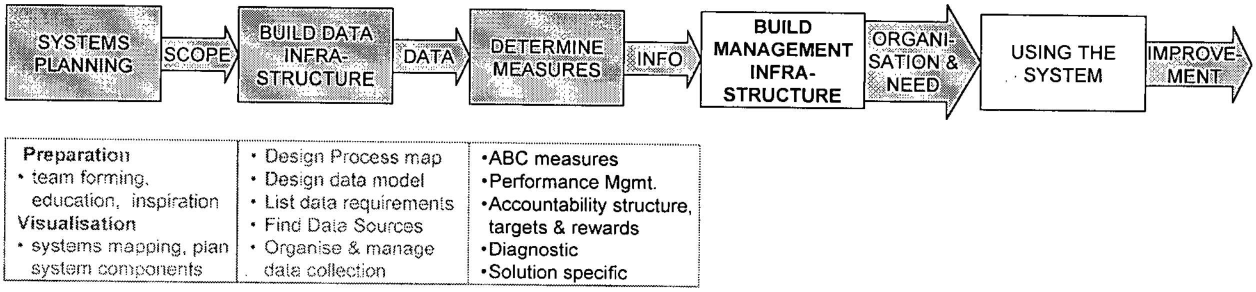


Figure 3-19: Determination of Measures

Ensuring that the managers will participate in a tactical management system will require structured rules, procedures and timelines, usually in the form of meetings. Through these meetings, progress toward goals are reviewed, identification and derivation of improvement initiatives are undertaken, and rewards are received and given.

3.4 Build Management Infrastructure Phase

A systems plan lays out the development of the capabilities of a tactical management system. Developing an IT infrastructure provides the raw data needed in the management system while measures provide the required information. In order to make use of the tactical management system, actions must be taken by managers to review the information, make decisions, and derive solutions. The field of study dedicated to the development of management procedural infrastructure is Organisational Design.[60]

Some of the tasks of developing and maintaining the TMMS should be undertaken by others. For example, the IT department can be expected to undertake the data collection, and maintenance of the IT infrastructure and software applications that derive the measures. Managers should be expected to spend time looking at performance and cost information, reviewing performance of subordinates and being reviewed themselves. The 'Build Management Infrastructure Phase' of TMMS development is where the activities that will be undertaken by the managers are designed. This section reviews the types of meetings and activities that benefit front-line productivity and should be instituted as part of the tactical manager's functions. As was reiterated before, all mines are different; therefore, a specific mechanism for all mines is not discussed. The types of meetings, the basic measures used in those meetings, and specific examples of management infrastructure are provided. Prior to discussing these issues however, the timing of the design and implementation of the management infrastructure require clarification as is indicated in the discussion of the systems planning phase.

3.4.1 Timing of Management Infrastructure Development

Establishing the management infrastructure is directly related to the plan as laid out in the systems planning phase. Figure 3-3 shows an example of a systems plan where several management components are built in the development of a TMMS. Table 3-1 provides some explanation of the various components of the TMMS. Note that for every component developed and implemented, the required management infrastructure is developed prior to establishing the following component. Figure 3-20 shows how the data infrastructure and performance measures phases of TMMS development precede the establishment of the management infrastructure required for each TMMS component. For example the 'informed process based budgeting' component (as discussed in Table 3-1) is designed to produce the performance measures for the superintendents. The first step in constructing this component would involve a detailed plan of how the process based budget will be built. The next step is to ensure that the necessary data is available. The performance measures would then be established, and in this example, the budget is created. Finally, regularly scheduled meetings where the managers review the performance measures are designed and instituted. For example, the meeting will follow a set agenda where the actual performance is compared to the target and a list of remedial actions is documented. In this particular example, the superintendent compares the budgeted performance against the actual performance for that month. Directives to his subordinates are then planned and communicated.

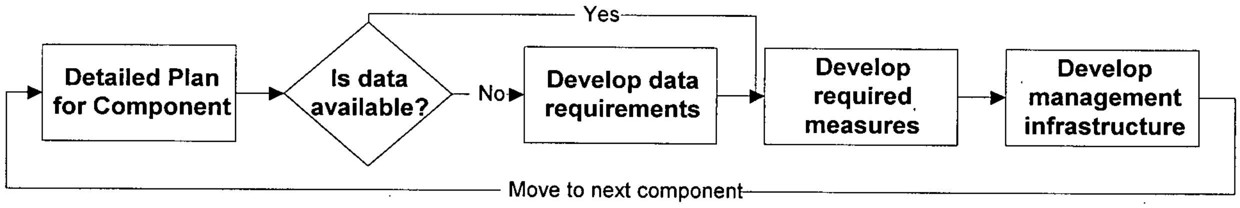


Figure 3-20: Management Infrastructure Development

According to most change management theory, complex management systems should be implemented incrementally.[61, 62] Similarly, the TMMS components should also be implemented incrementally. Therefore the 'develop management infrastructure' phase is undertaken throughout the development of the TMMS.

3.4.2 Types of Meetings / Managerial Activities.

Managers must participate in the TMMS by preparing for and partaking in group meetings. These meetings or managerial activities are classified into four broad groups: coaching sessions, solution identification , planning, and auditing. Within a single encounter, a group of managers may measure performance, identify solutions, and set goals from which to measure the success of the improvement. Therefore the term 'meeting' refers to a "meeting of the minds". Figure 3-21 shows a flow of inputs and outputs occur where the outputs of one meeting are used in the proceeding meeting. For example, consider that a manager does not fulfil his assigned targets when his performance is reviewed. This visible, quantifiable gap in performance induces the need to improve through active managerial intervention. A process of determining a solution to the performance challenge is undertaken. Once the solution has been identified, the improvement initiative is planned and quantifiable measures are designed to track the impact of the undertaking. During a subsequent coaching meeting, both regular and improvement initiative measures are reviewed, renewing the cycle anew. Once the improvement target has been achieved, the improvement measure no longer requires monitoring. Therefore the outputs of one type of meeting are used as inputs in other meetings. The four types of meetings or managerial activities mentioned above are discussed in further detail in this section in terms of their primary purpose, responsibility, and frequencies.

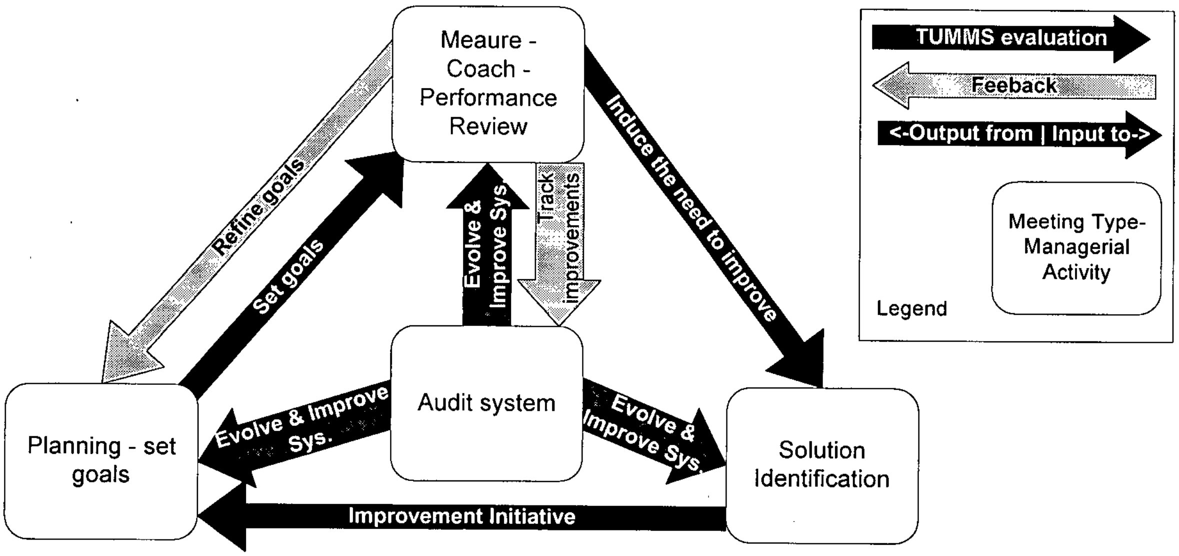


Figure 3-21: Flow of Inputs and Outputs between Managerial Activities.

3.4.2.1 Coaching – Performance Review

As was discussed in the performance management section, quantifiable performance should be reviewed frequently and as soon as possible, following the work that had been measured. The primary purpose of a coaching meeting would be for a manager to review the performance of one, or a group of subordinates. The meetings should be held as frequently as the measures would allow. Table 3-5 listed the management time-frame for the various management levels. These time frames also relate to the frequency of calculation and review of the performance measures. For example:

- a foremen should review the unplanned delays and achieved production with his crew daily, or even during the shift;
- a general foreman should review the key metrics with his foremen on a daily basis;
- a superintendent should review the costs of the key processes once a month and production once a week with the general foremen.

The meeting should not simply be a process of reporting the results. The meeting participants should discuss how the results were achieved and any potential issues that might come up. Indicating special conditions why the goals were met or surpassed will institute simple changes that can lead to incremental improvements. More long standing issues can also be raised as a potential opportunity during the solution identification meetings.

3.4.2.2 Solution Identification and Planning

Solution identification meetings are when the tasks, activities, processes, and systems are actively improved. These meetings are where an improvement initiative is planned, and progress on its implementation is reported. The foundation of these types of meetings are the assumptions that:

- All mines have operating problems which can be corrected;
- The real cause of the problem must be identified before any changes are made;
- Employees within the mine should assist in improvement initiatives;
- The culture of management/engineering in mines is proactive and interventionist and therefore should welcome improvements as part of their duties (as discussed presented in Table 2-2).

These meetings can be more flexible in their scheduling depending on the focus of the ongoing improvement initiatives. For example, if the improvement initiative of a redesign group is at the task level, more frequent meetings can be held. Similarly, the project should be implemented sooner. The meeting participants depend on the level at which the work is being redesigned. Again, Table 3-5 is used as a template: if the work is being redesigned at a task level, the experts of that task should be part of the redesign team. In this example, miners and foremen would be the main participants in redesigning tasks to be more efficient. IT experts or other technical support members should be part of most improvement initiative design teams. The mechanics of the meetings are identical to those suggested for Total Quality Management (TQM) or Continuous Improvement (CI) endeavours. Table 3-6 provides a summary of the steps, purpose, and tools of these meetings. Most of the tools described are simple and easy to learn.[63]

Table 3-6: Improvement Processes

Step	Purpose / Action	Tools
1	The purpose is to select the problem to be investigated.	Flow charts, process maps, and performance measures are the tools which can identify problem areas. Suggestions from participants within the production system are also an excellent source of information
2	Describe current work component	Using Pareto Charts, flow charts, and similar descriptive tools the problem and work component (task, activity, process, or system) should be described.
3	Determine most likely cause.	Tools such as fishbone diagrams, force field analysis and spreadsheet tools can aid team members to overlook the symptoms of a problem and identify the root cause.
4	Develop solution and action plan	Solutions to problems can be solved using management techniques, technology, or through changes in the system. These changes must be planned and justified, especially if increased spending is needed.
5	Implement the solution / action plan	Change to any system at any level will be met with resistance. Proper implementation procedures should always be taken into account.[64]
6	Review and Evaluate Results	Results can be tracked through periodic review of the core performance or specifically designed measures. Team members should be commended for successes. Failures should be investigated diplomatically.
7	Reflect and Act on successful improvements	The lessons learnt should be documented and extended to other areas of the organisation if successful. Steps should also be taken to make the improvements permanent.

3.4.2.3 Planning

Planning meetings in mining are typically held with both operational managers (foremen, general foremen) and technical personnel (engineers, maintenance co-ordinators, etc.). The general purpose of the meeting is to forecast and plan for tactical issues in the near future. Components of such a meeting can include analysis of the capacity and trends of the system and forecasting performance. Planning meetings are well established in mining as the engineering staff is typically in frequent contact with the front-line management. A basic example of planning meetings is crew line-up meetings where the explicit instructions for the shift are explained by the foreman to the crew.

3.4.2.4 Audit

Audit meetings are the means by which the tactical management system is maintained and its evolution monitored. A quarterly meeting is proposed, where the tactical managers assess the successes and failures of the TMMS. Solutions to the deficiencies identified are planned and assigned to be resolved by tactical managers and/or IT support staff. As with any system, maintenance cannot be under-emphasised.

The systems plan is the blue-print for the management system. The impact of the implementation of TMMS components should be evaluated in audit meetings. The decision to further evolve the TMMS can be made in an audit meeting.

3.4.3 Examples of Management Infrastructure

Two examples of management infrastructure are discussed in this sub-section. The first is a tactical management system designed by the Universal Schedulers Consulting (USC) group for INCO Limited mines. The second example is a management infrastructure suggested for the systems plan suggested in Figure 3-3.

3.4.3.1 INCO Management System

A tactical management system was developed for Coleman, Creighton, and Crean Hill mines over a two year period ending in 1993.[65] Figure 3-22 shows the tactical management system in terms of meetings and management techniques. Table 3-7 describes some of the components of the system. As can be seen, the system is complex and designed in detail. It is described in a Management Systems Manual.

The system required very large amounts of information, generated from raw data collected throughout the workday. Operators were required to keep track of all delays, productive units, and materials consumed in the production schedule review. These raw data elements were compiled in a spreadsheet and analysed daily. The system was developed over two years where capacities for each process were calculated and summarised into a benchmark matrix. The matrix would be used to compare worker productivity on a daily, weekly, and monthly basis. Not represented in Figure 3-22 is the continuous improvement process that was suggested to be run in parallel. This was a formal solution identification, planning, and implementation procedure similar to that described in section 3.4.2.2.

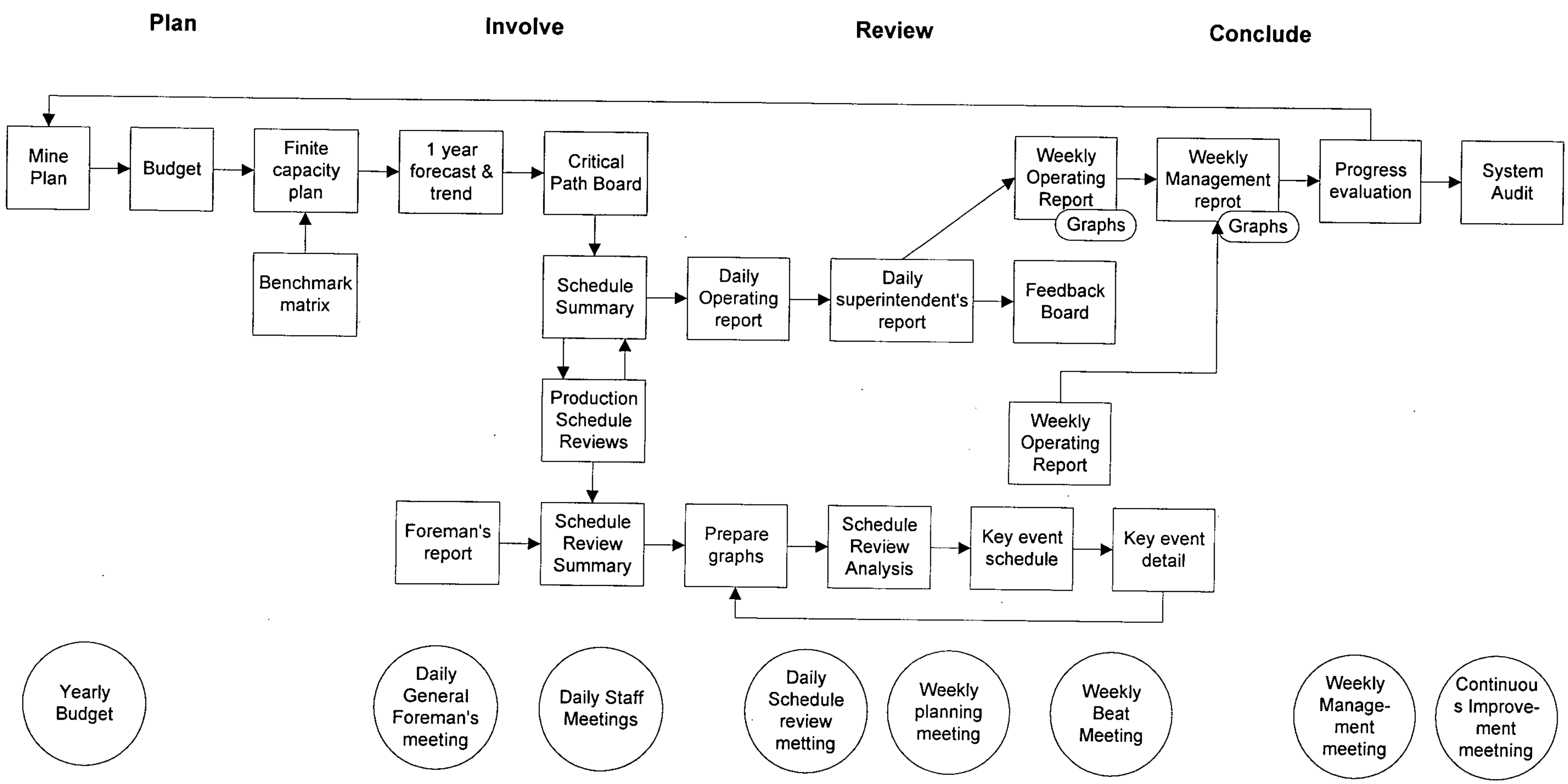


Figure 3-22: USC / INCO 1993 Production Management System Flow.[65]

Table 3-7: Descriptions of Some Components in the 1993 INCO Management System.

System Piece	Description	Frequency	Responsibility	Distribution
Mine Plan	Mine plans are already a standard part of mining operations	Yearly	Mine Engineer	Senior Managers
Capacity Plan	The resources, both equipment and manpower are identified using engineering, geology, maintenance, and productivity information.	Monthly	Divisional (area) planner	Planners
Forecast and Trend	Tool to monitor monthly progress. This provides management with a means to evaluate both the mine plan and actual resource distribution.	Monthly	Divisional (area) planner	Senior Managers
Benchmark Matrix	This matrix was developed through industrial engineering studies of each key process in the mine. The matrix can provide the number of standard man-hours to complete a particular unit of production, in this case, the required production set in the capacity plan.	As required (maintain validity)	Engineering	All Employees
Production Schedule Review	Each operator is assigned to fill out a shift report form where all productive units, changes in the plan, and delays are reported. One form exists for each type process in the mine. These are provided to the foreman as the data needed to form the schedule summary	Every shift	All operators	Production Foremen
Shift report	This report summarises the information required to pass on to the cross-shift.	Every shift	Production Foremen	Production Foremen
Production schedule review summary	This report is the summary of all the operator's production schedule reviews. The foreman compiles the information provided by the operators into another form that is completed daily.	Weekly	Production Foremen	General foremen
Schedule Summary	This is the foreman's control to summarise the shift crew list, the workplace, performance vs. target, and opportunities identified in the production schedule reviewed completed by the operators. This is where the foremen are expected to analyse the performance quantitatively.	Every shift	Production Foremen	General foremen
Production Review Analysis	This is similar to the foreman's schedule summary except it is a compilation of the analyses submitted by the foremen. This is where the GFs are expected to analyse the performance quantitatively then relates the performance assessment back to the foremen.	Every shift	Production Foremen	Production Foremen

The system was developed through a 1.5 year process where USC consultants undertook time studies. The use of the system was discontinued a few weeks after it was completed (as reported by all foremen who were present at that time). There were several reasons for the discontinuation of the system. The most important was a change in upper management support. A new mine superintendent, not present during the initial justification of the project, was promoted into the position a few weeks after the system had been completed. The system had lower-level management support such as foremen and general foreman because the management system clarified their functions, reduced the amount of waste, and made operators more accountable for delays. Lack of training and IT support were the second main cause of discontinuation. The foremen were inadequately trained in the necessary management techniques, statistics, and spreadsheet tools needed to create the graphs and undertake the daily, weekly and monthly analyses. A computerised IT infrastructure was not yet available, therefore the data was collected on paper forms and entered into various dispersed spreadsheets. Cost information was omitted for lack of availability and perceived importance. The system was implemented as a fully operational, integrated tool. There was no gradual progression into an increasingly more complex yet effective tool. Miners did not support the system as it required substantial amounts of time to complete the daily forms. From this experience it is concluded that a TMMS needs:

- IT infrastructure;
- Gradual introduction of measures and methods;
- Stepped evolution of the system into more complex elements;
- Cultural considerations such as training requirements.

3.4.3.2 Suggested Management System

Figure 3-23 represents a suggested management procedural infrastructure within the TMMS systems plan outlined in Figure 3-3. The process begins with the mine plan being filtered into short term mine production targets. This allows the calculation of the required productive units using the capacity analysis and process map. This also helps define performance targets for all levels of management. The frequency of meetings relates to the management and work level. For example, for task and activity management, a daily or weekly meeting reviewing performance, the plan, and improvement initiatives should be undertaken between the operators and foremen. A scheduled series of regular meetings can be set up so that individuals meet with required information-in-hand at a specified time.

The element unique to all components is the link to the IT infrastructure and common measures at a particular level of management. Calculations, analysis, reports, and information distribution are facilitated through the ubiquitous IT infrastructure. The standard measures are used as the medium of communication between levels of management and components of the system. For example, if the short term plan reports the productive unit as drill footage, the unit costs should be reported as dollars per drill footage, and the performance review should report the progress and targets of the drilling process in $/foot and footage to date.

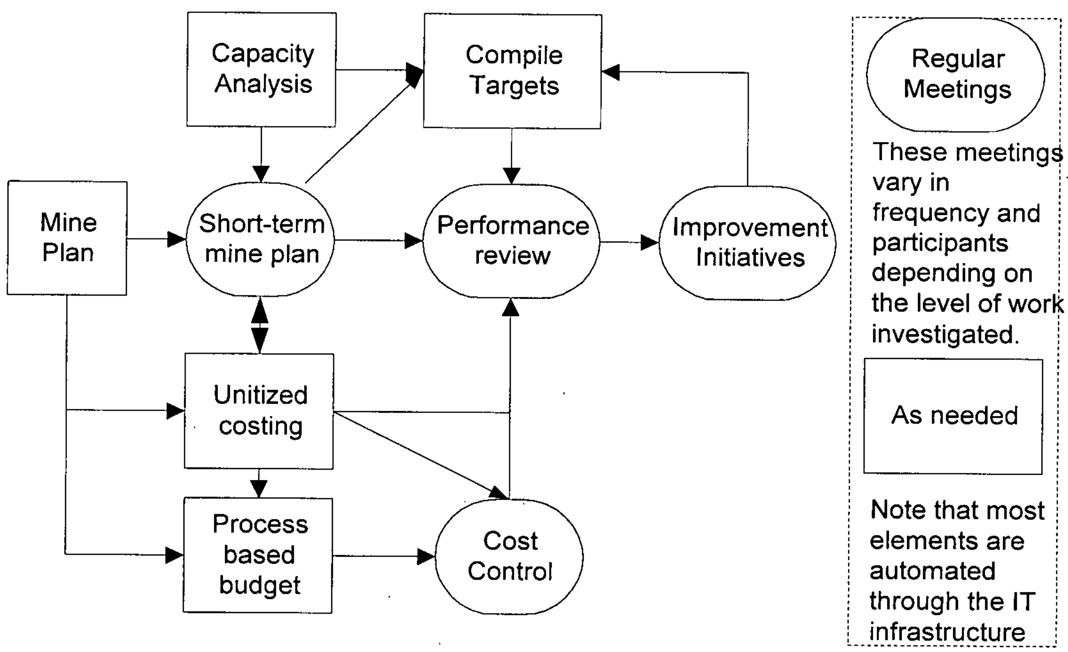


Figure 3-23: Proposed Management Procedural Infrastructure

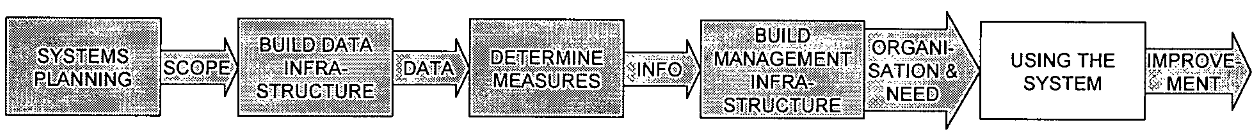
3.4.4 *Final Considerations for Management Infrastructure Development Phase*

Traditionally, tactical mine managers were not expected to undertake regular analyses, be quantitatively accountable, or use improvement tools. [45] Instituting mechanical procedures will help motivate these individuals to learn the skills needed to participate in such a system. Good implementation practice dictates that such cultural shifts should be undertaken slowly and in a step by step fashion. Organisational development theory can help design good management infrastructure and suggestions on how to structure the meetings themselves. Basic meeting guidelines include:

- Understand that the meeting is a process of planning and review;
- Start on time;
- Start with introductions (if new people are present);
- Review the agenda;
- Ensure everyone participates;
- Set and comply with ending time;
- Maintain decorum, enforce rules of good behaviour;
- Have a meeting chair;
- Completely resolve matters before moving on to the next topic;
- Ensure that the targets of the meeting have been met;
- End with a review of the decisions reached and assignments made;
- Schedule next meeting.

Some of the 'best practice' in other industries may not work well in mining. For example, in reviewing performance, public speaking may be required. Fiedler mentions how front-line supervisors in mining typically dislike presenting to peers.[66] This demonstrates that for every management activity or managerial decision, the cultural implications must be considered and planned for. As discussed previously, a conceptual mapping tool called Systems Thinking can be used to anticipate the effects of a behavioural system and identify appropriate countermeasures. [50]

As with all other steps in the development of a tactical mine management system, the best strategy is evolutionary. The management infrastructure should be developed alongside the components as laid out in the systems plan. Therefore the number and complexity of meetings and management activities should increase as quickly as can be tolerated by management. Figure 3-24 shows how the phases of systems planning, data infrastructure construction, measures determination, and management infrastructure have been discussed. The figure also lists the core components of the organisational design that ensures that performance is reviewed, system issues are identified and solved, the performance targets are accurate, planning issues addressed, and that the TMMS is maintained. The management infrastructure lays out the activities that employees within the mining system must undertake. Each meeting is designed to produce a particular result that is used in another part of the system. The final outputs from the TMMS should be a more active and informed front-line management and measurable increases in mining system performance. The first four phases discussed are the steps to be undertaken and issues to be considered when developing a TMMS. However, in order to clarify how this system would work, the fifth and final section of this chapter describes how the completed TMMS would function using a hypothetical example.



Preparation • team forming, education, inspiration **Visualisation** • systems mapping, plan system components	• Design Process map • Design data model • List data requirements • Find Data Sources • Organise & manage data collection	•ABC measures •Performance Mgmt. •Accountability structure, targets & rewards •Diagnostic •Solution specific	Organisational Design: • Measure - coach - review performance • Solution identification • Planning - set goals • Audit system

Figure 3-24: Building Management Infrastructure Phase Complete

3.5 Using the System Phase

Management can begin using the TMMS as soon as the data infrastructure, performance measures, and management infrastructure have been implemented. The system will undergo a state of change that will involve implementing added components according to the systems plan as managers become more acquainted with this new type of control and visible accountability. This final section briefly touches on some of the implementation issues that need to be considered when establishing a TMMS. Figure 3-25 shows how the TMMS' series of meetings induce a need to change, determine and plan that change, refine the targets to monitor the change, and audits itself. Changes to the TMMS are undertaken through the auditing task where the four phase methodology is once again used to either alter the existing components or implement additional management components.

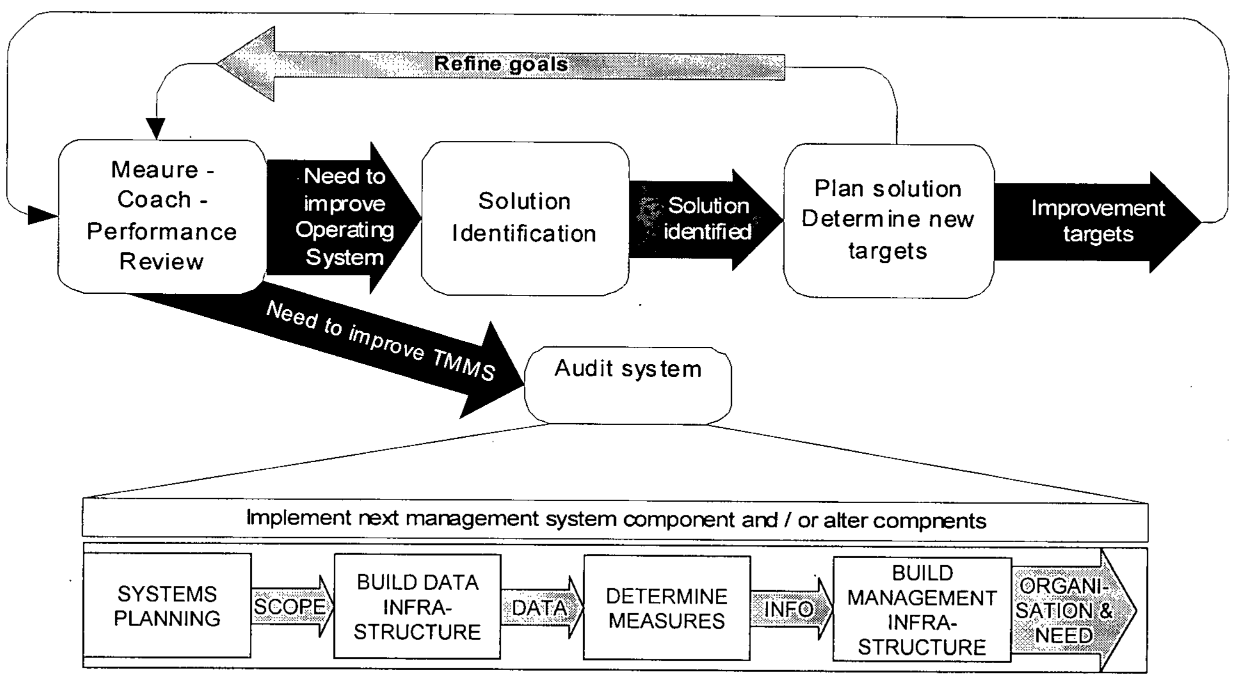


Figure 3-25: Using the System

3.5.1 Implementation Issues

Performance visibility is the most immediate difference between traditional management systems and the type of TMMS developed from the methodology. The move from a highly subjective and qualitative performance to a highly quantitative and active management is a fundamental cultural shift that will require a strong implementation strategy. Management system implementation strategies are discussed by many authors, as can be seen in the reference summaries in the appendices. Bashein *et. al.* suggest that in order to be successful:[67]

- Start small
- Conduct personnel transformation training
- Design improvement initiatives around growth opportunities rather than cost cutting
- Provide training in management techniques, personal empowerment, and teamwork ;
- Communicate frequently about the opportunities that exist in change;
- Initiate easily achievable projects leading to visible acheivements initially;
- Actively involve IS and HR specialists in all aspects of the system.

3.5.2 *Using the TMMS*

The first four sections of this chapter reviewed the procedure to follow and issues to consider when developing a TMMS. This subsection provides an anecdotal hypothetical example of using the TMMS once the above methodology has been followed. In this example the following is assumed to exist:

- **Systems plan**: several components of the systems plan have already been implemented. Further components have yet to be identified.
- **Data infrastructure**: a data infrastructure of productive units, their indices of quality, and cost data organised according to the process;
- **Performance measures**: information is available and understood relating to performance measures and targets for each manager. Furthermore, an automated capacity-assessment tool has been provided listing the expected performance rates for every heading and that was also used for planning purposes;
- **Management infrastructure**: series of procedures and meetings is organised whereby managers review their performance measures, identify potential solutions, and plan for those improvements and for upcoming production constraints.

3.5.2.1 Foreman – Coaching Example

Table 3-8 provides the foreman with estimated rates that his miners should be able to achieve and was calculated from time studies and historical data. For example, the development Jumbo operator should be capable of drilling two rounds in a single day and the mucking rate from a VRM stope should be about 30 buckets per shift. In the daily line-up meeting in the morning, the foreman lines-up his men according to the mine priorities as laid out in the engineering mine plan. Throughout the shift, the foreman visits the various headings and inquires about the progress of work. For those areas behind the assessed rate, the foreman discusses the reasons for the gap in productivity. They discuss possible solutions and the day's safety issue. For those headings that are ahead of anticipated production, the foreman takes note of how added productivity was achieved. Rewards and praise are lauded on the men who showed initiative while coaching those who were behind. At the end of the shift, the production data is compiled for the foreman's area. Information related to the equipment, workplace, and process (in-process work) is communicated to the foreman on the next shift in the same area. He also orders items for the material stores that need to be replenished, charging the appropriate items to the process where they are consumed. For example, bolts and screen are purchased for the development processes and ITH drill bits for the longhole drilling process. The production statistics for the day for all the foreman's areas are entered into the information infrastructure, allowing the mine's daily performance to be measured.

Table 3-8: Example of Foreman's comparative rates

Process	Equipment	Design	Expected Performance Rate	Resulting Expected Mine Performance
Development	Jumbo 671 (2boom)	5x4	3 rounds / shift	33 feet adv./shift
Development	Jumbo 791 (1boom)	4x3	2 rounds / shift	22 feet adv./shift
Mucking	Scoop 114 – 8yrd	Stope 4800A	30 buckets / shift	300 tons/shift
Mucking	Scoop 114 – 8yrd	Stope 4800B	20 buckets / shift	200 tons/shift
Mucking	Scoop 225 – 10yrd	Stope 4800C	18 buckets / shift	216 tons/shift

3.5.2.2 General Foreman –Improvement Initiative Example

The General Foremen (GF) review their performances with the Superintendent in the weekly meeting. General Foreman A (GFA) displays his performance over the last 30 days showing costs and productivity, as seen in Figure 3-26. Seeing the gap in performance, the Superintendent challenges GFA to perform better and requests that a plan of action be presented in the next meeting scheduled in one week.

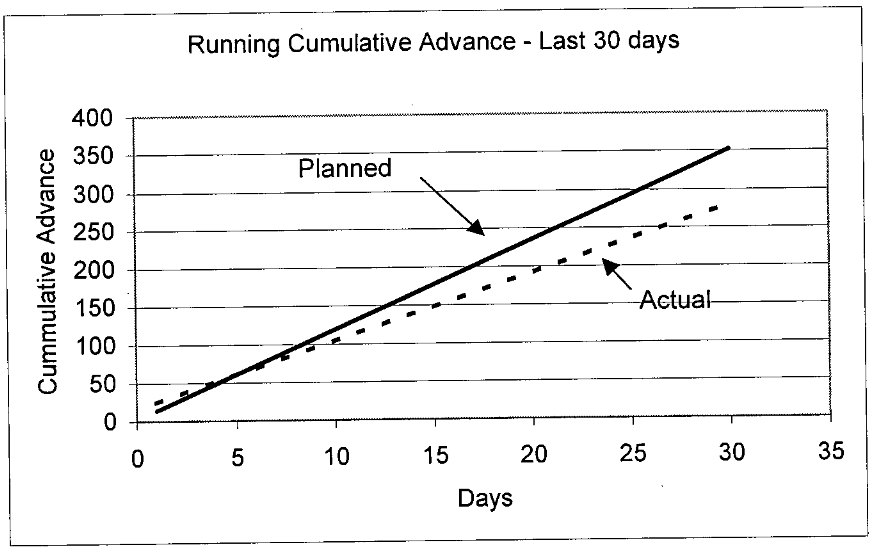


Figure 3-26: Productivity and progress performance measure for GFA.

All GFs have information related to the productivity trends for the individual shifts, workplaces, and equipment utilisation. Figure 3-27 and Figure 3-28 shows that a high-priority workplace, a ramp development, is consistently below its rated productivity and the trends show that it will not be completed by the due date on the mine plan. The operator comparison graph shows that the crews on the three cross shifts working in the area have virtually identical performance rates, indicating that worker productivity is not the issue. Similar graphs show that equipment availability is also not the issue causing the poor performance. Analysis of the delay information shows that "no material" is also not the problem. However, mucking and bolting processes seem to be taking far longer than what should be expected from capacity analysis. This information is readily available for comparison using the database tool's GUI for which the GFs are trained.

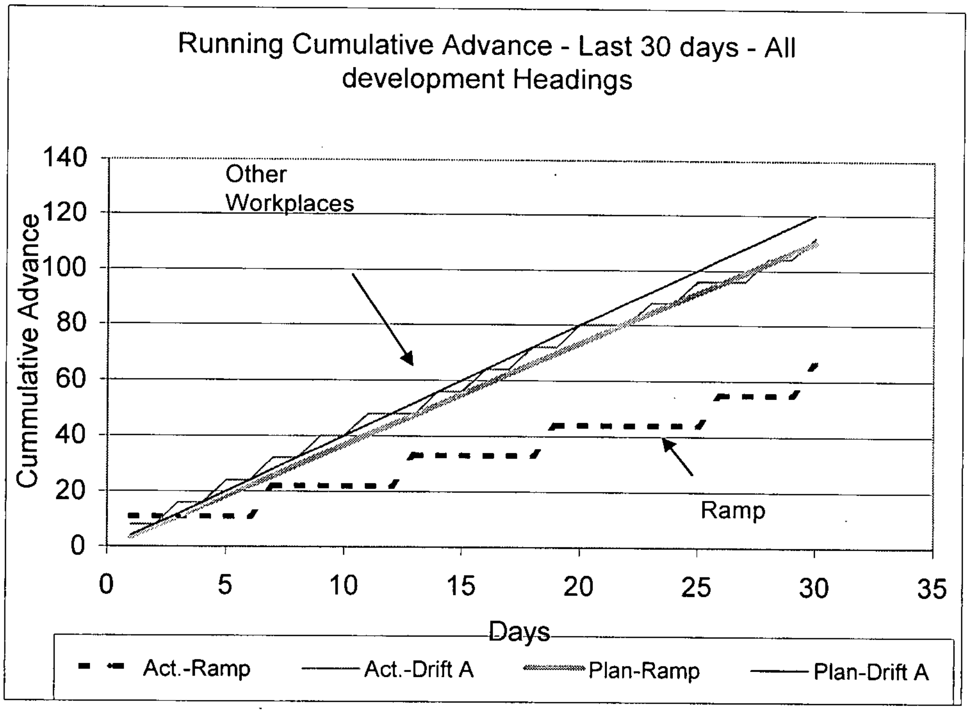


Figure 3-27: Indicative Productivity Graphs.

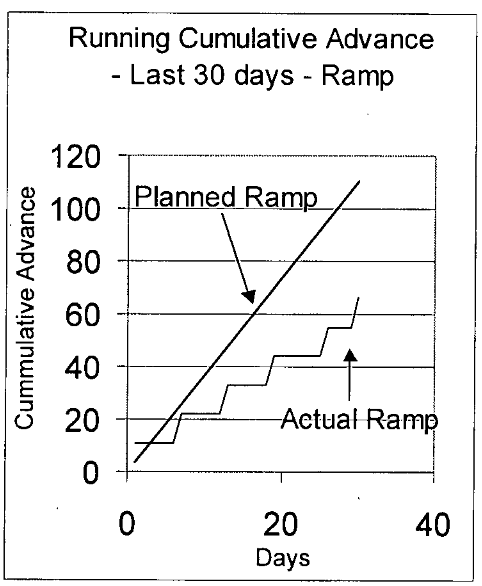


Figure 3-28: Ramp actual progress compared to plan

GFA discusses various options with his foremen on possible reasons for this lack of productivity. The discussions reveal that the ramp heading is plagued by a long travel time, de-watering issues, bad ground conditions, and long distances between the storage areas and the face. Every time a round is taken, considerable over-break occurs due to a weak zone (ground condition), resulting in poor quality walls and back that require more time to muck-out, support, and eventually recondition. After a few minutes of discussion, it is assessed that taking 8 foot rounds instead of the standard 12 foot and increasing the number of perimeter holes would significantly reduce the damage and perhaps speed-up bolting. A process of shotcreting is undertaken after every 100 feet of advance. It is estimated that there is 10% additional overbreak when a 12 foot round is taken. Therefore a proportional amount of additional shotcreting will be required to maintain the standard quality of drift. The surveyors and geologists indicate that the weak zone will persist for another 48 feet. With performance and cost information readily available, the new plan can be easily compared against the status quo.

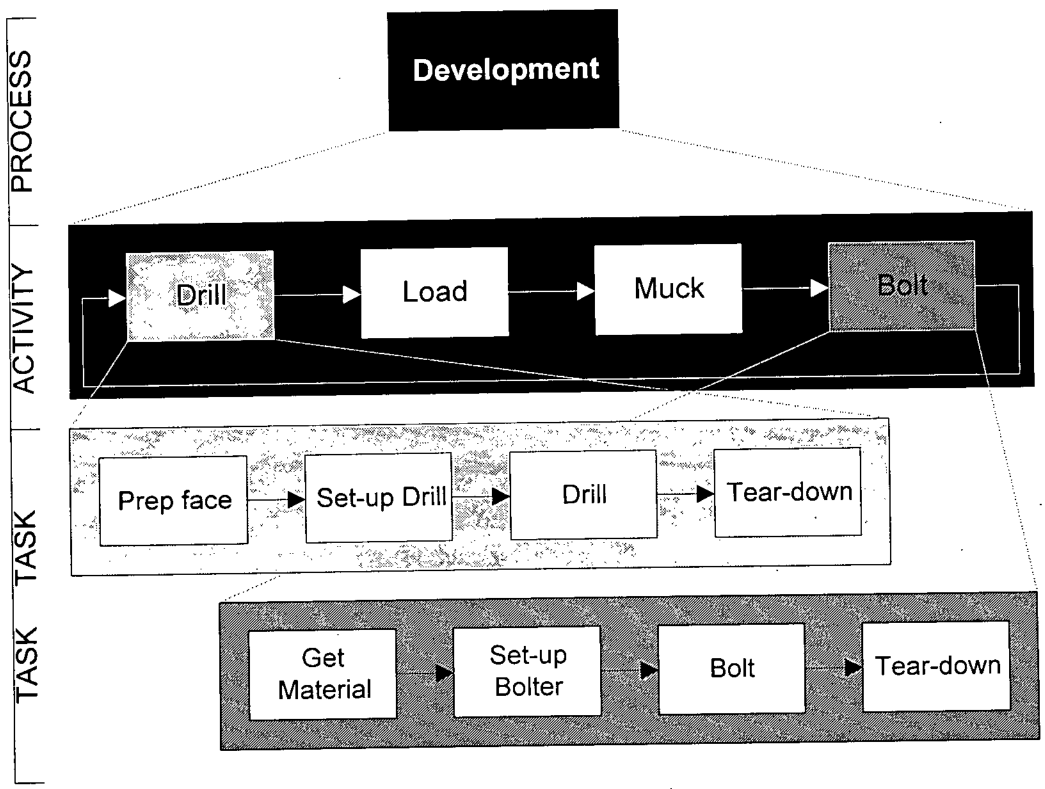


Figure 3-29: Hierarchical Process Map for Development Process

A redesign group consisting of a foreman, the best development and shotcrete crews, a technician familiar with the IT infrastructure, and the GFA is assembled and given the task to design and help implement the improvement initiative. Using the simplified process map, the group assigned to plan the improvement identifies the tasks which will be changed. Using the historical and planned performance information, the new rates for the alternative process can be calculated. Table 3-9 compares the standard process with the new process. The general foreman is accountable for both unit cost (ft. advance being the primary cost driver) and meeting the mine plan's deadlines. Table 3-10 shows that the alternate plan results in a better unit cost. Table 3-11 shows that the alternate plan does not result in an increase in development rate. Therefore. the decision becomes a trade-off between costs and meeting the schedule, although, considering that only three additional shifts are needed in the alternate plan, slightly altering the development method seems to be the best decision.

Table 3-9: Performance Information Compared

		Time (hrs)		
Activity	*Task*	*Current*	*Alternate*	*Comment for alternate*
Drill	Prep	0.5	0.5	Same
	Set-up	0.5	0.5	Same
	Drill	2.5	1.75	8 ft but more p. holes
	Tear-down	0.5	0.5	Same
Load	all	2	2	Same
Mucking	Mucking	3	2	less muck
Bolting	Get Material	1.5	1	more material needed
	Set-up	0.5	0.5	Same
	Bolt	4	2	easier and less back
	Tear-down	0.5	0.5	Same
Total cycle time		15.5	11.25	hours
Including delay & shift chang		5	4	shifts
Drill steel length		12	9	feet
Bootleg		1.5	1	feet
Total advance		10.5	8	feet adv.

Table 3-10: Cost Comparison

Factor	Current	Alternate	Unit
Manpower costs for development crew of 3	600	600	$ / shift-crew
Cycle time per round	5	4	shifts / round
Manpower costs per round	2944	2466	$/round
Manpower costs by foot of advance	280	308	$/ft. adv.
Remaining (equipment, materials, & overhead)	700	700	$ / ft. adv.
Total unit cost (GF performance measure)	980	1008	$/ft. adv.
Shotcrete costs			
Process cost (surface area is cost driver)	15	15	$ / ft^2
Perimeter of back & walls	50	45	ft^2
Total shotcrete costs	743	675	$ / ft. adv.
Unit costs for final drift	**1723**	**1683**	**$/ft adv.**

Table 3-11: Development Rate Comparison

Factor	Current	Alternate	Unit
Rate	2.1	1.9	feet / shift
Remaining adv.	48	48	feet
Total time	22	25	shifts

The following week, in the meeting with the superintendent, GFA lays out the plan as designed by the improvement team. The tradeoff between the rate and costs are weighed and the superintendent helps make the decision with the General Foreman. The cost targets for the month will reflect the 1683 $/ft adv. for the 48 feet remaining. The minor gap in productivity is excused as the resulting solution reduces cost. The superintendent and GF identify that overbreak could be a concern in other areas and request that surveyors measure overbreak for each round and that information is automatically entered into the workplace database so that long-term monitoring of drift quality can be undertaken. The meeting moves onto other concerns.

3.5.2.3 Auditing Example

Management has requested that a measure of overbreak be monitored long-term as part of the workplace database. Additional toping measurements will be required. Data items of height and width will be added to the database. Additional procedures are then put in place for when surveyors measure development drifts. Surveyors are asked to record 4 additional tope measurements for each round. A query is programmed to compare the designed and actual dimensions of drifts on a quarterly basis for upper level managers. A diagnostic query is programmed to run every time the development dimensions are updated and creates an exception alert when areas of overbreak exceed an acceptable amount. The workplace database is connected to the performance database, therefore the query tool can report which operators drilled the rounds exceeding the allowable overbreak. The foreman can then coach that operator on taking more care when drilling the outlying and perimeter holes. The quarterly reports provided to upper-level managers can be used to coach the appropriate foreman to take more action on the issue of overbreak, or reward individuals for keeping overbreak under control.

3.5.2.4 Example Synthesis

The example above shows the cycle of meetings as seen in Figure 3-21. Once a gap in performance expectations is identified, tactical managers are coached into finding solutions. Active management intervention seeks out possible causes, using process based performance records that can be compared according to workplace. Using the available standardised process map, historical performance measures, and accepted process costs (and cost drivers), the solution(s) are justified and planned. New targets are set to conform to this change in plan. From Table 3-5, it can be seen that this is an example of an activity-process level change at the general foreman level across a timeline of 1 week to 1 month. The auditing aspect of the surveying shows how the TMMS can be expanded as needed by augmenting the data infrastructure (added toping data), designing measures (measuring by workplace and operator), and meetings (induced exception meeting for the foremen and quarterly overbreak review by upper managers).

Using the system is relatively simple if the TMMS is designed correctly. The methodology as proposed in this chapter is intended to result in a TMMS that conforms to the requirements of modern tactical management systems. To reiterate, the purpose of this thesis is to develop a methodology that can create a TMMS which greatly expands the abilities of tactical managers in mines. These managers should be able to hold their subordinates quantitatively accountable, have tools to aid in identifying, planning, and implementing solutions, and improve the TMMS. The core components that allow this to happen are:

- Determining what is needed, (visualising).
- Collecting raw data into an IT infrastructure using processes as the focal point of design (automated through IT)
- Converting the data into measures thereby creating information (automated through IT)
- Instituting an organisational design whose objective is to design a tactical quantitative management system.
- In using the system, improvements to the mining system are made, along with the auditing functions that induce a new but involved cycle of augmenting the data infrastructure, designing new measures, and instituting management intervention.

Figure 3-30 shows this process, along with a rough time-scale needed to undertake the initial TMMS development. Improvements induced by deficiencies identified in the auditing function, can take anywhere between one week to a few months.

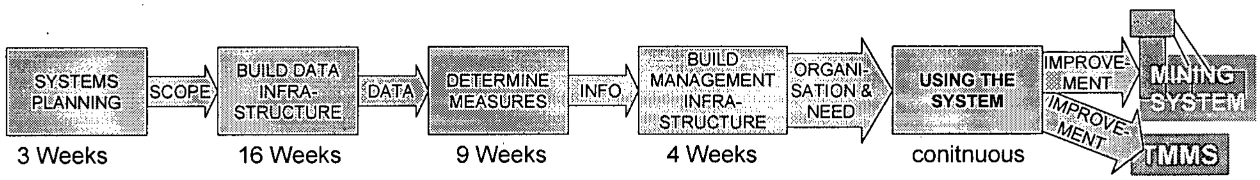


Figure 3-30: Using the System Resulting in Improvements for Mining and TMMS

3.6 Synopsis of Mechanics of the TMMS Methodology

The research objective in this thesis is to determine the core components in a TMMS. The five phases presented in this chapter provide the theory and reasoning behind each of the phases of development and use.

The systems planning phase provides the human infrastructure needed to form the TMMS. There are two main products of the planning phase. The first product is a team that is educated and inspired with enough resources to undertake the complex design and implementation of the TMMS. The second product is a plan of a series of management components that would ensure an adequate IT infrastructure, sufficient measures, and complimentary management systems. The series of components should include the creation and maintenance of an IT infrastructure, the use of measures in management systems to inspire performance improvements, while the last components are mechanisms for improving the production system.

Developing the IT infrastructure requires the designers to understand the needs of the basic technology used in information systems. Data models, collection mechanisms, and databases will need to be created. The methodology discussed in this chapter provides the basis necessary for IT infrastructure designers to appropriately design and construct the data requirements.

Developing measures require a substantial understanding of cultural and motivational issues. The discussion and examples of anthropology presented in this chapter should facilitate the creation of measures that can aid in steering cultural behaviour toward an active pursuit of appropriate improvements in the production system.

Establishing management infrastructure allows the measures to be reviewed, discussed, and acted upon thereby changing behaviours. Organising meetings or adding items in pre-existing meetings enforces the use of the performance measures, and requiring decisions or improvements to be set in such meetings enforces the desire to improve.

One of the key benefits of this methodology is the ability to use modern management techniques. The components of the TMMS are frequently modelled on these techniques. For example, establishing a TMMS component such as 'capacity analysis' or 'process optimisation,' (as seen in Figure 3-3 and Table 3-1) can be established by the continuous use of the Theory of Constraints. This methodology uses formal management techniques to design measures and management infrastructure. Management techniques can also be used in improvement initiatives inspired in the use of the system. Therefore management techniques are used in both the development and use of a TMMS.

Tactical managers in the manufacturing industry are trained in these tools as the central component of their education as Industrial Engineers. Unfortunately, mining engineers do not include industrial engineering as part of their education (perhaps a brief introduction of operations research). Appendix G reviews some basic management techniques that may prove useful in a TMMS.

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Chapter 4 Application of the TMMS Methodology at INCO

In the development and application of the original reengineering concepts, both Hammer and Davenport, the pioneers of reengineering, did not derive the reengineering methodology in isolation.[1,2] They had observed and analysed what some companies had accomplished by restructuring their organisations using IT. In the development of the management methodology proposed in this thesis, a general framework is devised, then improved through successive applications at several mining operations. The general framework for this work was developed from personal experience, extensive literature review, and analyses of management techniques and field projects at mines. Chapter three described the methodology that was implemented at various mines whose impact is discussed in this chapter. The primary purpose of this chapter is to describe the results of applying the methodology and the of impact a modern, IT empowered TMMS. It is based on the field work conducted in underground mines in the Sudbury area.

The consideration of cultural issues is a key aspect which distinguishes the proposed TMMS development methodology. Workforce behaviour is a factor influenced by the history and community of the area and management philosophy. This chapter considers the history of the Sudbury area and INCO Limited. INCO is Canada's second largest mining company and its Ontario Division is based in the Sudbury region. The production, management, and past tactical management improvement initiatives within the Ontario Division are reviewed. A history of the recent developments of IT infrastructure is also discussed since it prompted the interest by INCO in the TMMS methodology. There are three underground mines in the West Mines Complex: Creighton, Coleman/McCreedy East, and Crean Hill. Work for this thesis has been undertaken at each of these three underground nickel mines. The pertinent information about each of these three operations and of the West Mines Business Strategy unit is discussed. This background information will conclude by briefly describing the research project and collaboration with INCO. The remainder of the chapter will follow the five phase structure used in the previous two chapters, where the individual project steps, procedures, impact, and results will be laid-out.

4.1 Background

The following background will establish the long history of INCO which in turn explains some of the cultural characteristics of the metal producer. The background begins by detailing the origins of the company, then describes some of the cultural characteristics.

4.1.1 Origins

INCO was formed under the name Canadian Copper Mining company in 1883 by an American named Samuel K. Richtie to build the Murray copper mine in Copper Cliff (now a suburb of Sudbury).[3] The nickel in the ore was considered a contaminant until the 1890s when a market for nickel was established upon the discovery that it could be used for manufacturing steel armour plate. Consequently, INCO has its roots in the Sudbury region. Through aggressive investment and marketing, INCO held a monopoly for nickel until the 1970s, where a series of market downturns and strikes allowed competitors to break the monopoly, which was never regained.[4] At its largest, the company would eventually have operations in Ontario, Manitoba, Guatemala (now terminated), Indonesia, and processing facilities in the United Kingdom and the United States. INCO currently employs 10,143 people world-wide. In 2000 the company had listed assets of $US 9.676 billion, net sales of $US2.917 billion and net earnings of $US 400 million.

4.1.2 Organisational Culture Overview

Two contrasting cultures, management and labour, were characterised by Clement in the book Hardrock Mining: Industrial Relations and Technological Changes at INCO.[4] According to Clement, the tactical management between INCO Divisions is reported to have different cultures. This may reflect the different forms of worker resistance to change that exist at their various regions of operation, namely Sudbury (Ontario Division), Thomson (Manitoba Division), and Indonesia (PT INCO). This is also indicative of the flexibility of management culture as it changes to attempt more effective workforce coordination mechanisms. Clement also mentions that a tradition of antagonism has existed between workers and management despite changes to worker rights since the early 1980's. [4] The incentive system, established in the 1970s, is the mechanism used to motivate workforce. The current incentive system is based on time and resulting production.

The incentive system is organised by contract. The productive units for each contract are measured and managed by the mine surveyors. The total amount of productive units is calculated for the month, along with the number of hours of work for each miner on a particular "contract". Rates are set where a specific amount of productive units are expected to be completed in a set time. Figure 4-1 shows the calculations undertaken for a miner's bonus. Figure 4-2 is a numerical example of some of the activities within the development incentive contract. There are many rated activities within the inventive system (distributed through a 1 inch binder). All the units have to be collected by the incentive administrator, typically a surveyor, and entered into a DOS based computer mainframe program.

$$\text{Contract allowable hours} = \sum_{i}^{n} (\text{number of productive units})_i \times (\text{rated number of manhours per productive unit})_i$$

$$\text{Percent performance} = \frac{\text{contract allowable hours}}{\sum \text{total manhours changed to contract}} \times 100$$

$$\text{Incentive earnings in percent of base wage} = (\text{percent performance} - 75) \times 0.4$$

$$\text{Total incentive earnings} = \text{incentive earnings in percent of base wage} \times \text{total \$ of wage earned}$$

$$\text{Bonus for Miner}_x = \frac{\text{hours charged to contract for Miner}_x}{\text{total manhours charged to contract}} \times \text{total incentive earnings}$$

Figure 4-1: Calculation of Bonus for a Miner on Contract[5]

Rate Descriptions		# of Units	Rate (Manhrs/unit)	Resulting Allowable Manhours
Install Bolts & Screens (unit= # of bolts)				
	1.5 ft bolt & screen	56.000	0.240	13.440
	2 ft bolt & screen	42.000	0.275	11.550
	6 ft bolt & screen	419.000	0.390	163.410
	8 ft bolt & screen	220.000	0.440	96.800
	8 ft epoxy resin b&s	98.000	0.525	51.450
Install Vitaulic Steel Pipe (unit = feet)				
	Remove - 4 inch and under	80.000	0.041	3.280
	Install - 4 inch and under	30.000	0.021	0.630
	*** other work codes and units ***			
			total resulting manhours	1002.94
			Actual Manhours charged	695
			percent performance	144
			Incentive earnings in percent of base wage	27.6
			total wages earned for contract	16368.51449
			total incentive earnings	4517.71

Figure 4-2: Example of Rates and Incentive Calculation for Development[6]

The numerical example above shows the detail of production information necessary to calculate incentive reporting. For example, the type, length, workplace, and miner must be known for every bolt, screen, and pipe installed. The issue of data collection will be discussed further in the context of INCO's current IT infrastructure.

The work culture of INCO's management and workforce has been studied in depth by Clement[4] and other authors. It is understandably a politically sensitive topic, aspects of which may be inappropriate for this research. The basic components of its front-line culture appear to be the autocratic nature of its management and the militancy of its union. Further discussion of cultural issues in the context of how a TMMS may help to accommodate cultural considerations, is within the limit of the scope of this work. This project deals with the development of a TMMS across the West Mines Complex: therefore, cultural issues will be discussed only when they pertain to the development and use of a TMMS.

4.1.3 West Mines Complex

The West Mines Complex (WMC) is comprised of three mines and two service units each headed by a superintendent. Figure 4-3 shows how a centralised maintenance unit co-ordinates activities between the different operating plants. The business unit has only two employees and is responsible for co-ordinating human resource activities and evaluates and implements new business/management techniques. The tactical management hierarchy consists of four levels. Table 4-1 summarises each level in terms of its main functions, variances, work levels, and time frame. The codes, such as S2 (abbreviation for stratum II) for general foreman level, signify the level of promotion, authority, and pay-scale of the managers. For example, a Chief engineer would be considered an S2 while a Senior engineer, an S1. Table 4-2 summarises the key production, manpower, and equipment issues of the operating mines in the West Mines Complex.

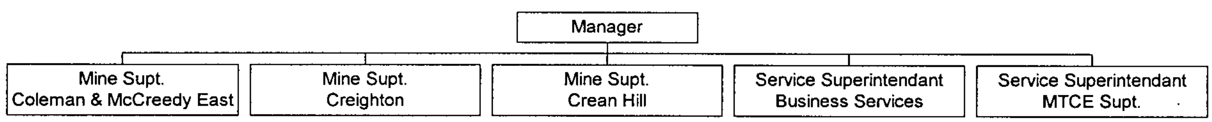


Figure 4-3: West Mines Upper Management

Table 4-1: Tactical Management Hierarchy and Job Function in the Ontario Division

Level	Description	Work level	Time frame	Code	Variances
Manager	One manager per complex	Manages several mines (multi-system or complex)	1 to 5 years	S4	• Mining • Surface plants • Services (example: IT, Mines Research)
Superintendent	One per mine	Managers a group of foremen at the system level	1 month to 1 year	S3	
General Foreman	One per geographical area or service	Manages a group of foremen, at the sub-system or process level	1 week to 1 month	S2	• Operating • Logistics • Maintenance
Foreman	One per work crew, several cross-shifts per geographical area	Manages a group of miners, at the activity or task level.	1 day to 1 week	S1	• Operating • Project • Services (maintenance, electrical)

Table 4-2: Summarised Description of Ontario Division Mines.

Mine	Creighton	Coleman/McCreedy East	Crean Hill
Age	100 (celebrated it centenary this summer)	10 years (3 different mines sharing a common infrastructure)	13 (from latest opening, has areas 70 years old)
Shift Schedule	10 hour shifts 4 day work week (mine down for 3 days)	10 hour rotating	10 hour rotating
Workforce	Over 300 hourly 50 contractors 30 management West Mines headquarters	Over 200 hourly 20 management	40 hourly 13 management
Median Age of Workforce	48.7	45.4	52.5
Remaining Mine life	50+ years	25+ years	1 year
Mining Methods	Cut and fill VRM Slot-slash Uppers	Narrow vein cut and fill Cut and fill	Modified cut and fill VRM
Daily Tonnage	4500	4500	1500

4.1.4 *IT Infrastructure at the West Mines Complex*

As mentioned previously, when the TMMS development methodology is implemented in brown-field sites, a pre-existing management and information infrastructure may already be established but not function as effectively as desired. A history of projects that intended to improve management techniques may also exist whereby managers may be already familiar with particular techniques. This subsection describes the IT and management infrastructure at the West Mines complex that had been implemented prior to the commencement of this project.

In the early 1990s, management was given training in TQM tools and provided with a booklet on how to apply TQM in the workplace.[7] After a few initial successes, the TQM initiative was considered to be too labour intensive (the meetings and education process took too much time) and soon abandoned. A second management improvement scheme was undertaken, this time at the West Mines Complex (then known as Levak Complex), where a detailed tactical management system was developed through a management consulting firm, Universal Schedulers (discussed in Chapter 3, Section 3.4.3.1). The management system was abandoned for lack of upper management support due principally to the excessive manual data collection and processing requirements. These events demonstrate how some managers became familiar with management system reengineering. The lack of data infrastructure was also clearly identified.

In the mid-1990s, INCO had identified the need to update their IT infrastructure and decided to buy MINCOM's™ Mine Information Management System (MIMS). The system began as a maintenance management system but would eventually be composed of financial, production statistics (Prodstats), and materials inventory modules. Although available, a human resources module was not purchased as it did not fully meet their human resources (HR) needs. INCO uses an HR computer system that was developed in-house in the early 1980s. Figure 4-4 shows the five modules in relation to each other and their implementation dates.

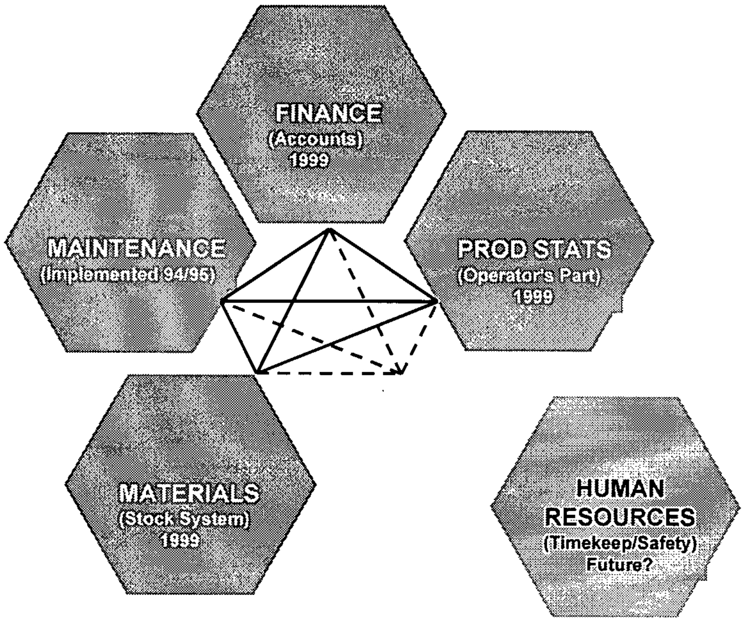


Figure 4-4: MIMS Modules and their Implementation Dates at INCO.[8]

The need to undertake research and development of new IT and management techniques was identified by late 1998 following a successful application of ABC in financially justifying a new narrow vein copper mine. A new chart of accounts based on mining processes was developed whereby the materials, labour, and equipment costs for a particular process were charged against an unique process based-account. In this system, each financial transaction would be charged against an account that represented a particular process. This financial transaction would be recorded in the Mine Information Management System (MIMS) relational database using the process based account as an 'identifier' (see Chapter 3, Section 3.2.1's discussion on relational databases). Figure 4-5 shows the basic components of each financial transaction's identifier. Figure 4-5 is an example of a cost transaction for Crean Hill mine, as presented by the first two digits (Crean Hill=13, Creighton=17, and Coleman/McCreedy east = 10). The responsibility indicators are the following two digits, the first representing the general foreman and the second foreman. The process is represented by the last three digits, in this example the development process (005). It is important to mention that every mine has the same process numbers to which they charge. For example, a Creighton transaction identifier would be 1765025 (17=Creighton, 65=general foreman and foreman id, 025 = process identifier for In-the-Hole (ITH) drilling). Over forty unique processes were defined. This list of accounts is referred to as the process-based chart of accounts.

However, no process map was created from which these processes could be visualised. This created discrepancies between mines and the accounting system in how people interpreted the account descriptions when charging costs. Therefore initially, virtually every foreman charged costs differently. As will be reviewed later, one of the steps involved in building a data infrastructure included redefining the data models so that the database would more closely mirror reality and would be consistent across the WMC.

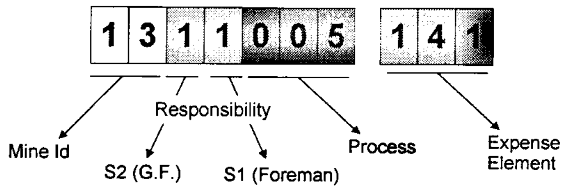


Figure 4-5: Cost Transaction Identifier

Table 4-3 shows the first 20 process based accounts as of early 2000. The creation of a new senior position, Superintendent of Business Systems, was the direct action undertaken by WMC management toward identifying and implementing new management techniques. Encouraged by the possibilities of process based management, an attempt was made to fully implement the ABC management technique. This experiment identified that ABC was incapable of functioning in a mining environment without integrated production information.

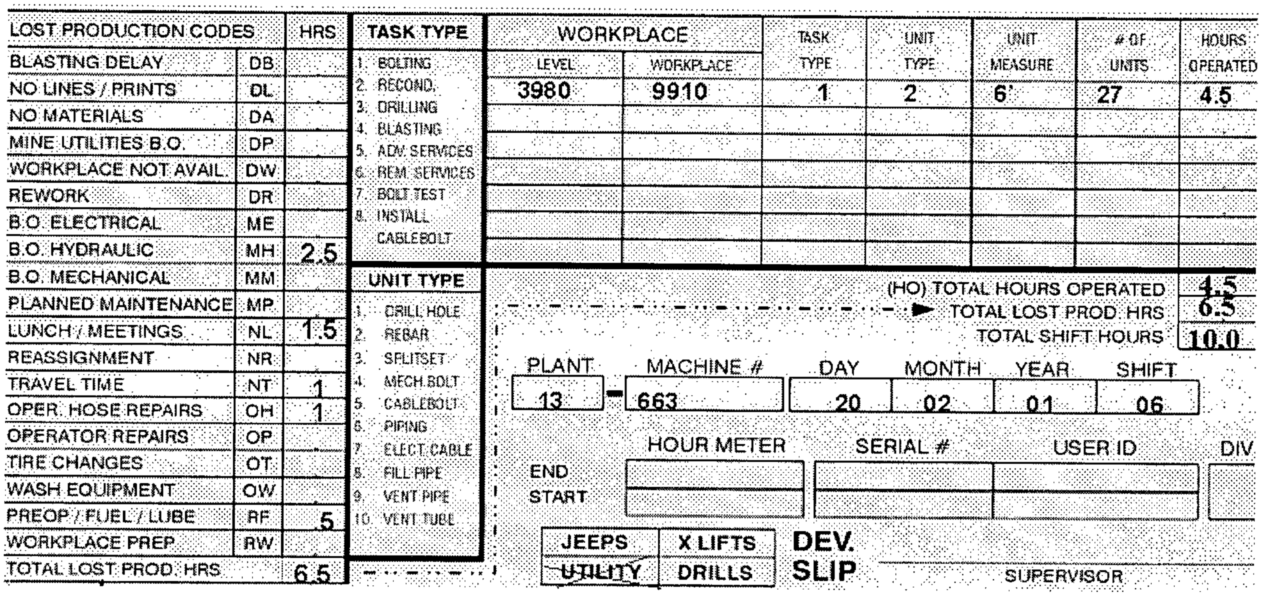
Table 4-3: The First 20 Process Based Account Numbers

Process #	Process Description
005	Develop Lateral
010	Development Raises
015	Diamond Drilling
020	Prdn Mining Cut and Fill
025	Prdn Drilling ITH
030	Prdn Drilling Top Hammer
035	Prdn Blasting Bulk
040	Secondary Blasting
045	Scoop Tram Mucking
050	Scoop Tram Re-Mucking
055	Track Tramming

Process #	Process Description
060	Truck Haulage Diesel
100	Hydraulic Backfill Syst
110	Rock Backfill
115	Barricade Constr Backfill
120	Supplies Distributn Acct
125	Supply and Person Hdlg
130	Underground Constructn
135	Recondition Conventional
140	Ramp and Roadway Mtce
150	Cable Bolting

While upgrading MIMS in preparation for the Y2K roll-over, INCO decided to purchase and develop the Prodstats system. Prodstats is an equipment based system where operators record all production, delay, and equipment status information onto a slip that is completed at the end of every shift. Figure 4-6 is an example of a short-hole/utility slip showing the production, delays, workplaces, equipment, and operator for that shift. An operator must complete a slip for every piece of equipment used throughout the shift. The slips are entered manually through a graphical interface into MIMS. The system takes that data and populates various relational databases that track equipment meter hours for maintenance and supplier contracts. Many data elements are recorded, including:

- task type;
- workplace;
- type and number of raw materials consumed;
- productive output;
- time to complete;
- delay types and times;
- equipment used;
- operator identification;
- frontline supervisor (foremen).



LOST PRODUCTION CODES		HRS
BLASTING DELAY	DB	
NO LINES / PRINTS	DL	
NO MATERIALS	DA	
MINE UTILITIES B.O.	DP	
WORKPLACE NOT AVAIL.	DW	
REWORK	DR	
B.O. ELECTRICAL	ME	
B.O. HYDRAULIC	MH	2.5
B.O. MECHANICAL	MM	
PLANNED MAINTENANCE	MP	
LUNCH / MEETINGS	NL	1.5
REASSIGNMENT	NR	
TRAVEL TIME	NT	1
OPER. HOSE REPAIRS	OH	1
OPERATOR REPAIRS	OP	
TIRE CHANGES	OT	
WASH EQUIPMENT	OW	
PREOP / FUEL / LUBE	RF	.5
WORKPLACE PREP	RW	
TOTAL LOST PROD. HRS		6.5

TASK TYPE
1. BOLTING
2. RECOND.
3. DRILLING
4. BLASTING
5. ADV. SERVICES
6. REM. SERVICES
7. BOLT TEST
8. INSTALL CABLEBOLT

UNIT TYPE
1. DRILL HOLE
2. REBAR
3. SPLITSET
4. MECH.BOLT
5. CABLEBOLT
6. PIPING
7. ELECT. CABLE
8. FILL PIPE
9. VENT PIPE
10. VENT TUBE

WORKPLACE LEVEL	WORKPLACE	TASK TYPE	UNIT TYPE	UNIT MEASURE	# OF UNITS	HOURS OPERATED
3980	9910	1	2	6'	27	4.5

(HO) TOTAL HOURS OPERATED 4.5
TOTAL LOST PROD. HRS 6.5
TOTAL SHIFT HOURS 10.0

PLANT	MACHINE #	DAY	MONTH	YEAR	SHIFT
13	663	20	02	01	06

HOUR METER | SERIAL # | USER ID | DIV
END
START

JEEPS | X LIFTS
~~UTILITY~~ | DRILLS
DEV. SLIP
SUPERVISOR

Figure 4-6: Short-hole Utility Slip – Example of McClean Bolter Operator's Slip

Several slip types record all activities undertaken throughout the mine. Material movement slips record source and destination locations. Utility slips record the activities of short-hole drills such as jumbos, bolting machines, and jacklegs. Production drilling slips record footage drilled, ore/waste contacts, drill bits and rods used, drilling location, and compressor used. All activities within the mines are recorded in this matter, including backfilling activities on surface.

The Prodstats system records all production information while the financial MIMS module records all cost information. Both Creighton and Coleman have implemented the Prodstats module. All the mines in Ontario division have implemented the process based accounts. At the end of 1999, no direct integration between the various MIMS modules existed; therefore, production data was reported independently from the costs. S4 and S3 managers at INCO decided to initiate a collaborative research project with UBC whereby the TMMS methodology would be implemented. The project was intended and has improved the accuracy, use, and value of the various information systems available at in the WMC. In summary, the pre-existing IT components prior to the application of the TMMS methodology included a process based chart of accounts, an HR/incentive system, and the following MIMS modules:

- Financial/cost transactions database

- Maintenance database
- Production statistics database
- Logistics/materials stock system

4.1.5 Ethnographic Results

Throughout the project, from early 2000 through to late 2001, an ethnography was undertaken of the INCO WMC culture. The material collected includes email messages, interview notes, a journal, internal reports, and meeting minutes. Table 4-4 provides a few cultural characteristics that may be considered in the development of the TMMS. Note that in some situations, the discussion of cultural characterisation may not be appropriate for a public forum. The development of management systems that address cultural issues may require confidentiality, as some cultural characteristics may be perceived as politically sensitive. The issues discussed here are tempered for the public medium which this thesis serves. The table discusses cultural elements according to the cultural characterisation model suggested by Ibarra as discussed in Chapter 3.[9] For each cultural element, some observations are discussed in the 'Findings' column. The 'Management System Components' indicate the key components or accentuation necessary for the TMMS to comply with the INCO culture.

Table 4-4: Summary of Ethnographic Results

Cultural Element	Findings	Management System Component
Organisational Heritage	INCO has been mining in the Sudbury area for over 100 years. A long history fraught with strikes, layoffs, and environmental issues has created a complex culture with many incidences that impact on the behaviour of INCO employees. The most discussed issue over the duration of the study was the performance measurement systems for both management and worker.	Highly complex system therefore the management system should be occasionally reviewed for effectiveness based on cultural specifications
Organisational Structure	Table 4-1 provides the official management hierarchy. Some of the front-line supervisors are former miners and therefore are more concerned with "security" than "order" as discussed in the previous chapter. Strong mathematical and engineering background may be concentrated at higher levels of management	Additional training in modern management technology may be required
Political & Economic System	The annual budget, ostensibly based on the mine plan and costs, is compiled for each mine and sent to the corporate office for strategic planning. The budgets are used as performance measures for the superintendents. Little trust is placed in these measurement mechanisms at a tactical level as the compiled costs and plans frequently change. There is no direct discussion of the effect or morale of workers. Supervisors and worker put forth many valuable ideas but there is no human/technical resources or management infrastructure to bring about the suggested changes.	A measurement mechanism for tactical managers will have to change with the mine plan. Morale or cultural issues will need to be addressed. Infrastructure to enable improvements is required.
Environment	The Sudbury area is one of the most important mining areas in Canada. INCO is also undergoing a labour shortage. These two issues factors create a very 'secure' environment for workers.	Labour will continue to be have strong maladaptive ability potential
Demographics	Subjecting an ageing workforce to training and education in new computer and management systems may prove difficult. For example, a clerk with 34 years at INCO (employees can retire after 30 years) indicated that he did not want to learn the Prodstats system and instead retired.	Most calculations will need to be automated. A change in demographics will improve a modern system's impact
Change Systems	No rewards for positive management behaviour currently exist. Management training is more philosophical and motivational rather than technical. For example, management workshops such as "Breakthrough by design" (based on Schaffer)[10] is a motivational program where managers are encouraged to engage in improvement programs. Specific tools, IT, or management systems are not discussed, the focus is on action.	Positive performance awards should be designed for managers. Both technical and motivational training should be provided and encouraged to be applied.

4.1.6 *Synthesis of Background*

The chronology of application of the TMMS methodology at INCO illustrates the flexibility needed to build management systems and how the methodology was applied at the various mines. A detailed chronology of the application of the TMMS methodology at INCO is provided in the appendices. A review of the application and impact of the methodology is discussed within the five phase structure as laid out in the previous chapter and in Figure 4-7. Therefore for each phase of development, the methodology, results, and impact will now be discussed.

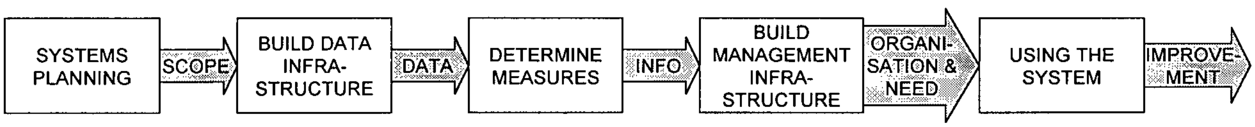


Figure 4-7: Five Phase Structure of TMMS

4.2 Systems Planning Phase

The systems planning phase is intended to create the blueprint for the management system taking into consideration the needs of the operating system. The procedure consists of preparation and visualisation steps.

4.2.1 *Preparation*

When preparing for designing a systems plan, a team needs to be formed, educated and inspired to undertake a reengineering of the current management systems. Visualising consists of understanding the needs of the operation and requirements, and the possibilities and limitations of modern management techniques. When INCO West Mines Complex initially conceived of redesigning its management support systems, a change team was formed that consisted of:[11]

- Cost engineer;

- Accountant;
- IS manager;
- Maintenance MIMS programmer (out-sourced from WMC maintenance department for the project as a MIMS expert);
- the Business superintendent as the project manager and leader;
- Chief geologist;
- Chief engineer;
- Project engineer
- Academic/management technique consultant (author).

Other team members would eventually join the change team including a GF, project foreman, mine superintendent, and project manager from the WMC Business Systems unit. For every mine where components of a TMMS were implemented, a process of educating stakeholders in TMMS methodology and modern management techniques was undertaken. For example, in the initial stages of the Crean Hill TMMS development, the consultant presented the purpose and benefit of the TMMS, the systems plan and reviewed some basic management techniques. The project sponsor and leader, the mine superintendent, then expressed his support for the project with the intention of gaining buy-in from the other tactical managers.[12] Once the preparation phase was complete, then the steps of high-level process mapping and management systems planning began.

4.2.2 *Visualisation of the Systems Plan*

The visualisation step consists of first analysing the current management system. This is undertaken through process mapping and other forms of analysis including ethnography. The first topic in this subsection is the procedure used and results of characterising the management systems at the INCO mines prior to the development of a TMMS. The second topic is the procedure and results of formulating a systems plan.

4.2.2.1 Characterisation of Current Systems

The current tactical management systems need to be assessed so that any redesign can incorporate functional components and eliminate inappropriate aspects of an existing system. Characterisation begins by defining current processes through consensus of all tactical managers within the system. A common comprehension of the current system is achieved through discussion, visualisation, and documentation. The issues to characterise include:

- Work, material and information flows;
- Accountabilities/responsibilities of the managers;
- Cultural limitations / relationships.

High-level process maps were drawn to identify key output, information, and material flows. These high-level process maps were essentially systems-level maps (note the hierarchy of work definitions in Chapter 2 and Appendix B) identifying the best areas to apply tactical management control or improve understanding. Specific mining processes that produce ore and service processes that produce equipment availability (maintenance) or engineering outputs (engineering) are delineated.

The maintenance functions at INCO are well defined, because the IT infrastructure provided by MINCOM is originally a maintenance system. Significant user experience also aids the maintenance service since the MIMS maintenance module has been in use since 1994. A reengineering of the equipment fleet management system had been undertaken several years earlier and had resulted in a structured equipment management system.[13] The West Mines Complex (WMC) has a centralised maintenance management hierarchy as seen in Figure 4-3, where a maintenance superintendent is of equal managerial status to the operating superintendents. Inventory issues were organised on a divisional level because Ontario Division has a centralised purchasing and warehouse group that handles most of the raw materials management. Intimate supplier relationships exist between INCO and local suppliers due to INCO's large market presence and proximity to the regional distribution centres in Sudbury. These close relationships further simplify materials ordering. Inventory, supplier, and maintenance issues at INCO are possibly not typical in mining, the process maps developed for INCO would therefore not necessarily be appropriate for other mining companies.

Figure 4-8 shows the high-level process map for the Coleman/McCreedy East mine. It can be seen that a single S2-level tactical manager is responsible for each service and mining area. However, the maintenance S2 reports to a Complex S3 manager, not directly to the mine S3. The logistics S2 is primarily responsible for delivery of material underground and for mine infrastructure, such as the hoist or crusher. As discussed previously, traditional inventory issues are dealt with at a Divisional level. Once the necessary education, team forming and high-level process mapping was undertaken, forming a more accurate systems plan could begin. The high-level process map was developed in discussions with the S2-level manager(s) where the accountabilities for each area were discussed and delineated. The information flows between the various production and service areas were identified.

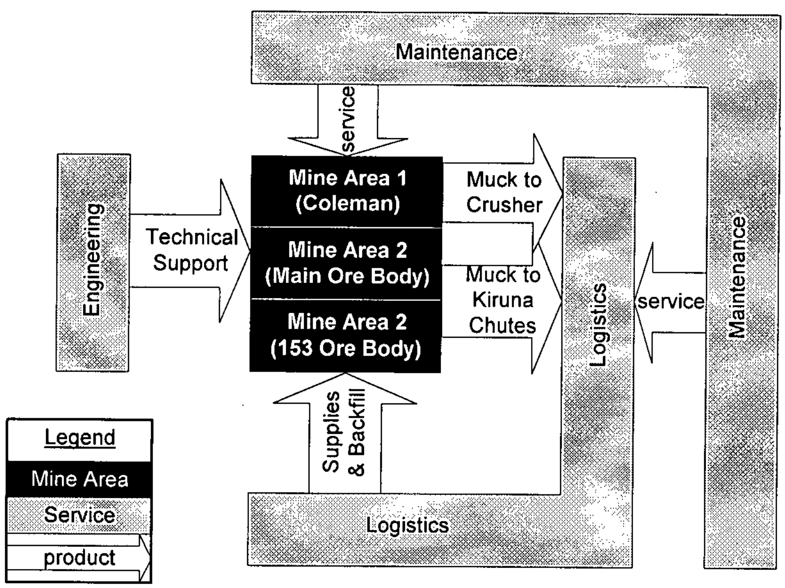


Figure 4-8: High-level Process Map using Coleman/McCreedy East as an Example

Figure 4-9 shows the original strategic systems plan for management support devised by INCO personnel. Figure 4-10 shows the tactical management systems plan that was derived from the strategic IT outlook.

The only extent to which the mine had been conceptually mapped prior to the application of the TMMS methodology is shown in Figure 4-11.

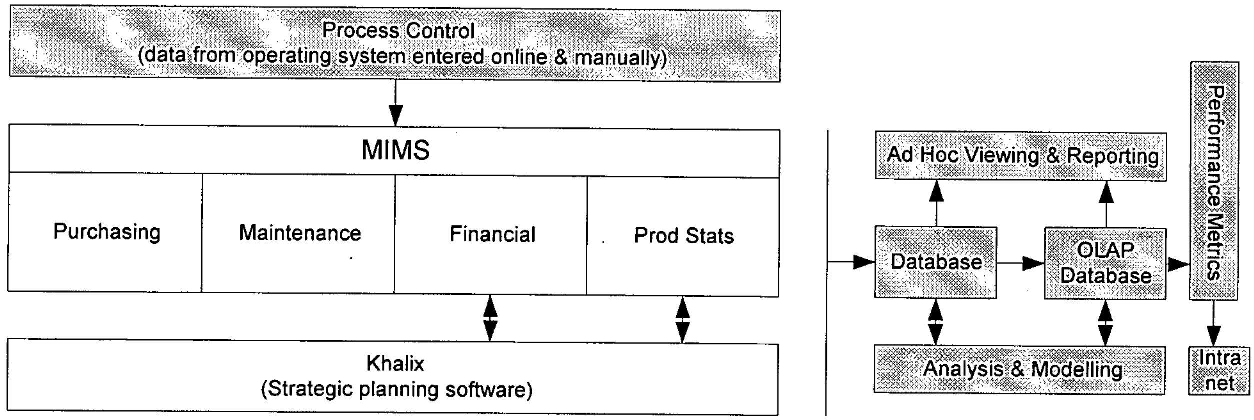


Figure 4-9: INCO 1999 Management Support Systems Plan.[14]

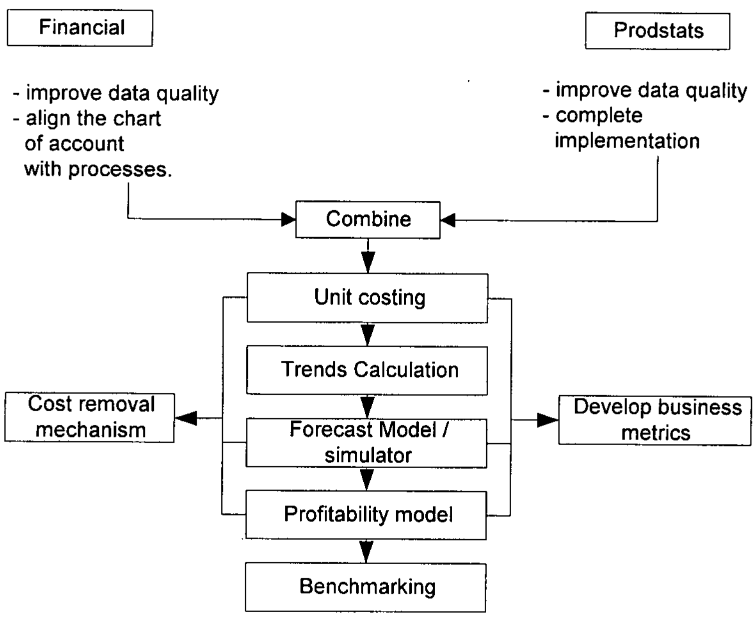


Figure 4-10: INCO 1999 Tactical Level Management Systems Support Plan.[15]

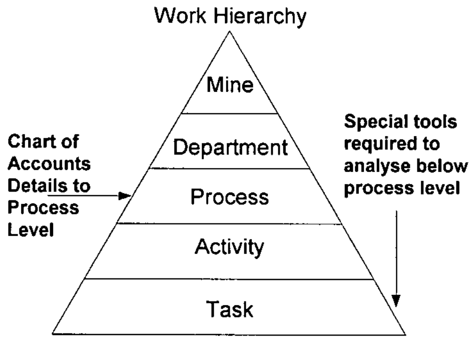


Figure 4-11: Work Hierarchy – solitary process graphic conception of work hierarchy prior to 2000.[15]

The systems plans shown in Figure 4-10 were later refined following a more detailed study of the current tactical management system at the WMC that was undertaken as part of the TMMS application. An in depth study of the management infrastructure at the WMC and particularly at Crean Hill revealed few instances of structured management intervention dealing with the production system. From an analysis of the Crean Hill conference room weekly schedule over 3 months, 87% of the hours spent in meetings related to non-production issues such as environment, safety, and labour relations. The tactical mine management system at Crean Hill prior to TMMS implementation had 3 formal meetings related to production:

- **Pre-shift planning meeting**: A daily meeting between the S2 and S1s where the work for the upcoming shift is planned;
- **Weekly production meeting**: Weekly meetings between all tactical managers and engineering staff to discuss upcoming production issues;
- **Bi-monthly planning meeting**: A meeting of all tactical managers to discuss the future long-term production issues.

Figure 4-12 shows the daily pre-shift planning meeting between the day-shift foremen, general foreman, and maintenance foreman. As can be seen, the only information used is the previous shift foreman's log report. The log report is a legislated requirement where the foreman must record the workplace and equipment hazards at the end of every shift. Unfinished work or work in progress is also communicated through these means. The log is simply a small paper notebook where the foreman summarises the necessary points in an unstructured format.

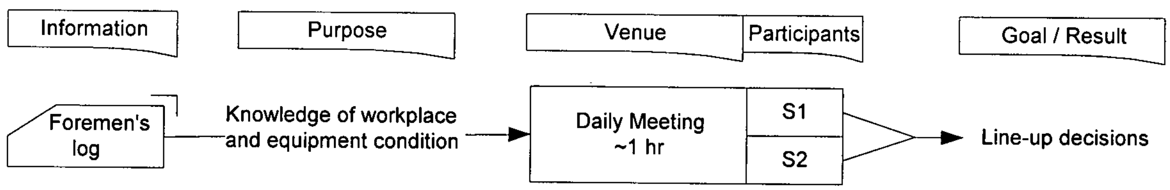


Figure 4-12: Daily Managerial Intervention

The second formal management intervention is the weekly production meeting. The main purpose of this meeting is to communicate to all tactical managers and engineering staff the overall progress in hoisted tons achieved the previous week in comparison to the monthly target. The secondary purpose is to communicate safety and divisional issues. No other past performance is discussed. In 1999, Coleman/McCreedy was the only mine reporting costs to their general foremen by process. During their weekly production meetings, costs are also discussed.[16]

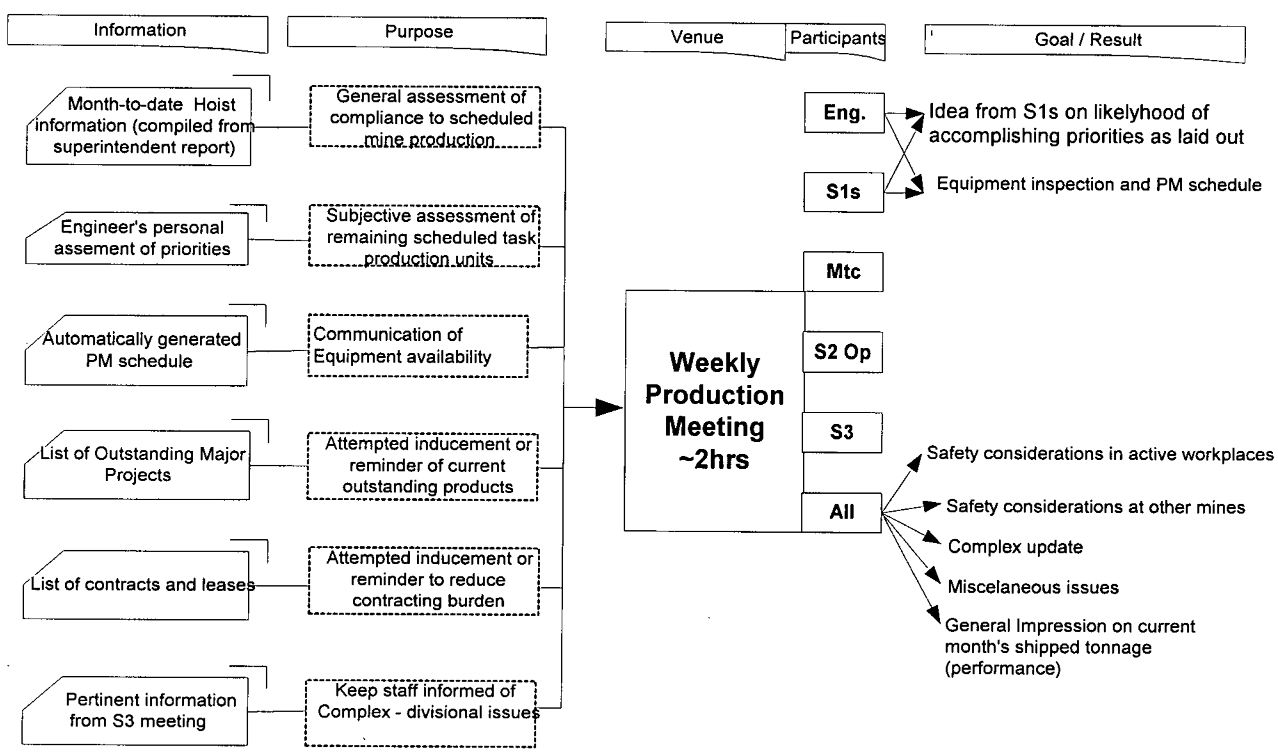


Figure 4-13: Weekly Managerial Intervention

A planning meeting (termed the "Pizza-pop" meeting), attended by all tactical managers every second month is held where the long-term mining plan would be discussed. Other topics of discussion include: changes to the mines-crew allocations, equipment overhauls, environment, and labour relations issues.

The superintendents of the WMC participate in weekly and monthly performance reviews. A variance meeting was held on a monthly basis where the superintendents would compare their performance and cost targets with their actual performance. Weekly superintendent meetings are also held weekly where divisional safety, environmental, and corporate issues are communicated.

This discussion is intended to characterise the existing management systems. As these were the only structured meetings dealing with production issues on a regular basis, it can be seen that within this management system, integrated input and output information was not required. Process level improvement initiatives are also not considered important as no clear accountability existed in which to pressure managers to initiate improvements.

The issues to be discussed as listed in chapter 3 section 3.1.2.2, and the cultural characterisations were discussed among the reengineering team, tactical managers, and workers during informal meetings throughout the TMMS application between late 1999 and late 2001.

4.2.2.2 Formulation of a Systems Plan

A systems plan is formulated through discussion among the team. The issues identified by analysis of current systems and ethnography are considered in the design of the new management system. For example, the original management system did not have complete budgeting procedures, production reviews, or explicit management performance measures. Weakness in the current data infrastructure would also necessitate auditing functions to ensure data validity. Figure 4-14 shows the systems plan proposed for the West Mines tactical management by early 2001. As can be seen, the cost and production reporting tools already existed to some extent, although tactical managers considered the data to be untrustworthy .

An auditing mechanism was required to gain the trust of the users of the data. Once the production and cost information was sufficiently accurate, the information would then be integrated at the process-level. This step would also automatically create the distributed and unitised costs. Establishing the data collection mechanisms, accuracy, and integration can be considered the 'Data Infrastructure Phase'.

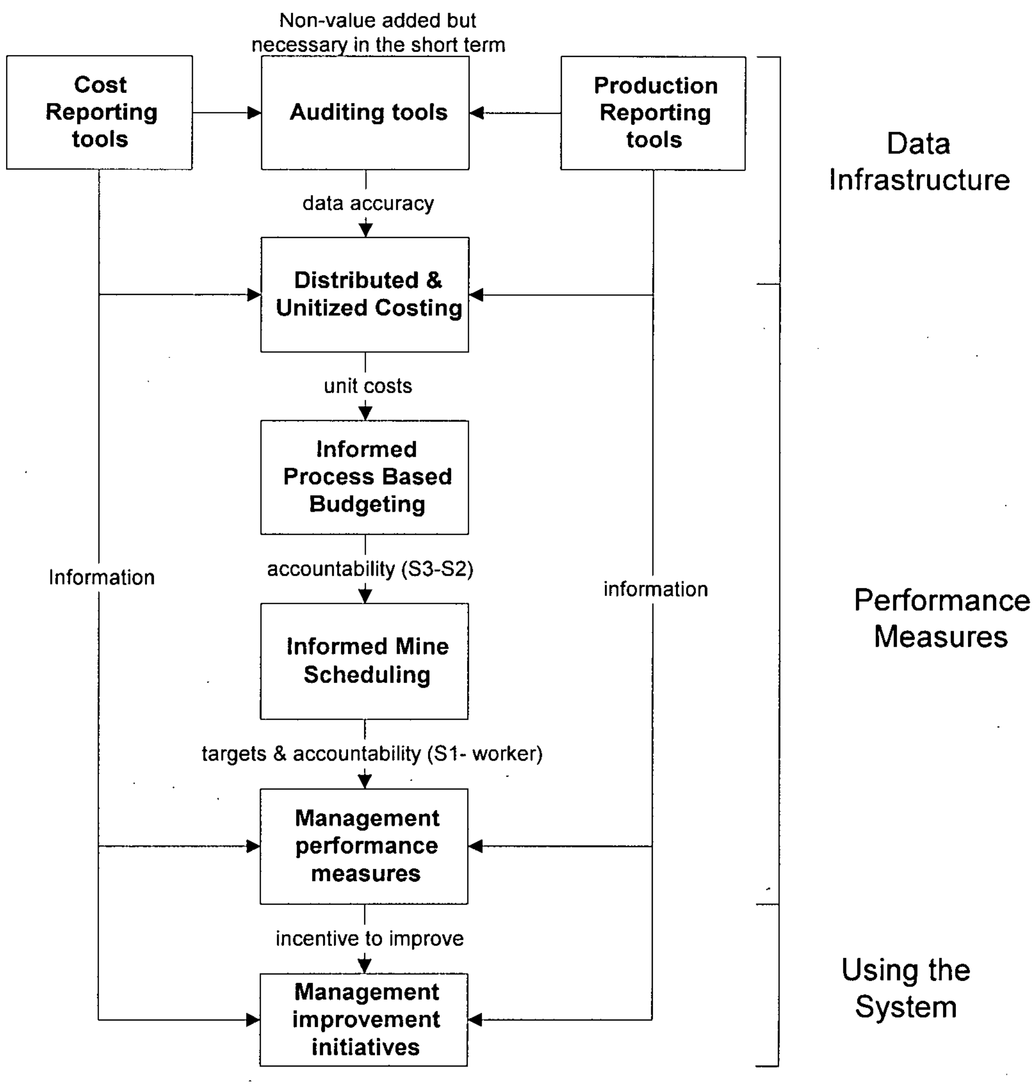


Figure 4-14: Standard West Mines Systems Plan, February 2001

Once process information has been developed, various management components can be developed. As discussed above, INCO has used the annual budget as the performance targets for superintendents. An annual budget was developed using the unitised cost and annual mine plan. A mine schedule based on actual performance rates of the processes (calculated process capacities based on performance) is developed for performance measures for lower-level managers (S2s and S1s). Other process based performance measures are developed so that specific core processes can be investigated. Although not shown, the systems plan takes into account the unfamiliarity of the lower-level managers with technical analysis and computers. These measures will need to be created automatically and have the capability to be printed. The development of these components can be considered to be the 'develop performance measures' phase.

As discussed in chapter 3, the establishment of management infrastructure is undertaken throughout the evolution of the TMMS. For each component, the required management infrastructure necessary to draw-out the required outputs is established before the next component is developed. For example, review and planning meetings are developed and implemented for the "Management Performance Measures." These meetings will result in the improvement targets and measures necessary to ensure there is sufficient incentive to improve the mining system being managed.

4.2.3 *Impact of Systems Planning Phase*

The methodology to develop a systems plan as discussed in Chapter 3 was used for each mine. Each INCO mine in the WMC underwent a tactical management change over the course of this project. Tactical management changes were initiated by both West Mines Business Systems unit and local mine personnel. Not every mine chose the same systems plan. Figure 4-14 is a systems plan devised as a standard for the West Mines Complex so that a standardisation of TMMS can eventually be evolved for all mines. However, each mine developed and accepted the various components at their own pace and with different rates of success.

Within the preparation step, each mine allocated appropriate tactical managers and technical personnel to a redesign team that was given a brief education session reviewing process mapping techniques, ABC, and operations management tools. Forming teams and providing education at each mine had varying degrees of impact. For example, tactical managers at Coleman/McCreedy East wanted to apply operations management techniques immediately, including process mapping, process based cost reporting and work crew analysis. These system components were designed and implemented by various tactical managers with technical backgrounds (the tactical managers, mainly GFs were former engineers). Comparatively, Crean Hill did not immediately embark on improvement programs following the systems plan because the mine was understaffed by five full time positions. The tactical managers on site had relatively little technical background (the tactical managers were former miners). Therefore the impact varied depending on the resources available.

High-level process maps were drawn clarifying where tactical management systems either did not exist or were functioning poorly. Mapping out these processes demonstrated the variances in understanding between the tactical managers. For example, some considered ground support as part of the development process whereas others considered it as separate. Areas of overlapping accountability were also identified as some managers incorrectly considered a process to be the responsibility of another manager.[17] For example, at one of the mines in the fieldwork the general foreman of the Main Orebody (production area in the mine) had incorrectly assumed that the maintenance costs on the Kiruna Chutes (part of an electric truck haulage system) were the responsibility of the Logistics GF who manages the Kiruna trucks (these accountabilities have since changed). After lengthy discussions, it was confirmed that Kiruna chutes are the responsibility of the manager who sends the muck to the chutes, therefore the operating foreman (not logistics foreman) is responsible. This is an example of where the impact of this phase resulted in clarifying accountabilities.

When undertaking a systems map, the mistakes of the past were identified in terms of why some improvement initiatives failed. Reviewing the reasons for why management system developments failed is an important aspect of systems planning. For example, a lack of data infrastructure, measures, and management support were given as key causes to the failure of the 1993 Crean Hill management system mentioned in Chapter 3.[18]

Generating a systems plan allowed the Business Strategy unit to see the importance of a common management system between the various mines. A Process Based budgeting system had been requested by all mine superintendents for several years.[19] This resulted in the allocation of dedicated resources on the project once the process based costs had been developed. Therefore the most important impact of the systems planning phase was to highlight the importance of undertaking the development of a TMMS.

Figure 4-15 shows the systems planning phase's key impacts within the context of the methodology's application. Once the first systems plan has been created, work is started on developing the data infrastructure.

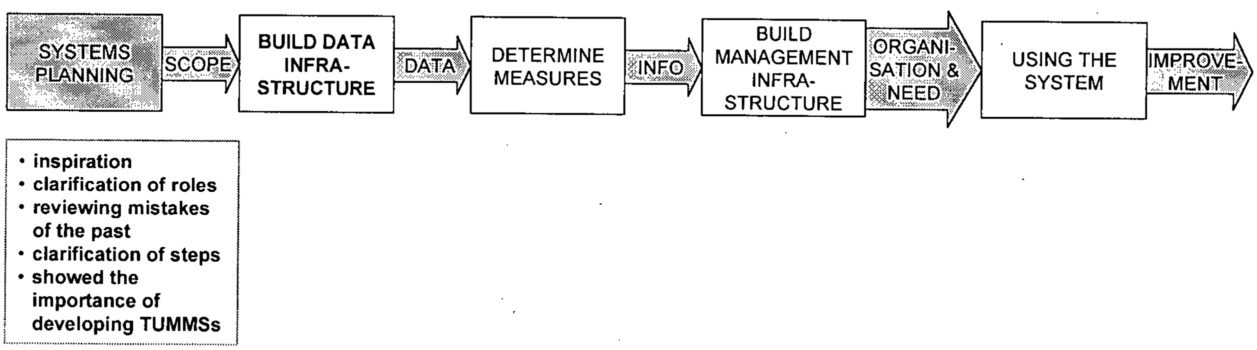


Figure 4-15: Impact of the Systems Planning Phase within the Context of the TMMS Methodology.

4.3 Data Infrastructure Phase

Building a data infrastructure is generally comprised of five steps. The first is to gain greater understanding of the processes through detailed process mapping. This is followed by the creation of a data model where data items are related to a process through textual and graphical definition. Once the data requirements are listed and sources for that data are found, then a mechanism of data collection and management must be put in place so that the data is entered in a timely and accurate manner. These steps are reviewed in the context of the application at the WMC.

4.3.1 Process Mapping

Ontario Division had purchased and implemented the MINCOM enterprise resource system called MIMS. The accounting module in this system was designed to be generic so that a common chart of account (list of account numbers) could be used by all mines. No process map or publicised definition were available at any of the mines and therefore some disjunction existed between the chart of accounts and the processes as understood by the foremen using the accounts. The initial process mapping activities consisted of clarifying the mining system in relation to the chart of accounts and between tactical managers. Production outputs measures from the Prodstats system did not exist at that time, only raw data was available. Prodstats data was being entered into the system and remained unused.

Detailed process mapping was undertaken at all three mines. The Coleman process maps were primarily focused on cost data accuracy since the mining methods and outputs were homogeneous within each mine area (as seen in Figure 4-8). Figure 4-16 shows a small section of the 'AS-IS' process map down to the activity level for the development process. The numbers below the activity names represent the account number associated to that particular process. Figure 4-17 shows the backfilling process used in the Main Orebody mining area. Note how several activities within the same process have different account numbers. This disjunction between processes as understood and the process-based account structure had to be corrected by a means of data definitions (discussed later).

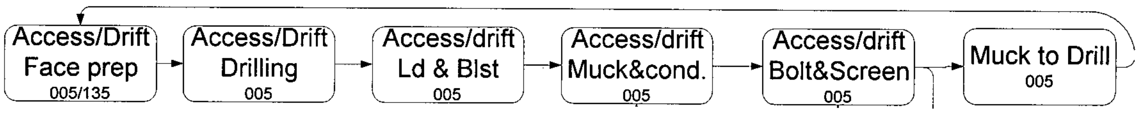


Figure 4-16: Activities within the Development Process and Associated Process-based Accounts

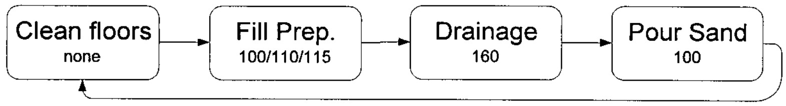


Figure 4-17: Activities within the Filling Process and Associated Process-based Accounts

Process maps to clarify productive outputs and workplace discrepancies were also created. Figure 4-18 shows a zoom-in of a large process map of the various workplaces at the Crean Hill mine. The process map required the representation of level, workplace, process, and cost account number. The workplaces were listed in smaller boxes on the left while the cost account number was on the right. This mine was unique in that a single general foreman and foreman were responsible for all the varied processes. Crean Hill has captive equipment and uses a variety of mining methods and processes, depending on workplace. Once process maps from various viewpoints were established, data models that best represented the processes had to be designed.

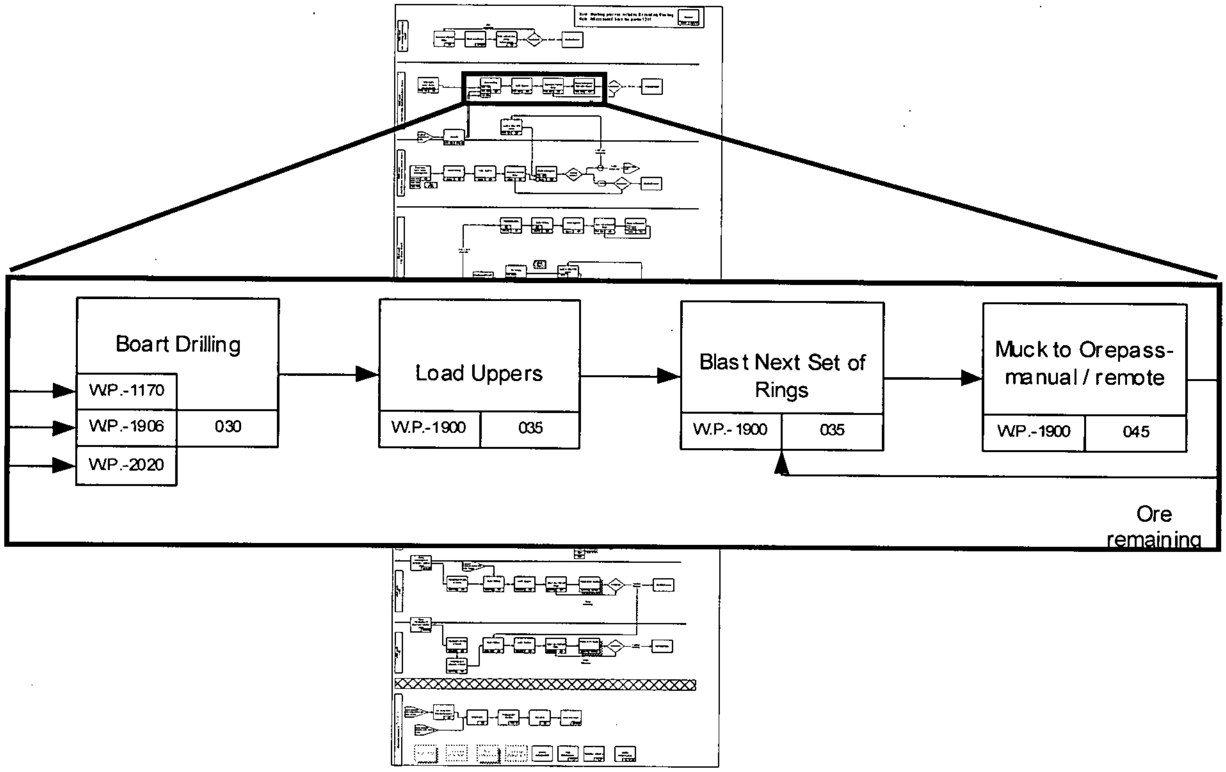


Figure 4-18: Workplace Process Output Map with Zoom on Production Drill-Blast-Muck Cycle.

4.3.2 Data Modelling

As was discussed previously, most of the data modelling had already been completed when INCO implemented their process-based accounting system and Prodstats systems. Linkages between the costing databases and production databases did not exist prior to mid-2000. Common attributes between production and cost data items had to be identified. It was decided that the most appropriate work level at which the linkages would be formed was at the process level, because the account structure represented processes. The data attributes that cost transactions and production slips had in common included:

- **Responsibility**: both costs and unit of output were directly linked to a particular foreman and general foreman.
- **Period**: both cost transactions and production records contained dates, however, purchases and consumption of the inputs purchased did not occur on the same day. For example, if a foreman ordered a pallet of shotcrete, that shotcrete would not be consumed for almost a week as the shotcrete

had to be delivered to the mine site, then transported to the work face. Therefore it was decided to link the cost transactions for a month to the productive units of that month.

- **Equipment**: one of the cost database identifiers included equipment number. Each productive unit was also attributed to particular pieces of equipment since the slips were equipment based. Therefore the repair costs could be linked to a particular piece of equipment, that in turn was linked to a process.

Using E-R data modelling diagrams (described in section 3.2.1), the equipment and transaction links are shown in the following two figures. Figure 4-19 shows how the Prodstats slip information is linked to the process by the task type and equipment number. Figure 4-20 shows how purchase requisition (ordering materials) and labour charges are charged to an account that represents a process. Every piece of equipment in Ontario division is allocated to an account number so that any work order charged to that piece of equipment is automatically charged to the correct account. This proved to be difficult when equipment such as scissor-trucks are used for multiple processes, however further breakdowns can be made using the task and activity information from the Prodstats data. Links not shown include the similarity in the date or periods of time or the link of responsibility of a particular foreman or general foreman. For example, a particular unit of production can be attributed to a foreman or general foreman through the Prodstats identifier shown in Figure 4-21 (note: 'beat' refers to the geographical, equipment, and workers for which a particular manager is responsible). Purchases by that foreman or GF are allocated directly the GF responsible. Therefore a general foreman's productive units and process costs can be linked.

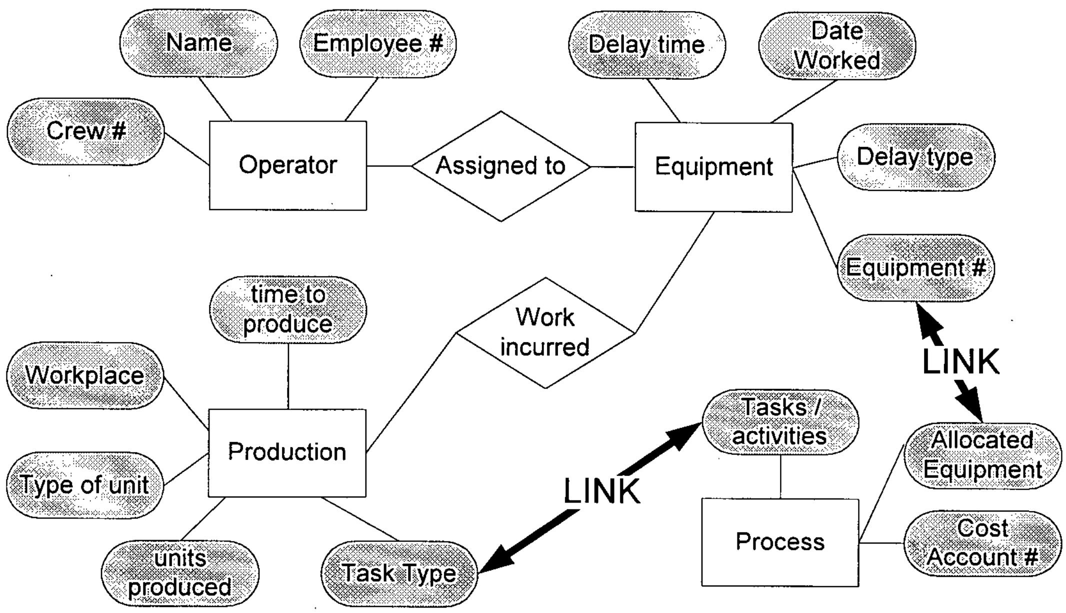


Figure 4-19: Data Model Linking Productive Units to the Correct Processes

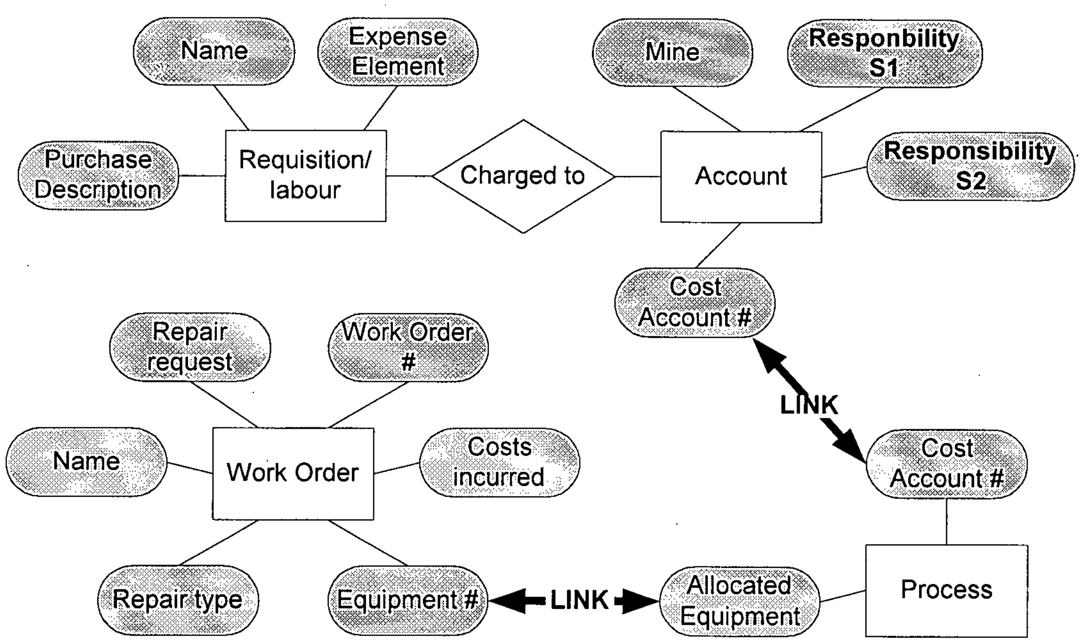


Figure 4-20: Data Model Linking Purchases, Labour Charges, and Work Orders to Processes

Data models and process definitions were created for all processes. The data dictionary was distributed to all foremen in the Foremen's Cost Charging Reference Manual.[20] As mentioned previously, the information systems at INCO were well designed for their particular uses. The MIMS modules were designed for the departments that used the information. For example, the MIMS financial module was organised and designed to suit the specifications of the accounting department. Similarly, the maintenance module was designed for the needs of the maintenance planners. Integrating the data from these disparate systems was difficult as none of the databases were designed using a common process map. Therefore when undertaking the process mapping and data dictionary, several missing data items were identified. Creighton and Coleman did not have many data gaps. Crean Hill, however, did not undergo Prodstats implementation since mine life was, at that time, only one year (it has varied between one and three years several times since). As a result there was no Prodstats information at Crean Hill prior to November 2000.

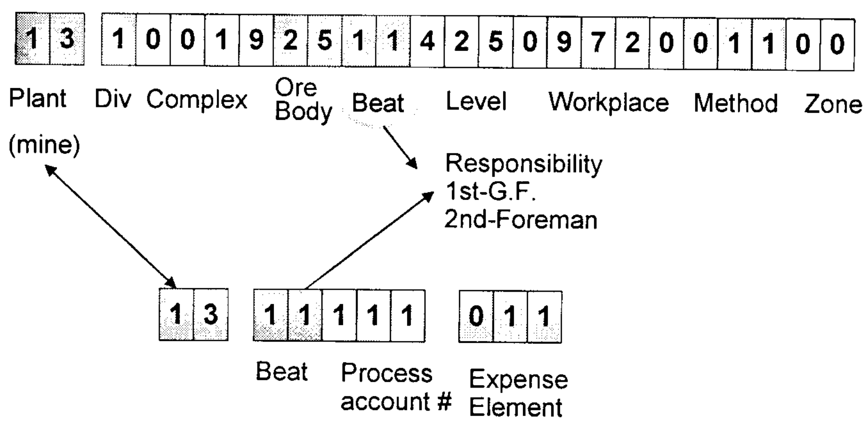


Figure 4-21: Linking Production and Cost Responsibility in Data Model.

4.3.3 Find Data Sources

As mentioned, many of the data sources at Coleman and Creighton were already established as all cost and production information was being entered into MIMS. Therefore there was no need to find or develop data entry mechanisms for these two mines. Crean Hill had MIMS but not Prodstats. Through mid to late 2000, a stand-alone production database was created and maintained using hand-written forms that were transferred to a large Excel database which was imported into the Prodstats database. Most Prodstats analysis is undertaken using the CorVu[21] software application. These "daily superintendent report" forms were completed at the end of every shift by the foreman. Figure 4-22 is an example of the form in digital format showing the production for January 4th, 2001. By early 2001, management at Crean Hill were convinced that Prodstats should be fully implemented at Crean Hill and a process of implementation was commenced.

January 4

Development Footage

Level	W.P.	6-4	4-2	total
2550	1750 sill			0
4240	Ramp			0
0	0			0
total		0	0	0

Production Tons Blasted

Level	W.P.	6-4	4-2	total
1000	940			0
2800	1906			0
3450	1220			0
3980	2705			0
4200	2636			0
4200	2670			0
0	0			
total		0	0	0

Ore Tons Mucked

Development				
Level	W.P.	6-4	4-2	total
2550	1750 sill			0
0	0			0
4240	Ramp			0
				0
total Dev. Ore		0	0	0

Ore Tons Mucked

Bulk				
Level	W.P.	6-4	4-2	total
1000	940	72	170	242
2800	1906	300	650	950
3450	1220			0
3650	2550	140		140
4200	2705			0
4200	2635			0
0	0			0
total Bulk		512	820	1332

Rock Tons Mucked

Level	W.P.	6-4	4-2	total
4200	downramp		30	30
0	0			0
0	0			0
0	0			0
total rock tons		0	30	30

Retram Ore Tons Mucked

Level	W.P.	6-4	4-2	total
4200	2635			0
3980	STOR			0
3800	#5			0
3800	9701			0
0	0			0
0	0			0
0	0			0
total		0	0	0

Backfill Tons

Sandfill				
Level	W.P.	6-4	4-2	total
2500	2020			0
3840	0			0
4200	2670			0

Backfill Tons

Rock as fill				
Level	W.P.	6-4	4-2	total
4240	STOR		100	100
0	0			0
0	0			0

Drill Footage

ITH				
Level	Drill #	6-4	4-2	total
2550	608 ITH			0
3840	611 ITH		240	240

Drill Footage

Boart				
Level	Drill #	6-4	4-2	total
2550	999 BRT	172		172
1000	558 BRT	272	211	483

Remaining Feet Open In Passes

Pass/level	6-4	4-2	
#1 OPAS / 3100L			
#2 OPAS / 3400L			
#3 OPAS / 2800L			
#4 OPAS / 3100L			
#5 OPAS / 3650L			

Hoist

		6-4	4-2	total
Rock Skips				0
Ore Skips			66	66

Shipped

		6-4	4-2	total
Loadout				0
Ground				0
total cars shipped				0

Figure 4-22: Superintendent Daily Report for January 4th, 2001

Figure 4-23 shows the core data infrastructure at INCO Ontario Division for process based production data. Labour is charged directly by a foreman in an early 1980s computer application called 'timekeep'. This application calculates the number of hours each miner has worked throughout a week. It is linked to the MIMS mainframe as a cost transaction in the accounting database. Equipment and supplies are charged using applications within MIMS. The PLC and wireless links are currently limited to the hoist and Teleremote equipment in Creighton. The information is translated into MIMS data and entered without human interference. Most of these data entry systems had already been established prior to this project. However, the accuracy of the data was an issue that was directly related to the implementation and management of these systems, as discussed next.

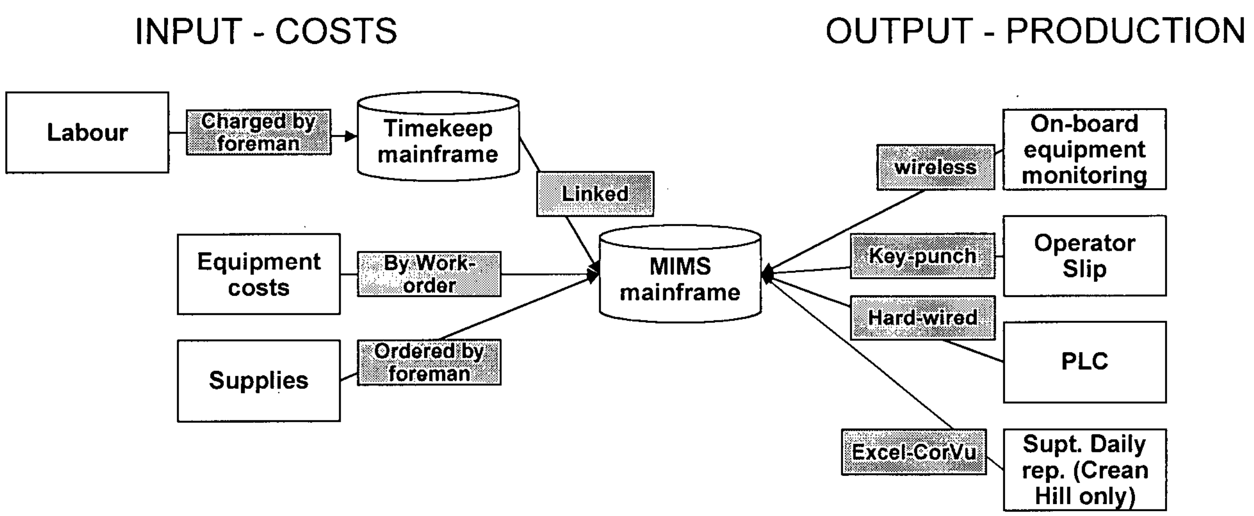


Figure 4-23: Production Data Sources and Infrastructure at INCO Ontario Division

4.3.4 Organising and Managing the Data Collection.

Data collection issues are important to note as other operations may face the same challenges in implementing systems where operator input is required. Research at INCO has shown that the difficulty of data collection was at first convincing the operators to fill out the slips and hand them in. Data entry was also an issue since light-duty miners of local 6500 (injured miners unable to undertake physically strenuous work) were used to enter the data. Miners would be more apt to audit or interpret the data as they understood the various processes underground. This caused problems as the union of office workers (local 6600), according to their job descriptions, should have been entering the data. Unfortunately, these individuals were unable to audit the information as they typically have no underground experience. Foremen were also unwilling to enforce the need for every miner to hand in slips or correct information as the importance of the information remained unrecognised (these issues were addressed and are reported in internal INCO reports). The main leverage points were found to be first, management support for the system, and second, using the information provided for calculation of incentive payments. If the operators did not hand in slips, that production was not counted toward the incentive contract. By letting the operators know that the information was being used to calculate incentive reports, the slips were entered on time and with far more accuracy. Initial overestimation of production was countered by maintaining occasional audits on production progress and correcting incentive values and payments. The foremen had to be trained to audit the information.

As mentioned previously, a key output of the Coleman process mapping exercise was to re-train the foremen and general foremen on how to properly charge costs. All mines had to undergo retraining procedures for their foremen:

- Coleman in January 2000 through the process mapping exercise
- Crean Hill using the foreman' charging manual and training sessions
- Creighton using an altered version of Crean Hill's foreman charging manual and a PowerPoint presentation.

Auditing processes for all mines also had to be invoked where the general foremen and superintendents used auditing tools to review the charges made over a period of time. Incorrectly charged items would be pointed out to the foremen. An auditing mechanism also aided in improving the accuracy of the Prodstats information. By tracking the type and number of errors on the Prodstats slips, foremen were held accountable for the accuracy of the slips their crews returned to the data entry personnel. Figure 4-24 shows one of the two graphs used to monitor the errors. This graph was reviewed in the weekly production planning meeting.

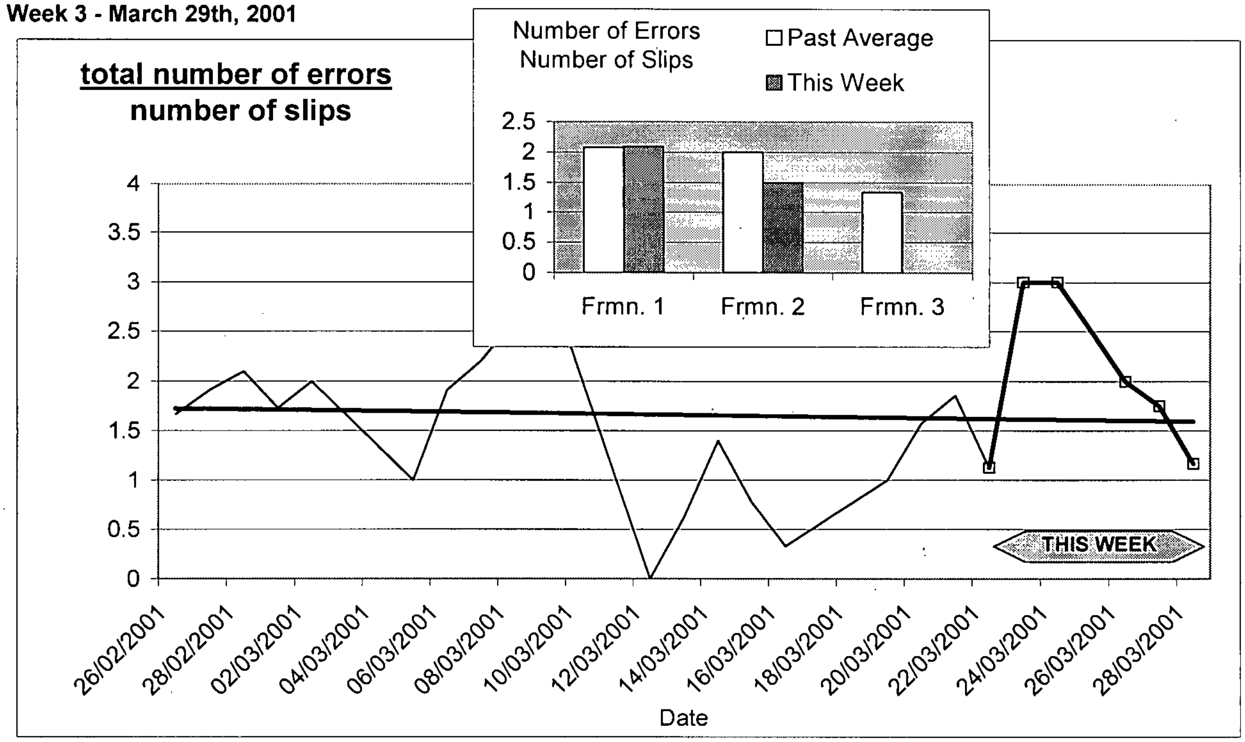


Figure 4-24: Error monitoring for Prodstats slip

4.3.5 Impact of Building the Data Infrastructure

Much of the data infrastructure was well developed at INCO Ontario division prior to the application of the TMMS methodology (known at INCO as the Process Innovation for Mining Systems project). Although, the conceptual linking of inputs with outputs along process lines did not exist. Substantial process mapping and process definition was undertaken to ensure a consistent interpretation for a particular process throughout the WMC. The data sources and collection mechanisms were also well established. However a key missing element was an auditing component to enforce the accuracy.

The specific impact of the build data infrastructure phase was:

- Creation of process maps and definitions enabling process based linkages to be created.
- Increased understanding among the design team and tactical managers about the systems for which they were accountable.
- The construction of a data model that facilitated the linking of outputs and inputs (creating the data models simplified the task of programming the links using query language in the CorVu database application).
- Formulation of an auditing process to enforce data accuracy.

The first impact of outlining process maps was to enable the creation of a standards or data definitions of processes. The second impact of process mapping was to engender a greater understanding of processes among the tactical managers. Talking about processes revealed the differences in understanding between the various processes. The impact of creating data models was to facilitate the programming of queries and tables within the database so as to conform more closely to reality.

This phase resulted in building a better data entry infrastructure that is more reliable, timely, and accurate. The impact of improving the entry system is the trust of managers to use the data. The first permanent use of the Prodstats system was to generate automatic incentive reports to replace the lengthy process of counting and surveying work, undertaken by the inventive administrators.[22]

The overall impact of the build data infrastructure phase was to create a reliable and accurate source of data from which to build measures. Figure 4-10 shows that the first step within the original INCO Systems Plan is to 'Clean the data'. Completing the process mapping, data modelling and auditing process was an instrumental step in gaining the trust of the tactical managers, thereby completing the 'clean-data' component of the original systems plan. The three components of the WMC systems plan (Figure 4-14) was also accomplished by building a data infrastructure. Figure 4-25 shows the impact of these steps within the context of the TMMS methodology. As was mentioned the core impact was the ability and trust that in turn obtained the permission to begin developing performance measures upon which the tactical managers would be evaluated.

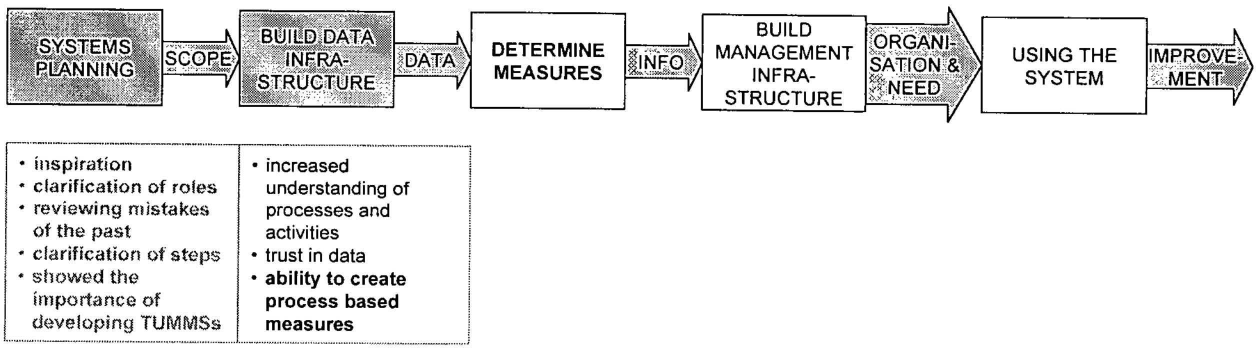


Figure 4-25: Impact of the Systems Planning Phase within the Context of the TMMS Methodology

4.4 Determine Measures Phase

The previous chapter reviewed the four steps or types of measures that should be created from process based data. Activity based costing measures provide basic measures comparing the inputs needed to produce a unit of output. Establishing performance management is an important step because it motivates the managers to improve the operation, measure job performance, and enforce accountability quantitatively. Diagnostic measures gauge the health of a process or system. Solution specific measures can be easily created or called for if managers understand the processes and data infrastructure. Solution specific measures are also used in the many operations management techniques available. These measures were created for all WMC mines. The following subsections provide the results of the determining measures phase of the methodology and discusses their impact.

4.4.1 ABC Measures

Basic ABC measures are direct input-output ratios calculated directly from the process-based data. By comparing the absolute costs per unit of output, a unitised cost, or process cost is calculated. Table 4-3, above, shows the first 20 process accounts in Ontario division's process based accounting system. As mentioned previously, some processes act in a supporting or overhead role. For example, the outputs from 'Supplies and Personnel Handling (account with suffix 125), are consumed by the other processes. However, considering that Prodstats keeps track of all material movement (muck and supplies), the time and money spent moving supplies for a particular process can be known. For example, if most of a supplies handling crew's time in a particular day is spent delivering shotcrete and construction material for backfill barricade construction, those costs could be automatically allocated to the Backfilling process. The ability to merge these support costs with the processes that consume their outputs involves a highly detailed process map and considerable programming in the database, however, the West Mines considers the project to be of value and has a Process Based Accounting team working to build a fully integrated core process based accounting system.[23] The intention is to include all support processes into the core production processes. The West Mines TMMS redesign team saw the utility of using this type of cost accounting for determining the budgets for the operating mines. Therefore the impact of producing ABC measures is to facilitate many various projects and other measures based on process costs.

Until the fully integrated process based accounting system is created, a less accurate process based accounting system was developed and is currently used. Table 4-5 shows the unitised cost for the Crean Hill mine. Note that the processes without measurable outputs and those that vary according to tons hoisted (hoist, crushed, conveyed, shipped), labelled 'cost by ton', have been compiled into a single output measure: the number of tons hoisted in the time period. To show the complexity of this system, over seven hundred thousand financial transactions, and over three hundred thousand production records are used to calculate the table. This is accomplished through querying tools, a database, and a systems map. On a Pentium III computer with a T3 connection (high-speed network), the table should be calculated in approximately one hour. Omitted from the table are the fixed costs charged against the mine from head-office such as taxes and corporate costs. In order to respect confidentiality, only the unitised costs are shown, having been altered by a common factor.

Table 4-5: Activity Based Cost Results for 6 Month Time Period for Crean Hill Mine

Unitized	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Unit
Development	288.00	369.92	856.02	1849.69	1261.49	2639.00	1210.68	$/ foot of adv
Tophammer Drill	8.06	8.94	12.35	10.03	17.85	5.96	10.53	$ / ft
ITH Drill	18.26	20.80	10.46		17.57	5.72	14.56	$ / ft
Mucking	7.67	6.93	9.21	6.91	7.39	10.12	8.04	$ / ton mucked
Truck	2.04	3.20	1.36	2.31	2.77	5.19	2.81	$ / ton trucked
Backfill	5.49	16.85	3.99	12.48	48.11	1.16	14.68	$ / ton poured
costs by ton	22.62	24.10	25.98	32.99	43.46	35.62	30.80	$ / ton hoisted

Figure 4-26 shows the process trends normalised (all numbers begin at 1) from the first month. The increased process costs reflect the difficulties suffered by Crean Hill related to equipment, materials stockpiling (sand and shotcrete), environmental issues (water treatment), and infrastructure reliability over this time period.

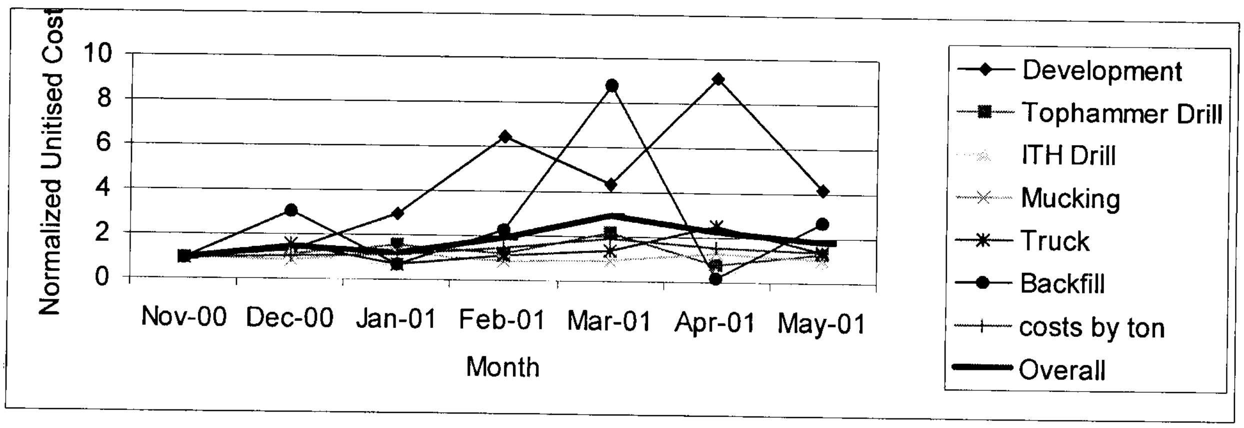


Figure 4-26: Normalised Unitised Process Costs Trends

4.4.2 Performance Measures.

The 'Determining performance measures' phase of the TMMS successfully resulted in performance measures for all three mines. Performance measures for Creighton and Coleman/McCreedy East were successfully determined and made available through an application called CorVu that creates reports from data in MIMS. The reports are either bar charts, line-graphs, run-charts, or tables. The software allows users to 'drill down' into the measures by double clicking on areas within the graph or table. The calculations programmed into the query application were developed using a methodology similar to the one discussed in section 3.3, where performance measures are closely associated to the job, work, and management level, have accurate targets, and appropriate rewards. Performance measures for Crean Hill were virtually identical to those of the other two mines except that there was only one S2 to measure.

In reviewing performance management at INCO, managers had difficulty producing a list of job responsibilities or accountabilities related to production or cost management (in fact none were ever produced). Environmental, health, and safety issues were effectively managed across all of INCO. Managers at INCO are held accountable quantitatively and qualitatively using various measures, evaluation schemes, and periodic reviews. In order to determine the responsibilities and accountabilities related to the production system, interviews were held with tactical managers.[24,25] These discussions revealed the desires of these managers to know explicitly what are the responsibilities and accountabilities of their positions. This was a reassuring result as it demonstrates the need and appetite for quantifiable measurement. The discussions used process maps so that process based performance measures could be derived. A full suite of performance measures for the S3 (superintendent) and S2 (general foreman) were developed by mid-July 2001 for all mines. The discussion below reviews the results of determining the performance measures for both S3s and S2s at the WMC.

4.4.2.1 S3 Performance Measures

Corporate objectives are well aligned with the TMMS application. For example, Ontario Division platforms are business literacy, organisational effectiveness, breakthrough improvements, and safety.[26] Part of business literacy relates to performance measures. Organisational effectiveness espouses accountability. The TMMS application was assimilated with other WMC initiatives such as the development of superintendent measures. The superintendent is responsible for the mine and is encouraged to manage it like a business. This psuedo-business, the mine, has to supply the mill with monthly quotas of ore at the highest grade and volume possible within the constraints of the budget and long-term mine plan. Table 4-6 shows the seven S3 measures developed by July 2000. Their performances are currently reviewed once a month at the variance meetings.

Table 4-6: Performance Measure for Mine Superintendents at INCO West Mines, July 2000.

Measure Name	Accountability Issue	Description	Method of Calculation
Equivalent Ni cost/lb	value produced compared to costs incurred	The overall value of the ore in pounds of nickel as a ratio of cost, compared with the budgeted value of ore in Ni pounds and actual costs.	$\dfrac{\left(\sum_{i}^{\text{all metals}} \text{metal produced}_i \times \text{value}_i\right)}{(\text{value of nickel / lb}) \times \text{total costs}}$
Mine Tonnage	Fulfilment of production volume	Traditional measure culturally necessary, compares the budgeted mine tonnage with actual mine tonnage.	$\sum \text{mine tonnage}$
Mine Costs	Maintaining cost control	Traditional measure culturally necessary, compares the budgeted mine cost with actual mine cost	$\sum \text{mine costs}$
Ore Recovery	Making full use of metal inventory	Measures recovery from the stopes by comparing the planned percentage oreblock excavation with the oreblock size. Actual volume is measured using a Cavity Monitoring Survey instrument.	$\dfrac{\text{volume excavated from oreblock}}{\text{planned ore block size}}$
Recovered Nickel Equivalent	Ensuring product quality	This is the measure of grade as a function of Nickel. In the graph, the value of all metal produced is divided by the value of nickel and tonnage produced.	$\dfrac{\left(\sum_{i}^{\text{all metals}} \text{metal produced}_i \times \text{value}_i\right)}{(\text{value of nickel / lb}) \times \text{total tons}}$
Dilution	Ensuring quality processes	A figure calculated subjectively by a geologist, ratio of waste to total material, compiled over a month compared to planned dilution.	$\dfrac{\text{tons of waste material}}{\text{tons of muck}}$
Product Surplus	Measure of overall performance	This measure is culturally divergent for mining, however, the need to reduce costs while increasing output is induced by this measure.	$\dfrac{(R_a - R_b + C_b - C_a)}{1000{,}000}$ R = Revenue C = costs b = Budgeted a = Actual

Figure 4-27 is an example of the performance trends over six months for the Creighton mine. All measures compare Budgeted or Planned performance with actual performance. Therefore budgets and plans are used as targets for performance. However, as these budgets are not considered to be accurate, a common omission of responsibility for poor performance is that the budget was not accurate.[23] This was an important issue and was also partly responsible for the West Mine's Business Systems unit to commission the process based budgeting project previously mentioned. Figure 4-28 shows the 'product surplus' measure described in Table 4-6. This measure is culturally divergent because for the first time in INCO's history, revenues are being measured with costs at a tactical level. Note that if all revenues and costs for a month are on budget the resulting performance will be a value of 1. A positive value results for each unit above the planned revenue and/or below budgeted cost. A cumulative measure of performance is also present on the graph as a bar. As can be seen, the cumulative performance for that time period has resulted in a loss of over $7 million. Therefore this may be a reflection of being under budget in terms of production or over budget in terms of costs.

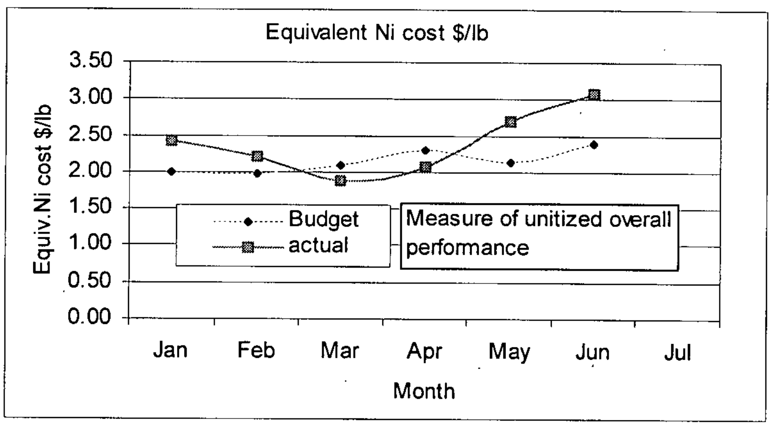


Figure 4-27: Performance Measure Trends for S3 – Equivalent Ni cost / lb

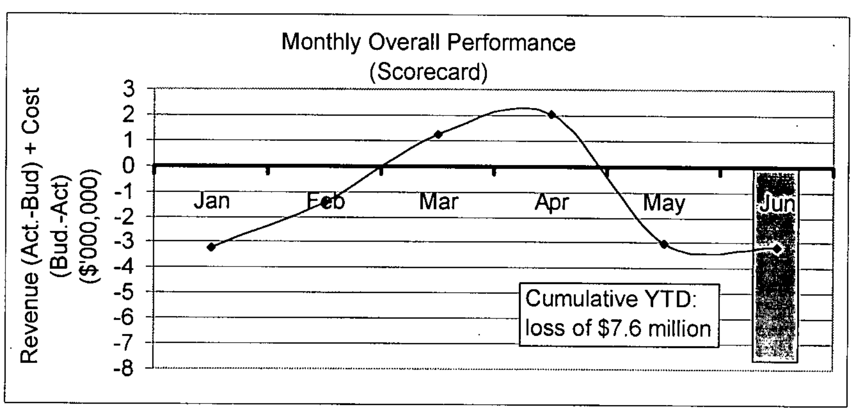


Figure 4-28: Performance Measure Trends for S3 – Overall Monthly Performance[27]

4.4.2.2 S2 Performance Measures

Performance measures for the S2 operational tactical managers (general foremen) were developed through a series of meetings between the project consultant/facilitator (author) and the Crean Hill S2. The same process was undertaken at Creighton by other personnel. Table 4-7 provides some of the core accountabilities of operating S2s identified through the interviewing process.

Table 4-7: S2 Level Operating Tactical Manager Responsibilities[24]

Primary Responsibilities	Secondary Responsibilities
• Manage core mining process interactions both in productivity and cost (unit operations) • Reduce process variation	• Co-ordinate engineering and operations (jointly undertaken with engineering supervisor) • Motivate operations workforce • Co-ordination between work groups (between operating beats and operations-maintenance) • Address safety issues and responsibilities • Plan and maintain process capacities for manpower, equipment, and supplies on a medium time-scale (2 weeks to 1 month) • Implement corporate assignments.

Specific quantifiable accountabilities and performance measures were developed in a process map format from the outlined responsibilities. These 'performance measure'-process maps were made into Tabloid-size posters and had explanation tables to provide further detail for the S2 managers. These resources were compiled into a manual for the S2 managers. Figure 4-29 shows a small section of the poster while Table 4-8 provides the accompanying explanations found in the S2 measures manual.

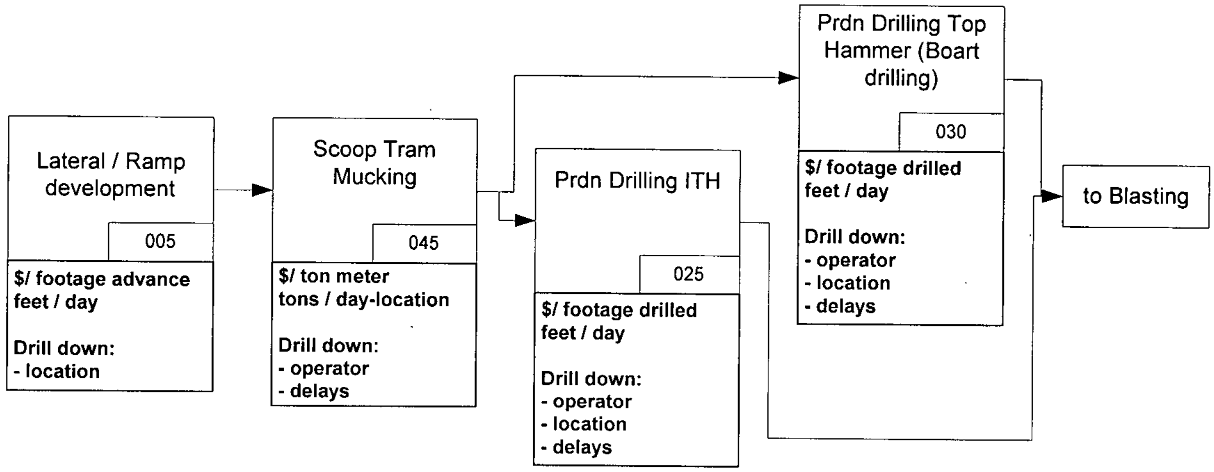


Figure 4-29: Section of S2 Performance Measures Process Map.[24]

The 'Cost Account' column in Table 4-8 shows the process based cost account used to calculate the input (costs) of the measure. The 'Pseudo-Revenue' column describes the output component of the measure. The 'Measure' column lists the performance measure. The 'Notes & Drill-down' columns describe the measure, its weaknesses, and drill-down options. Drill-downs options are related to how the data is modelled in the relational database. The performance measures described are reported as trends within a database querying tool that would allow the S2 manager to 'drill-down' into the information by simply double-clicking on sections of the graph to obtain more detailed information. For example, two performance measures for development are suggested: $/footage advance and average feet per day for the time period, typically one month. The outputs (production) are tracked according to data elements such as operator, workplace, time to complete or material used. The inputs (costs) are tracked by expense element and equipment costs. Therefore within the feet per day performance measure, the manager could drill-down into a particular operator's feet per day trend or compare the costs between the various pieces of equipment within the process as a function of their productive outputs. As might be expected, a manager can be lost in the multiple drill down options available, therefore key drill-downs for the performance measures are included as seen in Figure 4-29 (lowest item on the process boxes).

Table 4-8: Performance Measure Descriptions[24]

Cost Account/ Process name	Pseudo Revenue	Measure	Notes & Drill-downs
1311005 Lateral/Ramp Development	Footage advance	$ / ft. adv.	Lateral development footage is currently not being collected directly. Footage advance may be inferred from Prodstats information. A drilldown to specific locations would be important in order to distinguish between elevated costs between workplaces or drift layouts.
1311045 Scoop tram mucking	Tons mucked per unit of distance	$ / ton	Being the highest cost and most complex process in a typical operation, this measure may be the most important. Prodstats and the MIMS database provides the ability for many drilldown options: operator ID, expense elements, delays, source and destination, etc... Unfortunately, the database currently does not provide distance between workplaces. Therefore a measure that would ideally present the true cost driver of this process (ton-meter) is not easily available but is still strongly recommended. As an overall measure for the S2s, dollars per ton may be acceptable. However, many drilldowns should be made available so that analysis of the true performance is available.
1311025 Production Drilling ITH	Feet drilled	$ / foot	ITH drilling is undertaken throughout the division and therefore would be available as a comparative measure. However consideration should be placed on the drill pattern, as frequent drill movements would increase unit costs. Ideal drill downs when searching for improvement opportunities and reasons for variance would include: operator (some operators can drill far more productively than others), location (level induced delays can be identified), delays, and expense elements (to identify costing abnormalities).

The process cost performance measures are intended to be reviewed once a month in a S2 variance meeting (since costs were reported monthly). Figure 4-30 provides an example of the process based monthly performance measure for the development process for Crean Hill Mine. Other performance measures are evaluated in less structured environments but more often. Performance targets are typically the scheduled production rate or budgeted costs. No official extrinsic rewards are being given to managers yet. The intrinsic reward of meeting budgets or production quotas are the motivating factors used at INCO. Process based performance measures have allowed managers to identify areas of poor performance as discussed later in this chapter. Diagnostic measures and solution specific measures were used to pinpoint specific areas in need of managerial intervention.

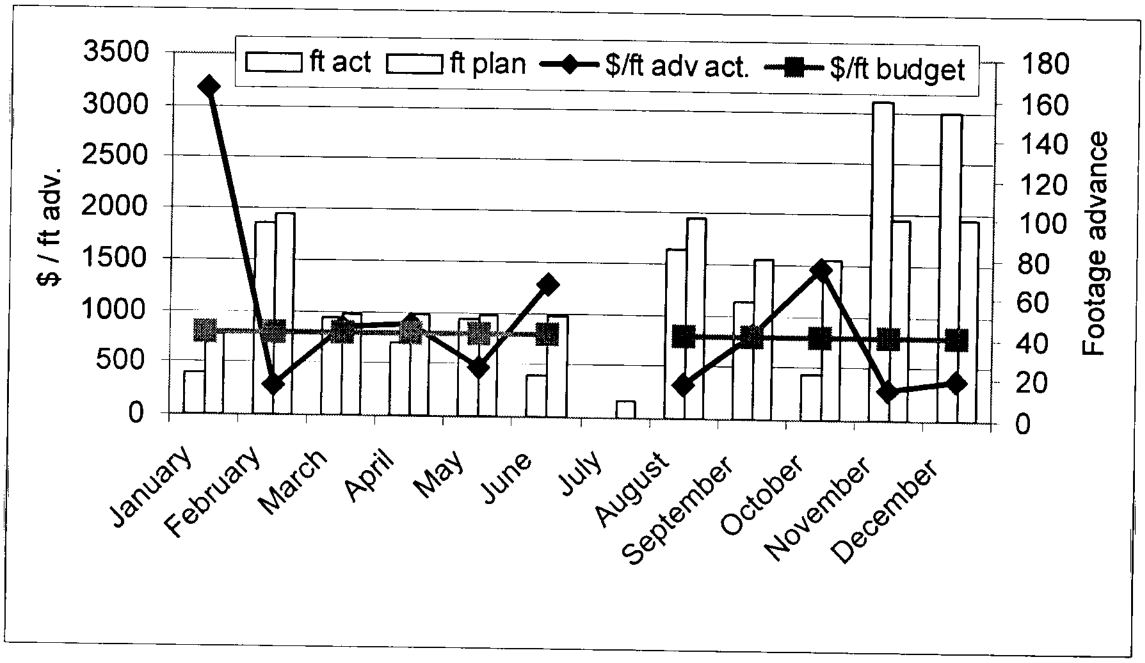


Figure 4-30: Development S2 Performance Measure Trends

4.4.3 *Diagnostic & Solutions Measures*

Diagnostic measures are tools which can be used to detect when a process is operating sub-optimally. Diagnostic measures are also often undertaken in conjunction with improvement initiatives in order to investigate problems with processes. Solution measures are the measures calculated specifically for improvement initiatives and will be discussed in the "Using the System" section. Several diagnostic measures have been requested by tactical managers through this project such as:

- **Mucking process stability**: In mid-2000, the mucking process was considered to be sub-optimal. Mucking rates by various workplace locations, operators, delays, and equipment were undertaken. The study revealed that excessive delays were being incurred. For example, in a ten-hour shift, the truck was hauling for only 2.5 hours.

- **Contracting-out reductions**: As part of an industrial relations improvement initiative, Ontario Division agreed to significantly reduce the dollars spent on contract workers, ensuring that local 6500 union members are employed in all possible positions. A measure was created to track the dollars spent on contracting-out expense elements. The integrated measurement tools allows managers to drilldown into the costs by double clicking on the month, supplier, or amount charged to obtain all available information on the financial transaction.
- **Scoop maintenance costs**: Maintenance costs were extremely high for all underground mobile equipment at Crean Hill. For the past two years, the equipment has had a book value of zero (very old equipment). In order to determine which piece of equipment was most expensive, a measure was devised to accurately compare equipment output to equipment cost. Table 4-9 shows ratio of average monthly maintenance costs to number of tons mucked (moved) in that month for the Crean Hill mine LHDs. Tactical foremen were surprised at some of the scoop costs and several scoops have since been retired. This measure was easily and quickly undertaken using the process based data infrastructure and measures. Over 36,000 cost records and 15,000 production records were used in the creation of Table 4-9.

Table 4-9: Scoop Maintenance Costs per unit Produced

Scoop MIMS name	Average Monthly maintenance costs per ton mucked ($ / ton moved)
Calculation →	$\dfrac{\sum_{Nov2000}^{April2001} \dfrac{\text{maintenance costs for month}_i}{\text{tons mucked for month}_i}}{6}$
13-SCOOPS-ST8A-689	15.43
13-SCOOPS-JCI125-791	12.2
13-SCOOPS-ST8A-690	11.88
13-SCOOPS-ST8A-709	7.59
13-SCOOPS-JCI600-865	4.95
13-SCOOPS-R1700-871	4.78
13-SCOOPS-ST8A-710	3.01
13-SCOOPS-JCI3.5-686	2.70
13-SCOOPS-ST8A-700	2.06
13-SCOOPS-ST8B-888	0.72

4.4.4 *Impact of Determining Performance Measures.*

In early 1999, the quantitative performance measures at INCO Ontario division were primarily the mining industry's stalwart 'tons hoisted' and 'costs', measured and reported independently on a monthly basis. Creating a core set of process based account measures has resulted in a proliferation of accountability and quantitative measures.

The impact of creating a core set of process based cost accounting measures facilitated the creation of performance and diagnostic measures. In developing such measures, the development teams had identified several other benefits of a standardised process accounting system. For example, the ability to easily determine the required budget for the mine plan.

Performance measures also clarified accountabilities and motivated tactical managers to improve performance. These measures allowed the managers to determine their accountabilities in relation to work processes, such as managing ITH drilling, instead of absolute output measures such as tons hoisted. The performance measures motivated many tactical managers to undertake improvement initiatives. Managers were so eager to initiate improvements at some operations that there was a lack of resources to undertake the initiatives.

Diagnostic measures, such as Table 4-9: Scoop Maintenance Costs per unit Produced, allowed managers to view their processes as never before. This measure, as well as others, sparked considerable discussion among the tactical managers. [28] The impact of solution measures is to enable improvement initiatives as will be shown in a later section.

The results of the 'determine measures' phase was the creation of process based costing, performance, diagnostic, and solutions enabling measures. These measures were made available in either Excel reports or on a MIMS Querying tool called CorVu. A West Mines menu was created by maintenance personnel with expertise in MIMS programming, the menu interface is seen in Figure 4-31. When viewed on-line, users can drill down into the various graphs or tables to view more detailed information. Figure 4-31 shows the Web-based reports that were available by June 2001, but these could be used only to report data, no drill-down abilities were available in this format. However, the creation of these various measurement mechanisms and the numerous methods of analysis and drilldown options, creates the need for structure. Without adequate structure to the analysis and review of measures, tactical managers can become lost in the many ways of viewing or analysing the information. Therefore, a structured organisational design is needed to define a procedure to manage performance and improvement initiatives. The motivation to improve through improvement initiatives must is also structured within the management infrastructure.

Figure 4-31: West Mines Report Menu for Creighton Mine.

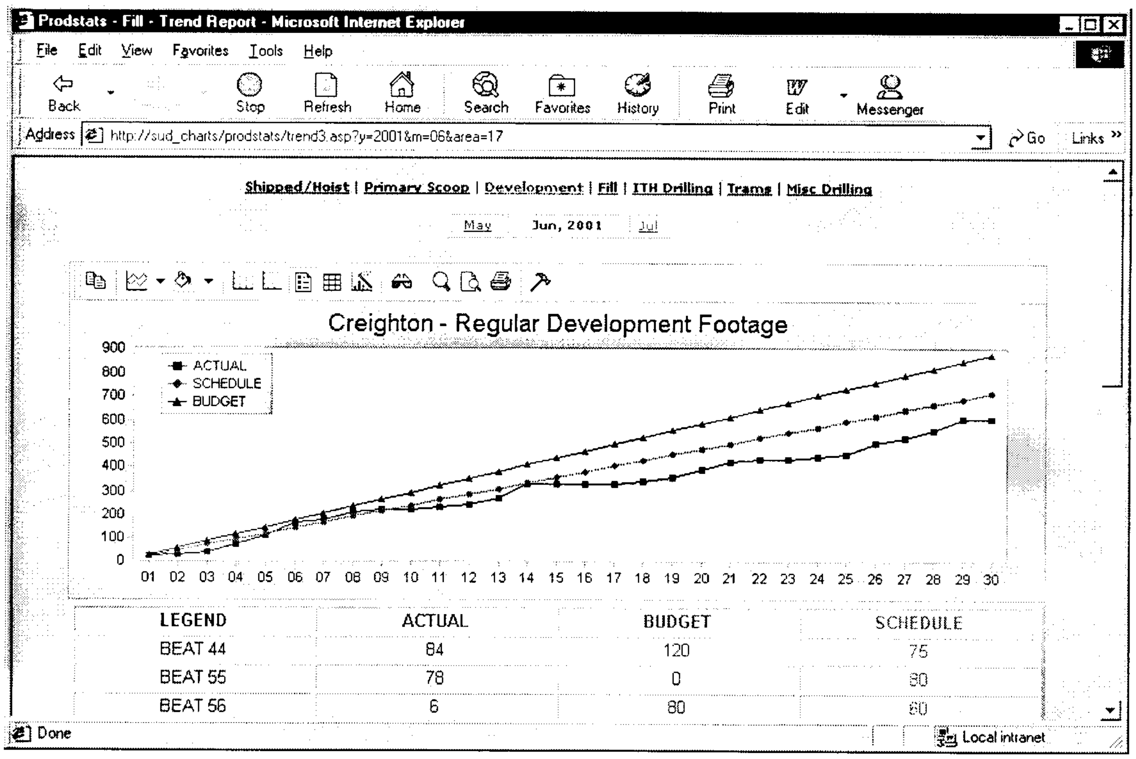
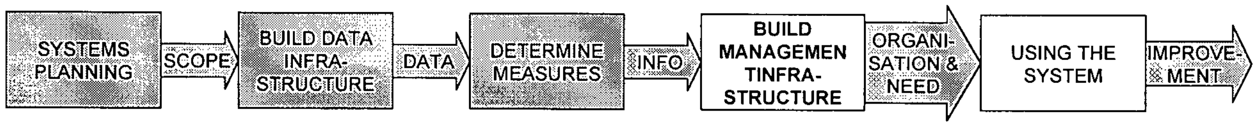


Figure 4-32: Web-based Reports for Creighton mine

Figure 4-33 summarises the impact of developing performance measures using the methodology proscribed in this thesis. The development of process based measures facilitated the development of the other types of measures. Performance measures clarified accountabilities and motivated improvement initiatives. Diagnostic measures facilitated the investigation of sub-optimal processes for the key factors causing the deficiencies. These measures were presented and made available through computer networks and drill-down capabilities.



• inspiration • clarification of roles • reviewing mistakes of the past • clarification of steps • showed the importance of developing TMMSs	• increased understanding of processes and activities • trust in data • ability to create process based measures	• core process based measures facilitate the creation of more specific measures • motivate improvements • clarify accountabilities • diagnose problems • enable improvements

Figure 4-33: The impact of determining measures

4.5 Build Management Infrastructure Phase

Managers at INCO have many safety, environmental, labour relations, and legislated duties. These legislated requirements reduced the resources for review or analysis of performance measures. The Divisional platforms of breakthrough, organisational effectiveness, safety, and business literacy provides no clear guidance on where, when, or how production management issues must be dealt with. Breakthrough improvements take time, resources, and perseverance. For example, an attempt to formalise a regular meeting to review, analyse, and identify opportunities using the S2 measures was often postponed or cancelled when equipment breakdowns and environmental issues came to the forefront. In an attempt to continue the contact and review process, some meetings were held underground or at the hoist control room.

The four suggested types of meetings for an effective management infrastructure include:

- coaching/performance review
- solution identification
- planning
- TMMS audit

4.5.1 *Coaching / Performance Review*

Creighton and Coleman had performance review procedures. The S2s would have daily meetings with their S1s to discuss the production issues and to review the foreman log book. The S1s would have daily 'line-up' meetings with the men on their crews where work allocations and safety warnings would be communicated. The S3 and S2s have daily meetings at the end of every shift, and since mid-2001 have used the Web Based report tools as seen in Figure 4-32. By mid-2001, performance measures for S3s and S2s had been developed for all of the WMC. The development of performance measures for lower-level employees are planned but not yet established. Those management levels that did have performance measures have been motivated to initiate improvements.

4.5.2 *Solution Identification*

Improvement programs were initiated by those managers for whom performance measures were established and reviewed. The S2 at Crean Hill was not motivated to undertake any improvement initiative without direct solicitation from the S3. This may be due to the fact that no official regular S2 performance measures review was undertaken between the S2 and S3. The other two mines, where an S3-S2 coaching/performance meeting was held on a regular basis, had many improvement initiatives.

The S2s lacked the time and training in operations management techniques to undertake improvement initiatives themselves. For example, the S2 of Creighton Deep noted that the development process in his area was consistently behind budget (can be seen in Figure 4-32). He allocated his most educated S1 as project foreman and set the goal of improving the capacity of the process. He also solicited the aid of the West Mines Business Systems unit which provided support by hiring a consultant from Hatch Associates and engaging the Crean Hill facilitator/consultant part-time. Regular 'improvement project update' meetings were held twice weekly.

Several improvement initiatives have been motivated and directed by process based measures such as:

- Crew analysis (Coleman/McCreedy East);
- ITH performance improvement (Creighton beats 55-56, under a GF with an engineering and project management background);
- Process mapping / workflow optimisation (Coleman/McCreedy East & Creighton);
- Cost auditing / rationalisation (Creighton);
- Mucking-Truck optimisation (Crean Hill);
- Development capacity improvement – Theory of Constraints – Simulation – Process mapping (Creighton Deep).

At the superintendent level, performance improvement initiatives include:

- Process Based Budgeting;
- Contracting-out reductions;
- Understanding our business education program;
- Process Innovation for Mining Systems (this project).

4.5.3 *Planning*

Planning meetings was already firmly established at INCO prior to the application of the TMMS methodology. However, a cost or process based component had yet to be added to the meetings. The planning meetings are attended by personnel from engineering, geology, maintenance, logistics, and operations. These meetings primarily review the short-term mine. Cost targets are set through the budgeting process that is currently being changed to a process based budgeting process. Following the establishment of an IT infrastructure and measures, the planning process at Crean Hill used the performance rates of processes such as mucking (tons per shift) and drilling (feet per shift) provided by Prodstats as an estimate in planning a stope.

4.5.4 TMMS Audit

The TMMS was reviewed on a quarterly basis. Small changes to the performance measures and data infrastructure occurred almost weekly. Meetings with the West Mines Manager (S4), the steering committee, and Mines Research necessitated a review of the success and issues of the TMMS. The Business Systems unit of the WMC undertakes reviews on a roughly two-week basis where issues of the management systems are discussed and changes planned. Some changes, such as the need for a standard TMMS across all the West Mines has been identified in these meetings. The audit function also continues to plan the implementation of the management components identified in the systems plan.

4.5.5 Impact of Building Management Infrastructure

Establishing the management infrastructure was found to be the most difficult phase to implement as the meetings that are developed consume a tactical manager's time and require decisions to be made. Meetings are also occasions for potential conflict as issues such as job performance, inappropriate decisions, and gaps in understanding surface. A good tactical manager will ensure that the discussion does not generate unproductive conflict. INCO culture has begun to change as managers are trained in personal interaction and are promoted based on their ability to treat subordinates with respect. The meetings are also occasions to make decisions from which action is derived. Indecisiveness was a frequent result of the meetings as the development of new performance measures was requested instead of developing action plans for improvement. When the management infrastructure was firmly established, and resources to initiate improvement were made available, improvement projects were motivated and subsequently initiated. Some of these improvement initiatives are discussed in the 'Using the System' phase, below.

The overall impact of building management infrastructure is to allow all the components of the TMMS to function as designed. The coaching or review meetings initiated improvements, the solutions identification meetings determined and implemented solutions, the planning meetings suggested targets, and the audit meetings continued the evolution of the TMMS. Figure 4-34 shows these basic impacts of building the management infrastructure.

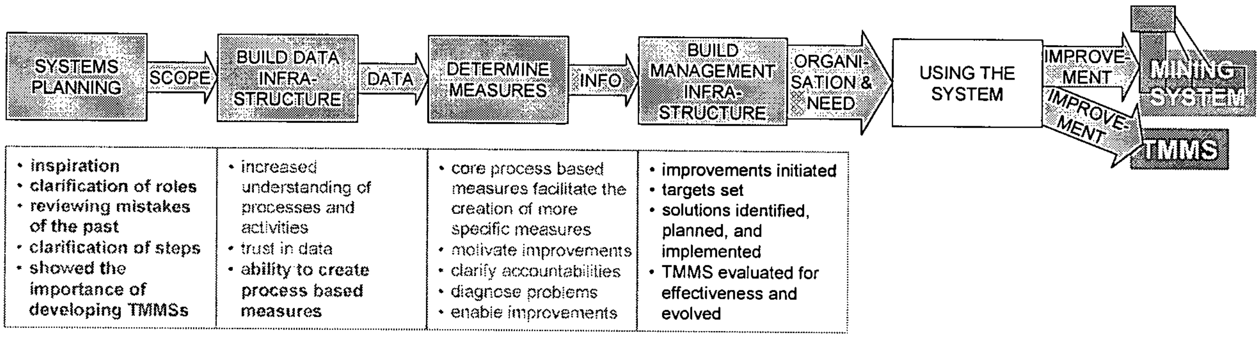


Figure 4-34: Impact of Building Management Infrastructure

4.6 Using the System

Presenting all improvement initiatives and system components, derived from the application of the TMMS at the WMC is beyond the scope of this thesis. Using the system is comprised of basically following the procedures as laid-out in the management infrastructure. The basic element of the management infrastructure includes a meeting where tactical managers review performance, decide on a course of action that would improve the most pressing issue, then monitor the changes. What makes this TMMS unique is the degree of integration of the information, the use of modern management techniques, considering the cultural issues, and instituted audits of the system. Three examples of using the system are discussed in this section, demonstrating the information integration, modern management techniques, inclusion of cultural issues, and TMMS audits. The first example discusses the efforts to improve the capacity of the development process at the Creighton mine's lower mining area, called Division 6. The second example discusses the anticipated required increase in truck haulage capacity at the Crean Hill mine. The final example discusses the need and development of an automated process based budgeting tool linked directly to the mine schedule.

4.6.1 Division 6 Capacity Improvement

The Creighton Prodstats system is considered to be the most accurate in the WMC since Creighton management enforced the use of the Prodstats data for incentive payment calculations (in early 2001). This prompted the creation of web-based performance measures so that the S2 managers could monitor the performance of their areas on a daily basis. A daily meeting is held at the end of each workday where the S3 and S2s would meet to discuss ongoing performance. Trends showing decreasing productivity in a particular area would be discussed. The core performance measures for the S2 operational managers at Creighton were considered to be:

- **Primary LHD mucking rate**: number of tons mucked from the stope per shift
- **Truck haulage rate**: number of tons hauled to the final dump-point
- **ITH drilling rate**: the number of feet drilled per shift
- **Development advance rate**: the number of feet of advance by area

The Division 6 mining area at Creighton mine is separated into three distinct areas where the development processes differ in equipment, excavation design, material mined, crews, and incentive contracts. Table 4-10 shows the characteristics of the various development areas.

Table 4-10: Comparison of Development Areas in Creighton Deep

Area Name	Equipment	Excavation Design	Material Mined
levels 6900-7000	Older equipment, 1 boom jumbo, x-truck	Smaller openings, sometimes pre-shotcreted, then bolted, then another layer of shotcrete	Developing through backfill and old workings to recover remnant ore
levels 7200-7400	Newer equipment, 2 boom jumbo, McClean Bolter	Large opening, occasionally shotcreted, de-stress blasting	Sill and x-cut development, higher priority.
levels 7530 and lower	Newest equipment, automated 2 boom jumbo	Large openings for truck access, shotcreted, de-stress blasting	Ramp development, highest priority

The general foreman of Division 6 was challenged to improve the development process, as it was falling behind its planned production rate and costs were higher than budgeted. An improvement initiative based on the Theory of Constraints and TQM management techniques was initiated, where the capacity of the development process was to be improved without additional capital spending. Specific improvement targets were not set, yet a general improvement of 10% above the budgeted cost and capacity was discussed.

Detailed process mapping analysis of capacities, delays costs, and prodstats information were undertaken. The detailed integrated data infrastructure enabled the calculation of the different production rates and costs of the various mining areas. A complex task-level simulation was developed to test the performance increases that would result from changes in crew and equipment allocation, procedures, and materials inventory availability (bolts, screen, shotcrete, etc...). The simulator was used to calculate changes in incentive payments to gain operator support for changes from the operators. This element fitted well with the 'security' aspect of the operators as it was demonstrated that increased incentive payments could be achieved with very little extra effort. The simulator also aided the acceptance of the technically minded managers as the changes were all tested mathematically prior to being implemented in the mine. In order to respect confidentiality, detailed descriptions of the suggested changes are not discussed, however, it can be mentioned that several changes were suggested resulting in increased performance. Some of these suggestions include performance measures of the underground inventory stores so that no stock-out delays would occur.

4.6.2 *Truck Haulage at Crean Hill.*

The dynamic nature of mining causes bottlenecks to shift between areas and processes. For example, if a particular mining area is close to the dump point, mucking is unlikely to be the bottleneck for that area. Crean Hill has few remaining stopes/workplaces as the mine is scheduled to close by mid-2002. Most of the production is expected to be mined from a stope located at the bottom of the mine where a truck is required to haul the material up the ramp to the crush/convey/hoist circuit. The capacity of the truck required by the mine plan is close to the theoretical capacity. An improvement initiative to increase the capacity of the trucking process was therefore required. This initiative was relatively simple as there is only one truck and route, and only two operators to observe. An analysis of the delays from the Prodstats system revealed that the truck was being operated for less than half the shift, as seen in Figure 4-37. Other information display formats allow increased information to be revealed. For example, Figure 4-36 shows the average delay per occurrence and frequency of occurrence. This would allow those delays with the most frequent and lengthy delay to be addressed first. Some of the delays such as 'travel time' could not be avoided. However, the fuelling and oiling tasks could be redesigned to consume less time and 'lunch/meetings' delays could be mitigated by having a different operator continue to operate during the primary truck driver's lunch-break.

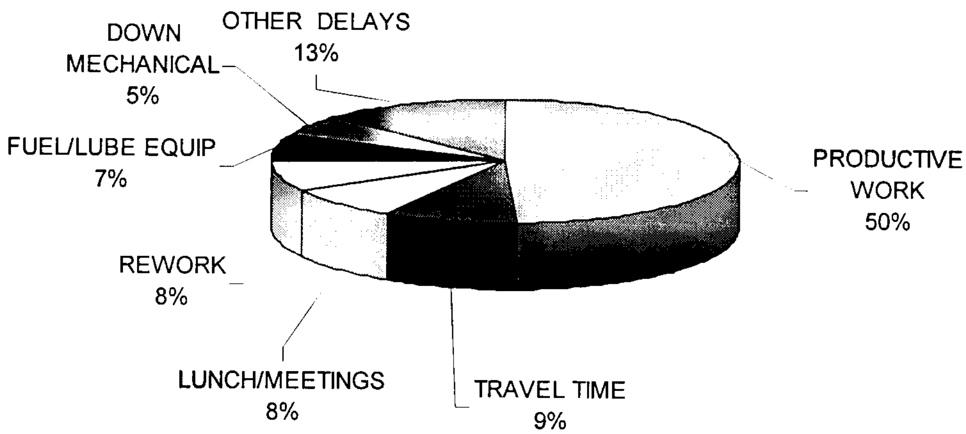


Figure 4-35: Historical Delays and Work Throughout Shift

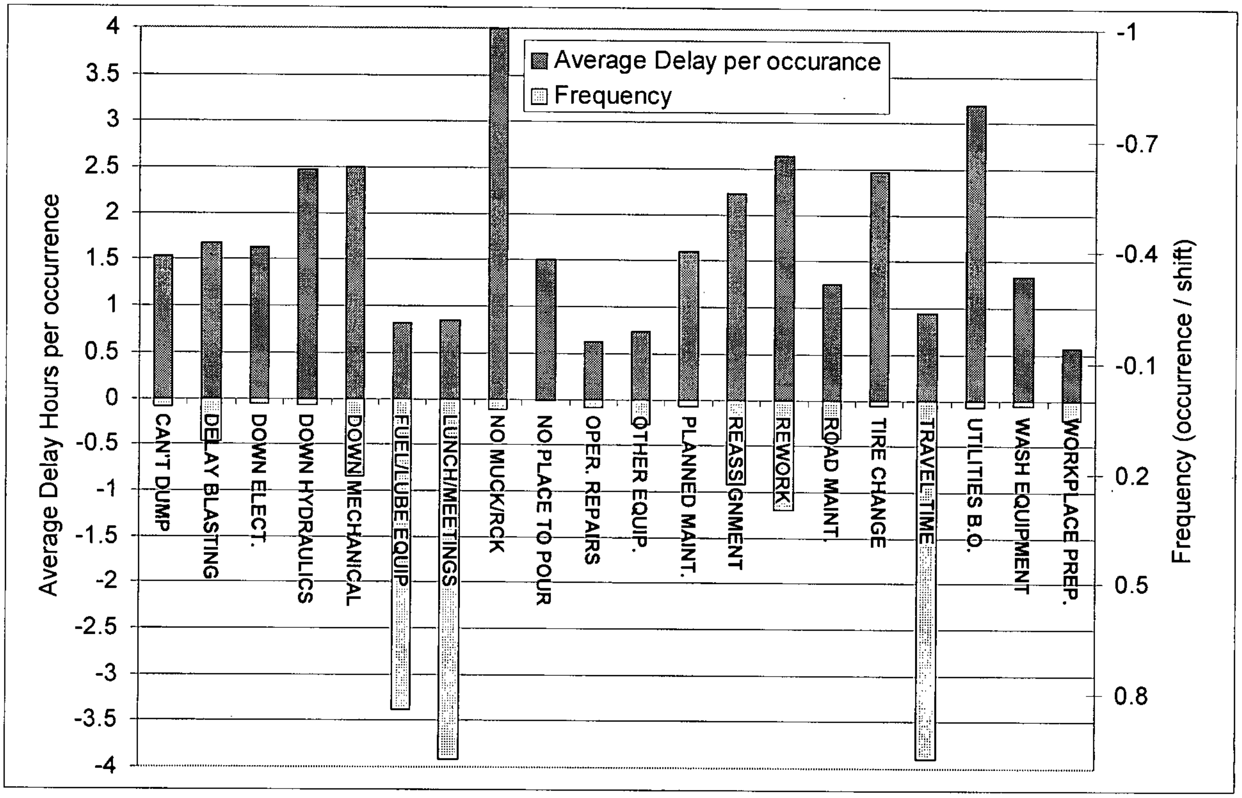


Figure 4-36: Graph of Historical Crean Hill Trucking Delays

Through a series of discussions with operators and tactical managers using process maps and process information, several changes were planned which would increase the productivity of the trucking process to the desired rate. These changes included operating the truck over the lunch-break and fuelling the truck only once a shift (the fuel tanks have enough capacity). A procedure whereby increased tactical management attention was encouraged for key bottlenecks was also discussed.

4.6.3 Automated Budget/Scheduling Tool

An informal audit of the planning, progress tracking, and scheduling procedures at Crean Hill revealed a lack of short-term mine schedule, lack of ability to easily track performance against the schedule, and develop productivity rates that could be used in planning. In the development of the new mine plan, it was decided to create an automated scheduling, planning, tracking, and budgeting tool, that forecasts and tracks actual costs and progress against the mine plan. The database information was already integrated as part of the 'data infrastructure' phase of TMMS development. Similarly, the performance measures for both cost and productivity were developed as part of the 'performance measures' phase of TMMS development. The mine plan was developed using Excel® and Project Scheduler 7® (PS7) (the INCO standard for mine scheduling). All changes to the mine plan, workplace/process rates, productive units, planned equipment, and duration were maintained in Excel.

4.6.3.1 Schedule

Calculating the progress and expected finish date for a PS7 task is a traditionally time-intensive procedure. A planner must first collect performance data by workplace and using spreadsheets, calculate the units produced and production rate, calculate the percentage progress (PS7 uses only duration and a percentage of the progress to calculate the start and finish times of a task) then manually input the progress for each workplace on the PS7 planning software. This process is simplified using the integrated data infrastructure because queries can be written to automatically poll the progress of particular workplaces for progress, production rates, and forecast the start and finish times. The Prodstats system keeps track of each process and productive unit by workplace therefore the schedule can be updated on a daily basis (although it is only updated once a week, before the weekly production meeting). This progress is then automatically transferred into the PS7 schedule revealing the workplaces that would finish before or after the planned date.

4.6.3.2 Budget

The annual budget at INCO WMC is used as the basis for the performance measures for the Superintendents. Traditionally, the budget is based on the previous year's annual costs and productivity. Typically, the previous year's budget is revised using planned changes to the overall production. For example, if the overall unit cost for the entire mine in the previous year was 80 \$/ton at 25,000 tons per month, and production is expected to increase by 5,000 tons per month, the expected annual costs should increase by 1/5 (5,000/25,000). This method can result in an inaccurate forecast as fluctuation of various parameters can affect the accuracy of such a method, for example:

- The use of different mining methods.
- Changes in technology
- Changes in workplace costs induced by depth, reconditioning requirements, or travel time
- Seasonal costs

4.6.3.3 Linking Budget to Schedule

Crean Hill was primarily a VRM mine but is now becoming a cut & fill, room & pillar, sub-level cave mine, inducing a shift in mining costs. Costs would also vary on a monthly basis as the primary mining areas may shift from cut and fill to room and pillar. However, by linking the mine plan to historical productivity and unit costs by process, a far more accurate cost and production budget (forecast) can be developed. This was undertaken at Crean Hill where the integrated database was first linked to the mine's PS7 schedule. Figure 4-37 shows the data model that allowed the budget to be linked directly to the costs and production information. As can be seen, workplace, time, process, and equipment are all data elements common to each record. Excel was able to link directly to PS7 since the scheduling software has the option of entering the workplace information as a database

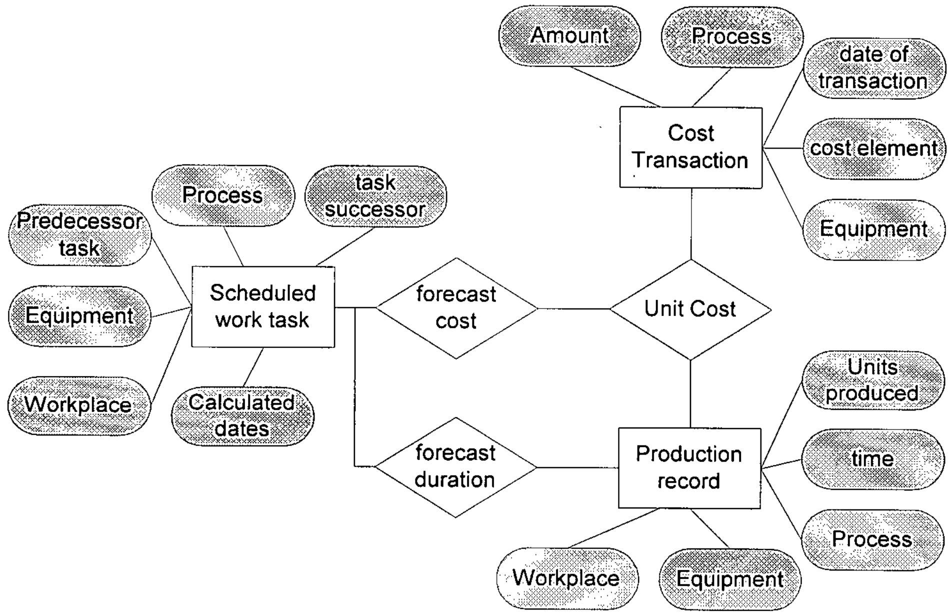


Figure 4-37: Data Model linking PS7, Production, and Cost Records.

For corporate requirements, annual budgets must be reported as monthly forecasted production and costs. The costs must also be reported by expense element (for example, labour, drill steel, shotcrete, safety supplies, etc…). However, production and costs for performance measurement at the S3 level should be reported according to process. When the data infrastructure is integrated as laid-out in the TMMS methodology, managers have the ability to easily convert the forecasted budget from expense element to process (development, production drilling, etc…). Figure 4-38 shows the simplified procedure undertaken to create this automated budgeting tool. The most complex step is to create the schedule and sequence, which is a planning function undertaken by the engineering staff. Database functions called 'pivot tables' in the Excel software in a pre-prepared spreadsheet allows the forecast cost in terms of processes to be presented as expense elements with a few mouse clicks. The process by which this is accomplished is summarised as:

- Through spreadsheet calculations, the process outputs by month are calculated. For example, the number of ITH drilling days for a particular workplace is assessed by calculating the start and finish time from a linked flat-file (table of records, see section 3.2.1) from the PS7 software.

- A set drilling rate per day (continuing the example) was used in the development of the schedule plan. This set rate is multiplied by the number of days in the month the workplace expects to be undergoing ITH drilling (calculated previously) resulting in the total number of feet drilled.
- The unit cost for ITH drilling calculated from the ABC measures ($/foot drilled) is multiplied by the total number of feet drilled.

These calculations are maintained in the spreadsheet with live links to the database. Therefore the sum of the monthly costs can be organised by any attribute such as process, expense element, or even workplace. A numerical example is provided to illustrate.

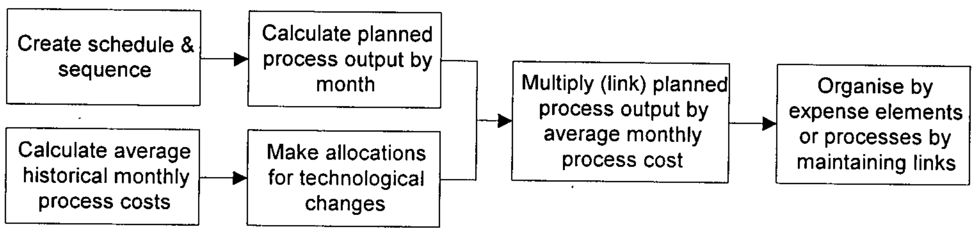
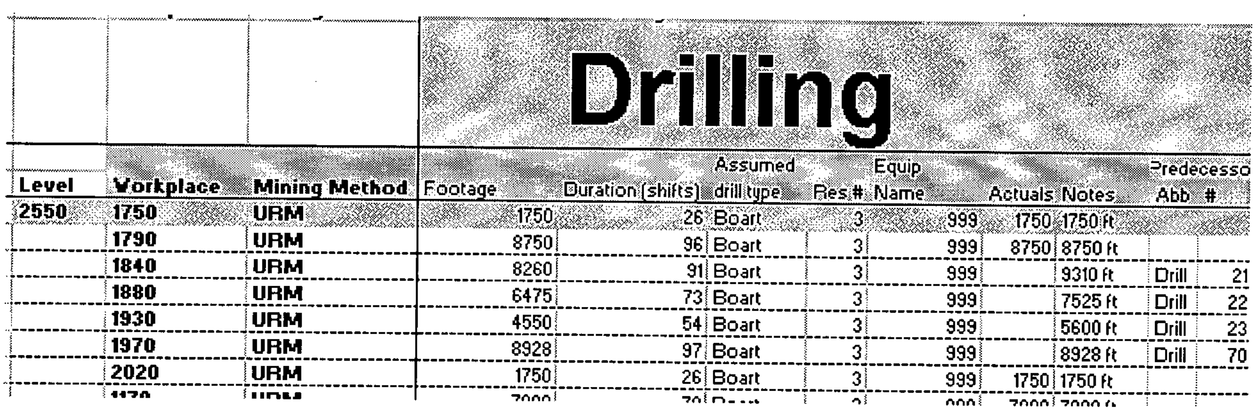


Figure 4-38: Simplified Procedure for the Development of Automated Scheduling/Budgeting Tool.

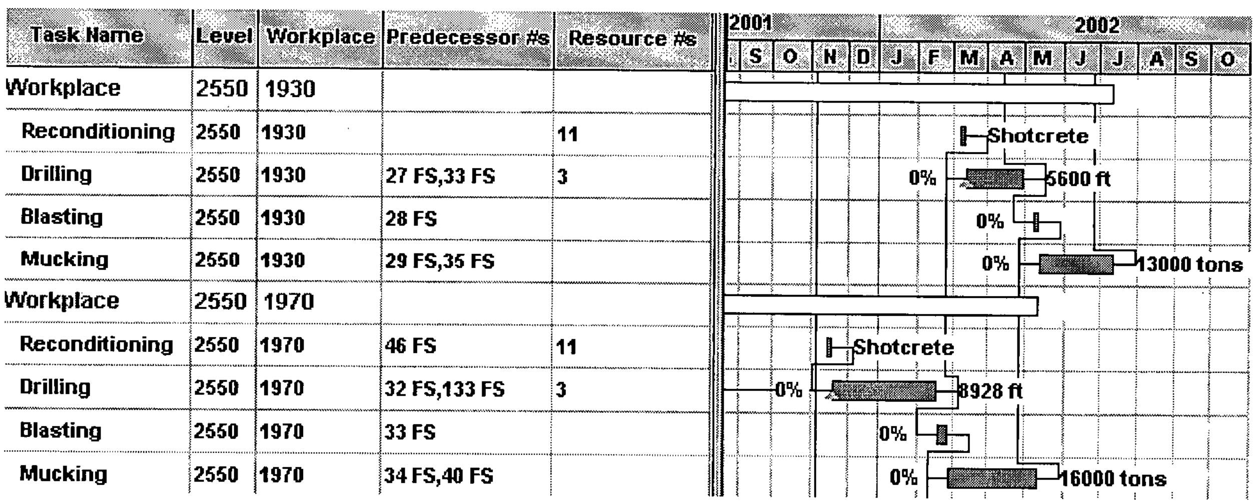
Figure 4-39 shows a section of the information inputs for the drilling process. Equipment number 999 (resource #3) is an Boart top hammer drill with an average drilling rate of 100 ft/shift.



			Drilling								
Level	Workplace	Mining Method	Footage	Duration (shifts)	Assumed drill type	Res #	Equip Name	Actuals	Notes	Predecesso Abb	#
2550	1750	URM	1750	26	Boart	3	999	1750	1750 ft		
	1790	URM	8750	96	Boart	3	999	8750	8750 ft		
	1840	URM	8260	91	Boart	3	999		9310 ft	Drill	21
	1880	URM	6475	73	Boart	3	999		7525 ft	Drill	22
	1930	URM	4550	54	Boart	3	999		5600 ft	Drill	23
	1970	URM	8928	97	Boart	3	999		8928 ft	Drill	70
	2020	URM	1750	26	Boart	3	999	1750	1750 ft		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

Figure 4-39: Screen Capture of Base Information Entry in Excel Showing Drilling Data

Figure 4-40 shows the section of the Gantt chart where the ITH drilling process is scheduled. As can be seen, the drilling process is underway between mid-November 2001 and mid-February 2002 for workplace 1970. The spreadsheet can automatically calculate the number of units produced in that period. For example, there are 38 shifts expected in the month of January (19 days x 2 shifts per day) and since the drilling rate for equipment # 999 is 100 ft/day, a total of 3800 feet is expected to be drilled in January. Since the average unit cost for the top-hammer drilling process (according to the historical data) is 12.36 $/foot drilled, the monthly cost for that workplace and process is forecast to be $47,000. A new flat file is therefore created where the costs can be organised according to process, time period. or workplace.



Task Name	Level	Workplace	Predecessor #s	Resource #s
Workplace	2550	1930		
Reconditioning	2550	1930		11
Drilling	2550	1930	27 FS,33 FS	3
Blasting	2550	1930	28 FS	
Mucking	2550	1930	29 FS,35 FS	
Workplace	2550	1970		
Reconditioning	2550	1970	46 FS	11
Drilling	2550	1970	32 FS,133 FS	3
Blasting	2550	1970	33 FS	
Mucking	2550	1970	34 FS,40 FS	

Figure 4-40: Screen Capture of PS7 Gantt Chart at 2550 Level, 1970 & 1930 Workplace.

Since the process costs are calculated using a database that includes expense elements, the average distribution of expense elements by process can be calculated. Table 4-11 shows the distribution of expense elements for the top hammer drilling process. The cost by expense element for the Top hammer drilling in January 2002 for workplace 2500-1970 can be calculated. The total costs for each workplace, process, or month can be calculated using these database tools, and by maintaining the links, these costs can be represented to expense element or process.

Table 4-11: Historical Percentage Expense Elements for Top Hammer Drilling process

Expense Elements	% of Process Cost	Cost for January @ 2550-1970
Operating Base Labour	15.43	
Operating Incentive Bonus	6.64	
Operating Overtime Allow	0.30	
Operating Labour Fringe	15.48	
Maintenance Base Labour	1.72	
Maintenance Labour Fringes	1.63	
Drill Steel Supply Contract	5.09	
Drill Supplies	2.91	
Mechanical Supplies	45.18	
Fasteners	0.04	
Pipe & Fittings	0.74	
Tools & Accessories	0.03	
Other Supplies	0.08	
Mobile Equipment Leases	3.36	
Maintenance Overhead	1.38	

The highly technical nature of this tool limits its use to managers and planners that are familiar with database, spreadsheet, and scheduling software. The ability to automatically generate a new budget with every minor change in the production schedule allows the performance measure to be as accurate as the plan. Other benefits such as a highly accurate mine plan, unitised costs, and budget are additional benefits of this tool. This additional TMMS component was initiated after an audit of the performance measures for the S3 was assessed to be inaccurate. Nevertheless, it has now become an integral part of the TMMS at Crean Hill.

4.6.4 Impact of Using the System.

The examples of the improvement initiatives and benefit achieved demonstrate that the impact of using the TMMS as designed enables the creation of improvement initiatives previously unavailable. The availability of delay, performance, and workplace information allowed the analysis of the development in multiple mining areas in the Creighton Deep area of the Creighton mine. The cultural recognition of the need to justify changes along incentives ('security') to labour and technical ('order') to engineering/management, induced the creation of a simulator to test the effect and effectiveness of the changes for management and to calculate the remuneration benefits for workers. The availability of integrated information to quickly diagnose and address the expected bottleneck in the Crean Hill trucking process allowed the increase in capacity before any production shortfalls were experienced. An audit of the TMMS identified the need to improve the S3 performance metrics. The resulting solution, a process based automated schedule and budget, also greatly improved the accuracy and efficiency of creating an annual production and cost forecast.

4.7 Synopsis of the Application of the TMMS Methodology at INCO

Much of the work undertaken in the application of the TMMS methodology is undertaken by INCO personnel. Virtually no direct intervention or directives have been issued to enforce the application of the methodology. INCO employees are encouraged to develop the systems as many saw the importance of increased utilisation of IT, and once measures were in place, they are encouraged to continue to develop the management systems in an effort to improve the production systems. The only direct involvement is from the WMC Business Systems unit that co-ordinate efforts and communicate experiences. As of July 2001, plans are in place to extend the application TMMS to the other mining complexes in Ontario Division.

Two issues pertaining to the nature of INCO makes this application somewhat different from applications in typical mines: size and cultural heritage. The presence of several INCO mines providing feed to a single mill creates an environment, where substantial flexibility exists between the mine and its customer. The effect of production shortfalls at INCO mines is lessened since several other mines would be capable of easily fulfilling the production gap. The size of INCO also allows substantial centralisation of inventory, expertise, and research efforts. The Sudbury region is also well populated, capable of supporting a diverse infrastructure of mining services. Expertise can be obtained with less effort, for example, than a mine that is a fly-in fly-out operation. INCO is a company with a very long and complex cultural heritage. The complexity of the political, technical, and cultural issues increases the importance of a well designed and quantitative TMMS. INCO would be capable of great synergy if a standard management and measurement system were used across all mines.

A synergy is being created through the establishment of a common systems plan for the WMC. The other Ontario division mine complexes are closely monitoring the impact of the new management systems, using the WMC as a pilot project.[29] The MIMS modules have been effectively integrated using data models, creating an IT infrastructure. The performance measures developed for S3 and S2 tactical managers include cost and productivity elements. Various communication media have been implemented including a Web browser for quick references (Figure 4-32) and an analysis tool (Figure 4-34). When the performance measures are discussed in structured meetings, managers are encouraged to initiate improvement in areas that need attention. Many improvement initiatives have been identified. The issue at present is the lack of resources to undertake the improvement initiatives. The Divisional research group, Mines Research, is undergoing a redesign program to provide more assistance at a tactical level. This will likely provide the additional technical expertise required to implement modern management techniques. Speculatively, INCO may have sufficient resources to establish expertise in addressing cultural as well as technical issues due to its size and proximity between mines.

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Chapter 5 Conclusions and Recommendations

5.1 Summary of the Investigation

The primary objective of this thesis is to derive a methodology to establish the core components of a tactical underground mine management system, enabling the use of modern management techniques to improve the production system of a mine. The thesis focuses on the unique aspects of a mine production system and the mining workplace culture in comparison to other businesses. The core of the thesis is the TMMS methodology and its application at INCO. Much of the background research undertaken to develop the methodology has been ground in the Appendices.

The research addressed the thesis objective by:

- Identifying and analysing the issues of current tactical mine management (Appendix C);
- Investigating the most successful management techniques available (Appendix E and Appendix G);
- Exploring how current management techniques have evolved in comparison to the management techniques in mining (Appendix E);
- Clearly laying-out a framework of key requirements necessary for a mining operation in order to apply modern management techniques (Appendix F);
- Investigating the technical and cultural differences between the tactical management of a mining operation and of operations in other industries. (Chapter 2);
- Distilling a reengineering model specifically geared toward a mining operation considering its cultural and technical uniqueness. (Appendix F)
- Identifying the need for performance measures, change management, education, communications, and structure so that the 'order' component of a manager's inherent cultural need is fulfilled (Chapter 2 - 3);

- Defining the concepts, issues, and phases of the development of a TMMS that would permit the application of modern management at an underground mine. (Chapter 3);
- Organising a methodology that would permit the development of the appropriate TMMS recognising that each mine is unique (Chapter 3);
- Providing an overview of the management techniques used in each phase of development in the methodology. (Appendix G);
- Listed the modern management techniques available to be applied to the production system of a mine following the development of the TMMS. (Appendix G);
- Described and provided some results of the application of each phase of the TMMS development methodology at INCO Ontario (Chapter 4);
- Discussed the impact of each phase of the application of the TMMS development methodology (Chapter 4);

5.2 Significant Contributions and Originality of this Thesis

The originality of this work is rooted in the focus on issues important yet rarely considered in the education or management of mining personnel, as follows:

- A comparative review of the mining industry with other business sectors to show the differences in an attempt to understand what is needed from management systems in mining to apply management techniques developed for other industries that are appropriate.
- Opening the debate on the effectiveness and importance of tactical mine management and the techniques currently used by mining companies
- Developing a reengineering model specifically for the current state of mining.
- Providing the architecture of a data infrastructure necessary for tactical management by emphasising the need to organise work inputs and outputs by process, including the workplace as an important variable.
- Considering the influence of mine culture on productivity.

- Fulfilling the need to begin using the information technology available to many mining operations.

5.3 Conclusions

5.3.1 Thesis Stimulus

The survival of the mining industry in the 21st century will require fundamental changes in both technical and managerial technology. These two sources of innovation allowed other business to sectors remain profitable. The manufacturing sector is the closest to mining that has experienced considerable improvements in productivity through improved process management and accountability. This is reflected by the opinion of mining leaders (as discussed in the RAND report) who identified information and communications technology as the most critical technology for the mining industry's future. The same leaders acknowledge that mines already possess a great deal of information technology and data and yet do not have the knowledge management to derive value from the data. Other industries have used similar productivity, organisational, and cost data in managing their production and distribution systems with spectacular success. Increased productivity, quality, profitability, and internal and external customer satisfaction are just some of the positive effects of using data in conjunction with advanced management techniques. These management tools have proved highly effective at the tactical level where information directly from the production system can be used to optimise the processes and their interaction.

Several inherent issues in mining induce the need for a formal and direct system addressing the production system in the mine. Tactical management systems at mines are rarely designed or evaluated, they typically evolve over time, especially in changes of management. The need to design a management system that directly addresses the needs of the production system is also made evident through the investigations in the appendices. Most research and education in mining is focused on strategic issues, design, and peripheral issues related to design. These issues are undoubtedly important but have distracted the duties of front-line managers and engineers away from the value-generating production system. Engineers, who typically become the managers of a mine, have relatively little training in the use of tactical management techniques. Therefore additional training for engineers and managers at universities and at mines is required to focus tactical managers and engineers on the issues and techniques involved in managing a mine. When successful management techniques from other industries were applied in a mining environment, the results have varied. Some applications met with success, others with failure. The dissimilarities between tactical mine management and those industries that developed the techniques complicated their use. Therefore a process of analysis was required to identify the peculiarities of mining and the needs of the techniques.

5.3.2 *Issues of Current Tactical Management in Mining*

An in-depth analysis of tactical mine management resulted in the identification of several broad categories of issues. These issues were then analysed to find leverage points that would resolve them. Some of the managerial issues have been experienced in other industries. The issues common to other industries and mining include a functional organisation, a lack of focus on the value chain, poor performance measures, and underestimating the impact of cultural effects. Issues that were exclusive to mining include the lack of advanced management techniques and the resources needed to use those techniques.

In functional organisations most managerial efforts are focused on maintaining and fulfilling departmental goals. This results in the inability to perceive the value chain and costs as integrated systems. When workers in a business do not understand their tasks in relation to the overall system, then inefficiencies may arise from failing to fulfil the needs of the internal or external customers. Therefore organisation and especially management systems, should be based on the processes within the value chain. Managerial focus can be directed away from departmental goals through performance measures that enforce fulfilling the needs of internal and external customers. The culture governing management and worker behaviour should also be considered in the management systems. The workplace culture determines the degree of effort, acceptance, and flexibility of the employee in regarding the work.

Mine managers have neither the infrastructure nor the training to use advanced management techniques. Unfortunately this problem goes largely unrecognised due to its politically sensitive nature. However, it may be suitable to suggest that on-site industrial engineers familiar with IT and mine management could provide an essential service: systems maintenance. This employee would ensure that the management systems are providing the appropriate information and motivation while making changes to the systems as needed.

5.3.3 Reengineering Management Systems

A decade of reengineering management systems in other industries has identified the leverage points that can improve management capabilities. Through a process of redesign using systems analysis, management can be made to focus on the value chain. The redesign is organised by a visioning and planning phase. Organisational design has been able to help the manufacturing industry to develop performance measures related to processes that increased accountability. Activity based costing is able to refine those performance measures so that a semblance of profit is recognised in management decisions. These, and other management techniques were able to improve the performance of production systems by improving tactical management. More than any other, IT is the tool that permitted these management techniques to be applied.

The lack of resources in terms of IT, management training, and few applicable management techniques were the limiting factors for the effectiveness of tactical management in mining. IT resources can be purchased and developed, management can be trained, and management techniques can be developed. The management techniques so successful in other industries are not applicable in their pure forms due to the differences between mining and other industries. However, by understanding the differences between mining and other industries, the differences can be compensated.

The most important difference is the dual nature of mining. It lies somewhere between an ongoing construction project and a factory. Like construction, production and development schedules must be met and planned sequences adhered to. Like a manufacturing system, the same processes are repeated cyclically to build the tunnels and move the muck. The materials handling systems, from mucking to hoisting, are similar to the materials networks found in factories. The influence of the workplace on the capacity and productivity variables complicates the management of a mine using factory concepts. Unlike mining, identical processes do not alter depending on where in the factory or when in the life of the factory the process is undertaken.

Mining culture also has a unique dual nature. Mine management culture was characterised as requiring a sense of order, competitive among managers, focused on short-term targets, and loyal to proven rules even through they may no longer be applicable. The miner or worker culture in mines was seen as focused on a sense of job security, having a long and complicated heritage, sometimes strong militant unions, and often utilising effective change resistant tactics. The dual nature of mining is derived from the fact that manager and miner culture are so vastly different except perhaps for the common attitude toward change. These cultural issues are exacerbated by the high skilled worker requirements for almost every mining process and legislated, close managerial supervision requirements.

Other broad categories of differences are:

- Information system: mining has information systems that effectively serve individual departments while manufacturing has integrated information systems.
- Supervision: underground metal mines are particularly difficult to monitor as the location and actions of mobile equipment are difficult to monitor.

- Equipment reliability: environmental and equipment market issues result in lower machine reliability in mining.
- Bottlenecks: underground mines may have a shaft or adit or other forms of production bottleneck;
- Hazardous, remote workplaces: increase the difficulty and expense of attracting and keeping highly trained employees

Considering these differences, some core components to redesigning mine management would include an integrated information system that keeps track of the activities of mobile equipment, workplaces, and miners. Accountability based performance measures would also be necessary as they can be used to encourage the use and improvement of the production system. Education and a gradual integration of increasingly complex management systems would reduce the resistance to change. The cultural need for 'order' would necessitate the use of a formal management system where the actions of each managers are planned and understood.

5.3.4 *Review of the Methodology*

The methodology described in this thesis is designed to provide some of the basic components necessary for a TMMS. The methodology is composed of four phases of development and one prescribed phase of usage. The first phase of development is the systems planning phase where a redesign team is prepared through careful selection and education. The team is then set to lay-out a general systems plan of the development of the management system over time. The second phase of development is establishing a data infrastructure. Mines have many sources of production and consumption data that must be organised into a single source. These bits of data are best organised according to the processes in the value chain. Much of the hard work in this phase is undertaken by IT professionals. Mine managers must still understand how and why the information is being collected in that manner. Data sources will most likely be in need of managerial control. The importance of the data will have to be recognised in order to gain acceptance and accuracy. Once a trustworthy source of data is available, measures can be established that provide the information necessary to good management. Performance measures facilitate better understanding of the accountabilities of managers. The performance measures will also provide a quantitative gauge of the manager's performance. Short-term risk mitigation is an additional benefit of greater production system understanding because random obstacles to production goals are better understood while solutions are more easily identified. Diagnostic measures allow a quantitative measure of the performance of the production system, and other measures allow the use of management techniques for improving the production system. The final phase of development is establishing a management infrastructure that would provide a formal set of instructions and tasks for managers in the compliance to their job tasks. These instructions would include a procedure to evaluate performance, identify problem areas, and devise solutions.

The primary tasks of tactical mine managers should be evaluating subordinates, undergoing self-evaluation, finding improvements to the production system, making decisions on improving the production system, providing and receiving training, and planning and implementing changes. Personal capabilities such as the ability to communicate, maintain good relations, and delegate are ubiquitous characteristics that are selected in the hiring process and therefore were not addressed in this thesis. An essential element to maintaining effective management systems is the occasional evaluation, evolution, and redesign of management systems. An auditing procedure was therefore a critical requirement in any management system. In using the system, the performance measures are meant to provide managers with the will and means to effectuate improvements in the production system. The diagnostic measures were meant to facilitate the improvement initiatives. Management techniques provide the improvement options.

The suggested performance measures listed as examples in this thesis should not be construed as specific deliverables to the mining industry. As mine management information systems mature, then a formal set of performance measures that can benchmark performance between mines may be established.

Performance measures should be designed for their intended audience and purpose as is directed in the TMMS methodology.

5.3.5 *Review of the Impact from the Methodology's Implementation*

The impact of the methodology's implementation is primarily the construction of a TMMS with the core components necessary for the use of modern management techniques. This is the intended goal of the methodology. The impact of developing a systems plan included the recognition by some that the tactical mine management systems at INCO can and should be improved. The desire and recognition of the need to change was present prior to the commencement of this project but the managers were uncertain as to how it should be done. Establishing a systems plan allowed resources to be freed to undertake this work.

The development of a data infrastructure organised around processes in the mining system has enabled the creation of process based measures. Most of the basic hardware, data collection systems, and software were already in place at INCO. Several auditing mechanisms were developed resulting in increased accuracy, participation, interest, and perceived importance.

The impact of developing performance measures was the participation of the tactical managers in evaluating performance and initiating improvements. For example, a reduction in cost and productivity performance in the development process at Creighton deep encouraged the S2 to solicit help from the West Mines Business Systems unit to undertake an improvement initiative. Development of diagnostic measures resulted in the identification of sub-optimal processes. For example, maintenance costs per unit of output (tons) identified LHD machines that were overdue for retirement. Other measures enabled the development of improvement initiatives. For example, average cycle times for development activities and average delays were calculated for use in a simulation within a Theory of Constraints initiative, aimed at increasing development rates at Creighton mine.

Unfortunately, not much headway was achieved at Crean Hill in the development of management infrastructure. Tactical managers were unable to commit to sessions where performance would be reviewed. Comparatively, Creighton and Coleman currently have established tactical management review sessions at the S2 level. The S2s, who were most motivated to improve from the performance measures, were mostly professional engineers promoted laterally into an operations role as general foremen. Therefore the impact of performance review sessions on S2s, who were part of the engineering culture, was the establishment of improvement initiatives. This may stem from the competitive nature of the engineer or the sense of 'order', since the performance review sessions were meant to promote performance improvement. The impact of measurement sessions on tactical managers who were part of the miner/worker culture was reluctance to be evaluated. This may stem from the need for 'security' as the performance review sessions may reveal the past mistakes and therefore negatively impact job security.

The impact of meetings to plan performance targets and improvement initiatives resulted in the establishment of performance targets. The impact of auditing the management system resulted in several revisions of the system plan, process map, and S2 metrics presentation.

5.3.6 *Validity of the Approach*

Several core assumptions may impact the validity of the approach adpoted. The most important assumption is that there is management support for reengineering the tactical management systems. Without management support reengineering efforts will not succeed. This was made evident by the example of the Universal Scheduling Consultants' 1993 INCO management system, where a change in management support resulted in the abandonment of the planned system.

This approach also assumes that the tactical managers have the technical, human, and conceptual skills necessary to be good managers. Figure 5-1 shows how the importance of the skills of these managers change with management level. Managers need to be good listeners, respectful, flexible, and have the ability to learn. Good management systems will not make a poor manager into a good manager. Tactical management systems would enable a technically strong manager to improve performance. This is evident in the INCO application since the managers who appeared to benefit most from the TMMS had an engineering background (Creighton and Coleman S2s were engineers).

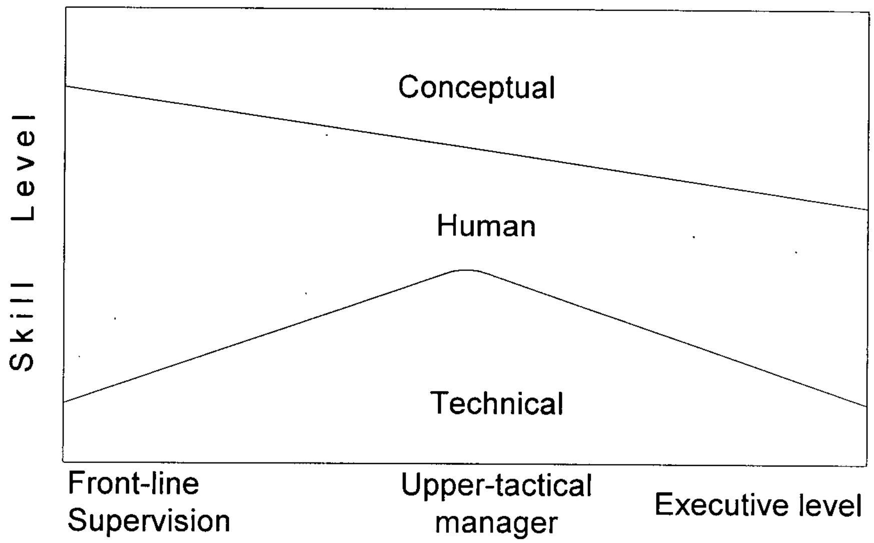

Figure 5-1: Relative Significance of Managerial Skills[1]

This approach is also only valid for operations complex enough to warrant a tactical management system. For example, a mine with very few pieces of equipment, minimal workers, and uncomplicated geology may not gain any increases in productivity through a management system that simplifies management objectives.

The ultimate purpose of this thesis is to provide current mine management with the will and knowledge required to develop an effective TMMS. The structure of this thesis provides the purpose, reasoning, background, theory, examples, and results. In the interest of the reader, only the core elements of the thesis is provided while the investigations and reasoning of how the methodology was developed is made available in the Appendices. The thesis begins by briefly mentioning the reasoning and purpose for exploring these issues. The differences between mining and other industries is explored so that the differences can be compensated in the design of the methodology.

Segments left out of the main body of the thesis are important in justifying the unique nature of this thesis and in the development of the ideas. For example, clearly laying-out the concepts and issues of this topic provides the analysis required in a doctoral study compared to a consulting project. A discussion of the differences between mining and other industries provides the ability to distil a reengineering framework for mine management from the history and structure of modern management techniques. A methodology for the development of a TMMS is derived from the framework so that the critical components to a modern management system are developed. The management techniques used in the development and use of the TMMS is described. Finally, the results of the implementation of the methodology, presented in the main body of the thesis, provides evidence that this methodology results in the development of a TMMS that has the core components of data, information, structure, and improvement. The challenge of communicating to the industry the importance of tactical management and the availability of management techniques to help improve performance still remains.

This thesis cannot adequately emphasise the importance of tactical management to the industry. Marketing these methods to tactical and strategic managers in venues, such as workshops, would allow a greater appreciation of the lack of resources or focus on managing the production system. Advancing the skill level of management in mining to levels equal to those found in other industries should be a component of future work. A presentation in September 2001, to mining executives at the World Mining Equipment (WME) Executive-level Survival 2001 Seminar series provided such an opportunity.[2]

5.4 Recommendations for Future Work

Future work in this area should include the following:

1. Mining IT providers may be able to develop an official data model for mining. Attempts to standardise how information systems account for production information and costs across the industry could be achieved through agreements between software providers and further research of the needs of mining operations.
2. Data mining is a new field of study used in marketing to discover patterns in large amounts of data. The technique uses search algorithms to detect patterns within a defined database. This technology could be used in automatically characterising the patterns of mine productivity using the vast amounts mine production and cost data available in future.
3. Metrics for each management level can be further defined. This thesis provided suggested metrics for General Foreman and higher. Foreman level metrics may be derived from further TMMS development. Standard performance rates for the industry can also be developed so that the performance of miners can be easily compared. For example, the development rate and cost of one contractor can be compared with the development rate and cost of on-site personnel.
4. Modern mining technology has potentially devolved the work of a miner from skilled artisan to a dial-watcher or gauge reader. However, a good equipment operator would reduce the maintenance costs of a piece of equipment and may even develop methods at improving the speed and quality of work. Miners should not be measured solely on their ability to operate a machine effectively. Considering that 70-80% of the time spent at the face involves preparing supplies, setting up equipment, tearing down equipment and re-sorting supplies, logistical and organisational skills should also be developed. An improvement in set-up and tear-down time would potentially have more effect than improving the performance of the drill or drilling activity. Miners would therefore require education in the techniques and information on how to become better at logistics and organisation. Performance measures gauging these skills may provide benefits.
5. Supplementary education for the management and workforce in mining needs to be developed that would allow more complex systems to be used in mines. Education programs could be developed to address the technical expertise needs of the mining industry's typical tactical manager.

6. Ethnography is not a traditional tool in mining yet should provide powerful insight into the effectiveness of any TMMS. Additional ethnographic study of a mine's work environment may point to even more effective management system designs.
7. Modern management techniques used and mentioned in this study, i.e. ABC, TOC, Reengineering, SPC, TQM, JIT, and MRP, justify further refinement for mining. This can be achieved through further practical application.
8. Implementation issues are critical to the success of any management system. Implementation issues have been covered extensively by management experts and by the author in other works.[3] Further refinement of the issues and techniques of implementing a management system in mining is recommended.
9. Educating future managers in management techniques and operational issues could be undertaken at the undergraduate, graduate, or professional levels. Tactical management and worker-manager relations are recommended as core courses in universities.
10. Considering the unique characteristics of INCO Ontario Division (centralised supplies warehousing and ordering, a primary mill processing all mining output, a community that was built and still depends on a monolithic mining company, etc...), the nature and key performance measures of a TMMS appropriate in other mining scenarios should be researched. This would provide additional insight into performance measures, critical system components, the effect of workplace culture, and management techniques.
11. Extending this methodology to surface mining to take advantage of the higher level of computerised monitoring and control is recommended.

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[1] Arul, M.J. *Managerial Skills*. June 24th, 2001 http://members.tripod.com/~arulmj/mgrlskls.html.

[2] World Mining Equipment Online. *Survival 2001 Seminar*. July 31st, 2001. http://www.wme.com

[3] Dessureault, S., Malcolm Scoble, and Ken Mathews. "Factors Controlling the Success of Mining Technology Development and Implementation." *Proceedings of the 102nd Ann. Gen. Meeting, Can. Inst. Min. Metall.*, March 5-10, Toronto, Ont. 2000, CD-ROM.

Appendix A. Definitions within the Scope of Work

This topic deals with concepts and issues with ambiguous meaning. This discussion provides formal definitions of the key concepts within this scope of work. These issues were briefly discussed in section 2.1 and explained in greater detail below.

A.1 Mining Systems

Mining is formally defined as: "The process or business of extracting ore or minerals from the ground."[1] When 'mining' is used in this body of work it signifies the mining activities from geological modelling to the mine-mill interface. The operation and control of a concentrator resembles a factory more than a mine and therefore would be managed accordingly. It is recognised however that the output of a mine directly affects the costs and productivity of the mill therefore the mine-mill relationship directly affects profitability.

Webster's Dictionary's formal definition of system is: "a regularly interacting or independent group of items forming a unified whole."[2] Another definition of a system, from a modelling perspective, is that a system "is a collection, from a circumscribed sector of reality, that is the object of study or interest."[3] The scope of a system is relative to what purpose modelling or defining the system serves. For the purpose of this thesis, the main system being described is the mining system. Therefore the mining system would include all those aspects within a mine that would be subject to cause influence and be observed, analysed, and potentially improved. Hence, if the purpose of the model or description would be to improve the mine as a whole, then the following components would be considered some of the descriptive aspects of the expression 'system':

- Functional organisation
- Culture that influences the output
- Technology in the mine

- Goals of output including quality, volume, etc…

Through the course of the thesis, systems within systems are discussed. Some of these systems are reality based, others conceptual. A conceptual example is the value system influencing motivation within the culture of the mining system . The components within a value system affecting motivation may be:

- The influential factors leading to various forms of behaviour
- The factors in the evolution of specific forms of behaviour
- The rules in place attempting to change behaviour
- Incentive agreements

Defining the differences between systems, functions, processes, activities, and tasks is important to this discussion. In a later subsection, each of these terms is defined separately followed by a discussion of how they relate to each other. For now, in considering mining systems, several key concepts are discussed. Figure 6-1 shows some of the key concepts within mining systems that will be discussed. Only shaded boxes will be defined as they are the key concepts in this thesis.

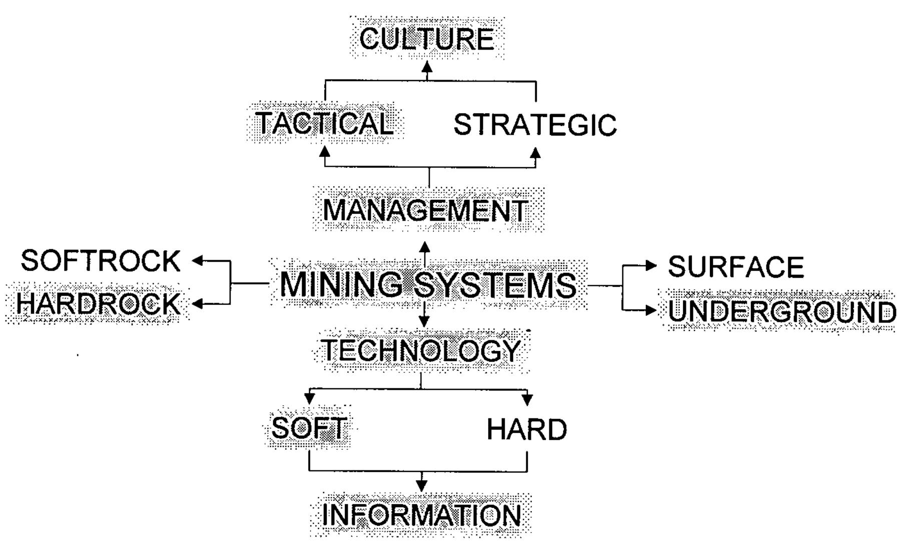

Figure 6-1: Key Concepts within Mining Systems

A.1.1 Management

The formal definition of management is: "The act or art of managing; the manner of treating, directing, carrying on, or using, for a purpose; conduct; administration; guidance; control; business dealing; negotiation; arrangement."[4] Management can also be considered a group of managers: "The collective body of those who manage or direct any enterprise or interest."[4]

Mine management is the guidance and control of the mining system with the intention of fulfilling the business objectives of the company that owns the mine. For the purposes of this thesis, a mine will be considered a business where profit for the company that owns the mine is the primary objective of management within social, moral, and environmental constraints. Publicly owned and operated operations will not be considered.

Management can be loosely classified into two groups: tactical and strategic. Most education and research in mining has thus far concentrated on the strategic issues. This thesis develops a methodology that creates the core components of a modern TMMS.

A.1.1.1 Tactical

Dasys (1997) defines tactical decisions in mining as the decisions "that allow you to make changes to the process as it is ongoing. Deciding where an LHD, or work crew should be allocated for the next part of the work period is an example."[5] The term tactical is used in this thesis to differentiate from strategic aspects of mining. Tactical mine management deals with issues or procedures that sustain day-to-day or month-to-month production. The scope of tactical management decisions would not normally extend beyond one year. Tactical issues involve the planning, operating, and managing the mine, for example:

- decisions relating to work crew assignments
- eliminating delays from processes
- monitoring, controlling, and reducing unit costs

For purposes of comparison, strategic management or decision making is briefly discussed. Dasys describes strategic decision making as those decisions that affect the long-term results of the mining system.[5] Major changes in the mine that will affect fixed costs, long term productivity, or workforce relations (in the long term) are all issues that can be considered strategic. These types of changes will most likely require capital dollars and/or corporate involvement. Corporate initiatives in the mineral industry would also be considered strategic. Examples of strategic concerns are:

- looking for new markets for the mine products
- assessing and managing the mine's role in the community
- major infrastructure changes to the operation, or
- the analysis of price fluctuations to decide when to schedule production increases.

Culture must be managed on both strategic and tactical levels. The culture of the community where a mine is located is a strategic issue that must be managed long-term through compliance to the rules and regulations of that community along with addressing their concerns about issues such as the environment and global market fluctuations. The culture of the workforce is a tactical issue as it relates to the motivational factors that have a direct impact on production performance.

6.1.1.1 Culture

Culture is the body of beliefs, values, and motivational factors for the actions of those within the culture. Culture is considered by most modern management philosophers as being one of the most important variables to be considered in a company's efforts to change to new methods of operation. Effective use of information technology requires a new style of management that is less autocratic, where information and decision making is distributed to those that would make the most efficient decisions (not necessarily the highest level).

The new style of management advocated by most management authors advocate a more open, less hierarchical culture. The management of a software or Internet company, differ significantly from mining. Davenport considers that processes that involve largely repetitive physical work performed by high turnover employees should not be expected to be overly committed to their jobs. He suggests that these types of operations are more appropriately managed in a control-oriented culture. Mining jobs are repetitive and at times high-turnover yet require a high skill level. Firms in these industries constantly seek IT innovations to afford greater control and enable the capture and display of process knowledge.[6]

Cultural heritage is rooted in the experiences of companies. In the case of mining, one of the oldest industries in the world, a significant amount of industrial history is the basis of the cultures of the various companies. Historically in many communities, mining is not only a source of employment but a way of life.[7] "Mining in the blood" is a common expression denoting the tendency of mines employing several generations of the same family as miners. When there have been changes in the culture within mines, it is most frequently motivated by issues of safety, where major accidents may induce investigations of worker and management behaviour and its influence on safety.[8]

Incentives are a common source of either increasing safety (through the institution of safety-related incentives) or productivity (that usually negatively affects safety)[9]. Recent changes in culture among mining companies may be due to mass-media induced popular pressure for mines to operate with as little impact on the surrounding environment as possible, while sustaining the communities that provide the labour.[10] The lack of published research that describes mining culture in terms of productivity makes characterising it challenging. Most mining culture studies focus on safety issues. The management-miner relationship has been characterised for some coal mining operations but few underground hardrock mines have been studied (and published).[8]

This body of work develops a methodology to create TMMS with key components found in successful manufacturing and IT management techniques. Components and concepts from management techniques such as reengineering principles, TQM, organisational development are considered. Most of these techniques address issues dealing directly with the culture of the systems where they are applied. The distinct mining culture should also be considered, when new mine management tools are developed since mining culture is significantly different from the industries where the techniques are developed (example: manufacturing). In the thesis mining culture is characterised to identify necessary changes to the management techniques so that mining's particular culture is considered. Management must address cultural issues since these are the most ubiquitous but elusive variables to track and control. In order to anticipate cultural issues that may affect the outcome of these tools, common cultural idiosyncrasies are considered, described, and a plan of action on how to deal with the cultural element (if undesirable) is formulated, as discussed in the following example of peer pressure. In implementing a productivity improvement initiative, some miners perceive the effort as positive since the incentive system will ensure that if productivity increases, the incentive system in place will provide compensation for participation. However, some miners may resist the change. If the productivity rates are posted per miner, those who are not contributing to maintaining an acceptable production rate will be identified by others who will impose peer pressure to work harder, smarter, or to get more training.

A.1.2 Technology

Technology is one of the most important terms in this thesis. The formal definition of Technology is: "the practical application of science to commerce or industry; the discipline dealing with the art or science of applying scientific knowledge to practical problems"[11] Considering the common discussion of technology in modern media as being primarily relating to computers and software, further clarification is required.

A.1.2.1 Hard and Soft technology compared

Hard technology is technology that deals with the physical. For example, the technology needed to mechanise or automate processes such as mechanisation and computers can be considered as hard technology. Soft technology can be considered both software and business concepts/tools. Examples of business concepts are: reengineering, or activity based costing. Software is also soft technology.

A.1.2.2 Information

Information is defined as: "1. Knowledge derived from study, experience, or instruction.; 2. Knowledge of a specific event or situation; intelligence.; 3. A collection of facts or data: statistical information. 4. The act of informing or the condition of being informed; communication of knowledge."[12] All these definitions are appropriate when the term 'information' is used in this thesis. For example, performance information is a collection of facts from which knowledge of a specific situation or process can be derived.

Information technology (IT), constitutes the integrated computer networks, software, and the data manipulation used to provide information from a system. IT is widely accredited as being the primary enabler behind most modern management changes in the past decade. Many of the concepts of improving businesses and processes were developed prior to the advent of the computer, although digitally distributed information has allowed that information to be collected, interpreted and distributed with far less cost than ever before. For example, in the early years of the last century, management science pioneer F.W. Taylor improved worker activities through data derived from time studies.[13] By integrating cheap, well organised and accessible information about a process or system, these business reengineering tools become far less expensive and therefore viable management options.[14]

A.1.3 Underground - Hardrock

This thesis focuses on underground mining. Ample scope exists to undertake a thesis on tactical mine management in surface mines. Open pits are adopting information and tactical management technology at a pace even faster than underground mines.[15] Furthermore, research and development of software tools for surface mines has been undertaken in the recent past in an attempt to take advantage of the advanced

Global Positioning System (GPS) sensors and wireless information networks implemented in many open pits. Many aspects of surface mining are different from underground mining. For example, a supervisor in an open pit could easily view the work being undertaken by the various equipment operators by looking down to the workplaces from the crest of the pit. An underground supervisor must travel to the various, and sometimes widespread workplaces, in order to inspect the work being undertaken, one work-face at a time.

Within the realm of underground mining, clear distinctions can be made between the coal and hardrock mines. Coal mining uses different mining methods and equipment. Furthermore, considerably more study of tactical management issues has been published about underground coal mining than metal mining especially in dealing with safety issues.[7]

Underground metal mining is the main focus of this work. This does not disqualify the findings or tools developed in surface or coal mines. Nor do the techniques developed in this thesis hold true only to hardrock metal mines.

A.2 Scope: Innovating the Mining System's Management Processes

As can be surmised from the above definitions, this thesis is about developing a methodology to innovate tactical mine management for underground hardrock mines through the application of soft/hard technology and IT, whilst taking culture into account. Innovating management is accomplished in other businesses through various managerial techniques that focus on processes. This is a topic that is widely discussed in business literature, therefore, there are many different views from various authors. Davenport provides the most accurate definition of the phrase 'process innovation' as it relates to this thesis.[16] He defines a process as a structured, measured set of activities designed to produce a specified output for a particular customer or market.[16] A process is a specific ordering of work activities across time and space, with a beginning and end, and clearly identified inputs and outputs and procedures that structure action. Consequently, *'process innovation'* involves performing a work activity in a radically new way.

There are two critical elements of this work that conform to the above definition. Firstly, the tactical underground management method as proposed in this thesis is new as no published reference of a management system in mining that have all its components has been found. Hence, the novelty, or innovation element necessary for doctoral work is fulfilled. Secondly, innovation in mining systems can take many forms. This work concentrates on developing innovative *management* mechanisms. Therefore, this thesis is about the reengineering of a mine's organisational framework at lower to mid-management levels. By considering underground hardrock mining at a tactical level, the subject matter becomes manageable for a single thesis.

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[1] "Mining." *The American Heritage Dictionary of the English Language*, Third Edition, 1996, Available: <http://www.dictionary.com/>

[2] "System." *Webster's Ninth New Collegiate Dictionary.* Springfield Mass.: Mirriam-Webster. 1985, 1199p.

[3] Prisker, Alan A., O'Reilly, Jean J and David K LaVal. *Simulation with Visual SLAM and AweSim.* New York: John Wiley & Sons. 799p.

[4] "Management." Webster's Revised Unabridged Dictionary. 1996, 1998 MICRA, Inc <http://www.dictionary.com>

[5] Days, Andrew. "The Evolution of Information Management Applications Towards Mine Automation in Underground Mines." *4th International Symposium on Mine Mechanisation and Automation.* Brisbane Australia, July 6-8, 1997 <http://www.el-equip.com/evo_doc.html>

[6] Davenport, Thomas H. *Reengineering work through Information Technology*, Boston: Harvard Business School Press. 1993

[7] Mitchell, John. *The Mine Worker's Life and Aims.* July 22nd, 2000 Letter by the President of the United Steel Worker of America, 1904. <http://www.history.ohio-state.edu/projects/coal/mineworkerslifeandaims/>

[8] Leeming, J R. "Engineering a Culture Change." *Mining Technology*, Vol. 79 no. 915, November 1997

[9] Wilde, Gerald J.S. *Risk awareness and risk acceptance at the Westray Coal mine.* March 25th, 2000. Queens University Psychology Department. <http://pavlov.psyc.queensu.ca/faculty/wilde/westray.html>.

[10] Hodgkinson, Lee A. "Triple Bottom Line Reporting in the Mining Industry." *Mining Millennium Proc. Can. Inst. of 103rd Min. Met. and Pet. Annual Gen. Meeting*, March 2000, Toronto. CD-ROM.

[11] "Technology" Princeton University WordNet 1.6. February 12th, 2001. < http://www.dictionary.com/cgi-bin/dict.pl?term=Technology>

[12] "Information." Webster's Revised Unabridged Dictionary. 1996, 1998 MICRA, Inc. <http://www.dictionary.com>

[13] Taylor, Fredrick Winslow. *The Principles of Scientific Management.* New York: W W Norton & Company. 1967 (1911 org.). 144p.

[14] Davenport, Thomas H. and James E. Short. "The New Industrial Engineering: Information Technology and Business Process Redesign." *Sloan Management Review*, Summer 1990, pp.11-27

[15] Mining India. "Mining Enterprise Solutions." June 5th, 2000. <http://www.miningindia.com/planning/general/2.htm>

[16] Davenport, Thomas H. *Reengineering work through Information Technology,* Boston: Harvard Business School Press. 1993

Appendix B. Organisation of work

The organisation of work into a linguistic classification system was undertaken in chapter 2. The definitions provided in this appendix provide additional clarification and definitions of each level of work. Note that the definitions provided here may not be identical to the connotation these words have in popular language. Nevertheless, an organised manner of describing work hierarchies is necessary. This characterisation model is consistent with modern management techniques used in other industries such as Brimson's Activity Based Cost Accounting technique.[1] Figure 6-2 presents the conceptual breakdown of work as will be used in this thesis. The definition of a system was presented earlier in this chapter. As work is broken down into increasingly simple actions, then the complexity involved in managing the work components so decreases.

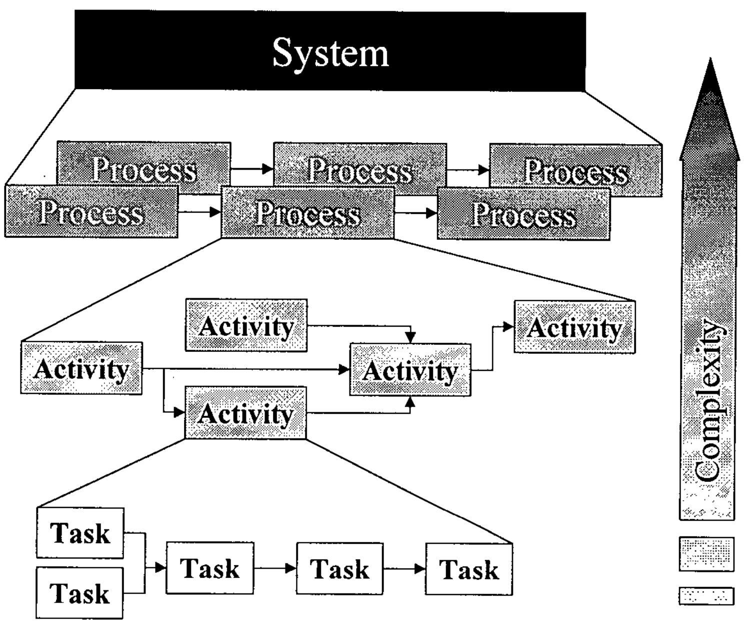

Figure 6-2: Conceptual Breakdown of Work

B.1 Process

The formal definition of a process is: "a particular course of action intended to achieve results."[2] Processes are the core of a system, several processes can make up a single system. Each has an intended output that is a major contributor to the outcome of a system. Processes cannot be managed directly and can be considered the lowest *conceptual* form of work. An example of a process in the mining industry is the production drilling process in an underground mine. This process has several inputs and outputs, for example, inputs would include blasthole layouts, survey lines, a workplace, compressor, drill, operator, and drill bits.

B.2 Function

The formal definition of function is: "The act of executing or performing any duty, office, or calling."[3] In terms of work organisation, a function is an aggregation of activities related by a common purpose customarily associated with an organisational categorisation such as engineering, operations, or logistics.[1] Fragments or aspects of a function can cross the frontiers of a business process and vice-versa. For example, within the process of 'production drilling' the engineering activities of 'design/schedule drill layout', are organised functionally under 'engineering'; and drill set-up, drill, and drill tear-down activities are organised functionally under operations, and the delivery of bits, power, and men to the workplace is organised under the 'Logistics' function. Functions are commonly conceptually perpendicular to how work is undertaken in terms of processes. However, functions are parallel to the expertise of the individuals working within the functions. For example, engineers with technical training work within the 'engineering' function, whereas miners who have operational expertise work within the operations function. Figure 6-3 provides a conceptual view of how processes are perpendicular and expertise parallel to functions.

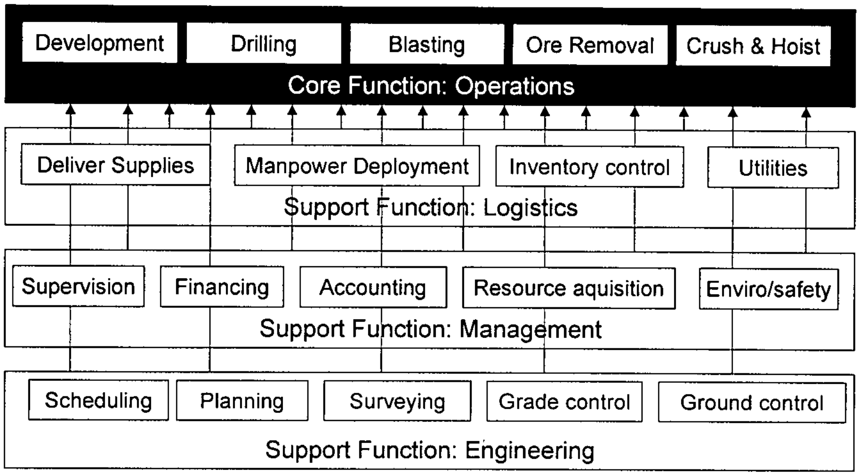

Figure 6-3: Functions Perpendicularly Feeding Processes in a Mine

B.3 Activity

The formal definition of an activity: "any specific deed, action, pursuit"[4], is broader than its significance as a work-organisation definition. An activity is a combination of people, technology, raw materials, methods and environment that produces a given output or service. Activities are the first level of work that can be managed directly. In terms of an activity within a work hierarchy, several activities can make up a process. For example, the 'production drilling' process in an underground mine would include the following activities: workplace set-up, drill set-up, drilling, and drill tear-down.

B.4 Task

The formal definition of task is: "a function to be performed; an objective."[4] In the hierarchy of work, a task is the lowest form of work that is practically managed. Any lower classification of managerial influence would be impractical. In terms of tasks within the work hierarchy, several tasks would make up an activity. For example, the 'drilling' activity in the 'production drilling process', in an underground metal mines production system, would include the following tasks: collaring the hole, optimising the feed rate, pulling rods (the steel for ITH drills), changing rods, changing bits, and moving the drill into position. Managing the specific movements within a task, such as pulling levers to optimise feed rate is not within the scope of a manager to control.

Figure 6-4 summarises the example discussed in the definitions above. The purpose of using these statements within this text is to organise the units of work within a mine into manageable logical components that can be described. The ambiguity of these terms may create some confusion where language used within a particular work culture may differ from that used by system improvement experts in, for example, the consulting sector.

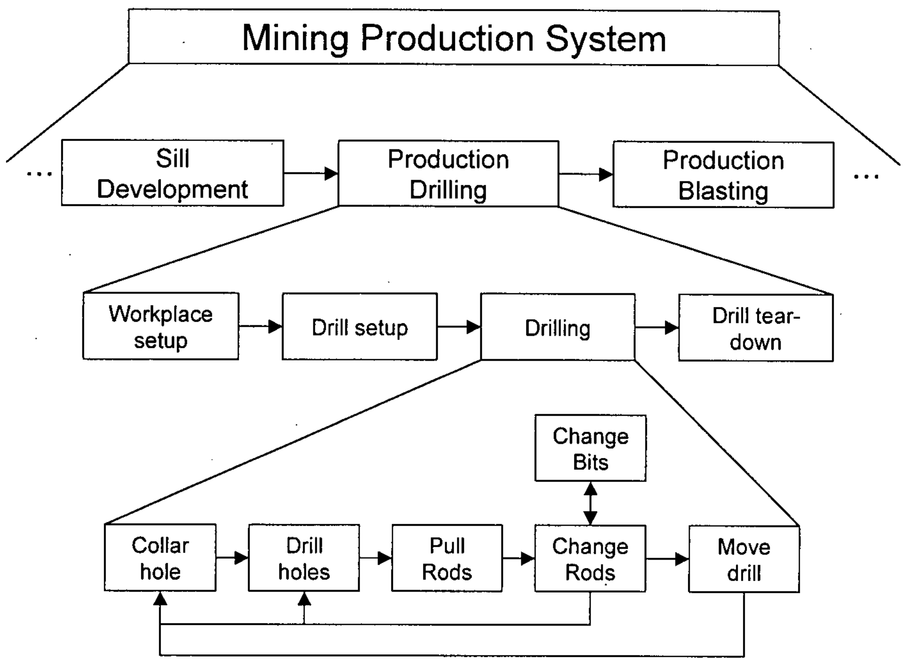

Figure 6-4: Work Hierarchy: Underground Production Drilling Example

[1] Brimson, James A. *Activity Accounting: An Activity Based Costing Approach,* John Wiley & Sons Inc.: New York, 1991

[2] "Process" Webster's Revised Unabridged Dictionary. August 4, 2000 <http://www.dictionary.com/cgi-bin/dict.pl?term=process>.

[3] "Function. Webster's Revised Unabridged Dictionary. February 25, 2001 <http://www.dictionary.com/cgi-bin/dict.pl?term=function>.

[4] "Task." Wordreference.com, February 25, 2001 <http://www.dictionary.com/cgi-bin/dict.pl?term=task>.

Appendix C. Issues in Tactical Mine Management

The following is a critical exploration of the issues in current TMMS. The primary goal of this discussion is to identify limitations of current management practice. Some of these issues are common to all industries, while some are particular to the mining industry. Both will be discussed. For each issue described in this text, both the effects and root causes are discussed. Discussing the effects should help mine managers and engineers reading this thesis to recognise problematic areas within their own operations. Exploring the root cause of each issue will form a framework for a more effective tactical mine manager by correcting the root cause instead of addressing the symptoms. Figure 6-5 clarifies the structure of this appendix as described above.

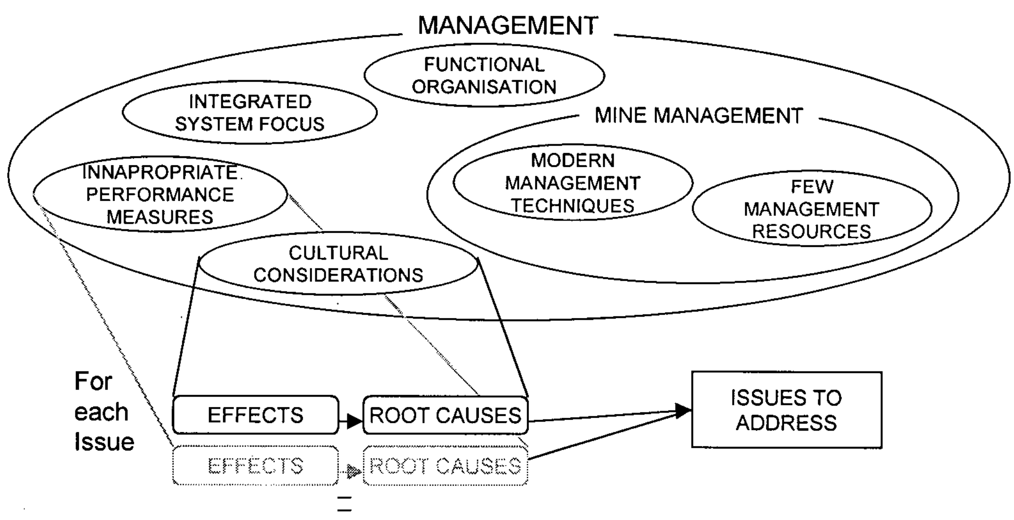

Figure 6-5: Structure of the Exploration of the Issues in Mine Management

This analysis relies on published material to outline potential problematic areas within tactical mine management. Not every mine will have all the problems discussed here. Similarly, many operations may have already developed management systems that counteract the issues discussed. This discussion aims to be an objective analysis, not a critique of the industry or those employed in it.

Virtually all published material on this subject does not directly address the problems facing organisations or mines but instead describes them within the context of a solution. This discussion attempts to distil the main organisational problems facing businesses from published sources. The discussion begins with issues that are facing all industries and will progress into issues dealing directly with mining.

C.1 Functional Organisation

Fundamental redesign or reengineering is the most common forum of discussion when exploring the effect of functional organisation. Many published discussions criticise functional organisation. A common critique is that managers who control the functional units of a company commonly see their organisations vertically and functionally. Goals for those units are established for each function independently. This environment causes other functions to think of themselves as 'enemies'. [1] Figure 6-6 illustrates how "Silos" (tall, thick, windowless structures, also known as stove pipes) are built around departments.

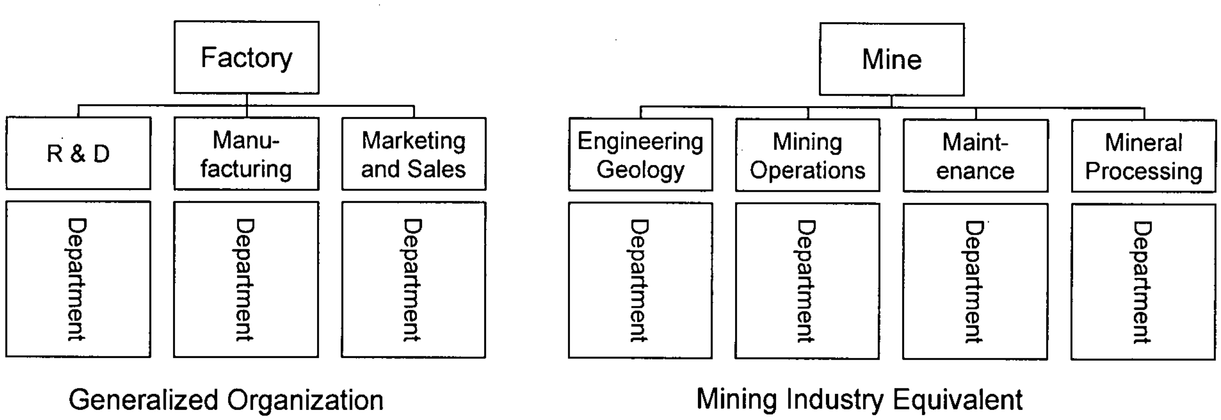

Figure 6-6: The 'Silo' Phenomenon in Mining [1]

C.1.1 *Effects of the Functional Organisation*

Several issues result from managing according to a company's functional organisation. The discussion below describes these issues and provides examples.

FUNCTIONAL MISALIGNMENT

Inter-departmental rivalry is a common symptom of this vertical organisational design[2], where the control of a process is split between several functional departments. Departments may place the blame for not achieving targets on actions in other departments. This is common where no single manager is in control of an entire process. For example, the priority of the operations department may be to begin working in a particular workplace which is contrary to the electrician's priorities. This may delay work as the electrical power is not be installed in time. Resistance to improvement similarly results from this "turf" mentality.[3] Cross-functional process improvements inevitably result in 'turf wars' when a functional manager attempts to change a component of a process under another manager's authority.

FUNCTIONAL FOCUS

In vertical organisations, business unit functions are maximised, not the system or processes that make up the system. [4] A vertical organisation results in improvements that focus on departmental functions. Similarly, functional departments commonly have goals not linked to the process that they serve.

POOR PERFORMANCE TARGETS

Cavender,[5] one of the few mining oriented authors that directly address this issue, highlights that these vertical organisational structures create inappropriate goals/targets. Functional managers typically set performance goals for themselves without regard for the needs of the other functions or overall system.

COMMUNICATION BREAKDOWN

Vertical organisations create communication breakdowns between the low level workers in different functions. [6] If problems identified in one function require changes in another functional department, then the improvement suggestion or identified problem must be communicated up the chain of command, then horizontally to the other functional department's manager, and finally down vertically to the individual that can make a change. Figure 6-7 illustrates this circumstance in mining terms. Consider a drill operator that would like the survey lines to be marked in a different fashion. This request must move up to his shiftboss, then to the production captain (or general foreman), over to the manager of engineering, down to the senior engineer, then finally to the survey leader. Conveying this request consumes time, resources, and inevitably leads to a garbled message once it reaches its final destination. Roman[7] provides another mining example of this situation where a lack of understanding or tension between the mining operations and maintenance functions was revealed during a process mapping exercise. Substantial improvements were achieved when a process view was taken.

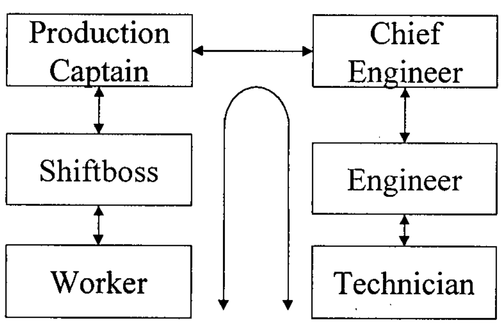

Figure 6-7: Communication Flow between Peers within Vertically Organised Mining Companies

Lack of Accountability

A vertical management infrastructure blurs accountability for a particular process that spans across functions.[6] For example, consider the dependence of the drift development process on mine engineering outputs. Engineering must provide layouts and survey lines for development yet the operations tactical managers are ultimately responsible for development rates and quality.

Excessive Bureaucracy to Link the Functions

Establishing bureaucracies or activities that attempt to smooth the links between functions is a further attribute of vertical systems. Hammer[8], uses a Humpty-Dumpty analogy where companies take a natural process, and breaking it into lots of little pieces. Then, the company hires 'all the king's horses and all the king's men (example: auditor, expediter, controller, liaison, supervisor) to paste the fragmented work back together again."

C.1.2 Root Cause of Functional Organisation

Exploring the root cause of these issues will lay the foundation for how they can be avoided instead of addressing the symptoms.

HISTORY

The vertical management system was effective in the past. Functions were created in the early 20th century to manage the increasingly large business units and complex production systems of the corporation.[8] In order to integrate the various complex functions, experts had to be hired that could perfect those functions. Henry Ford and Alfred Sloan were the most successful managers to apply those ideas. Bureaucracies had to be created to integrate their inputs and outputs so that they would be aligned. However, as the production systems grew in complexity and information gathering and analysis simplified, these bureaucracies and the management structure which created them, were not altered, remaining large and inflexible. Therefore a key element in any TMMS includes the foresight to maintain a flexibility through an auditing process.

THE ACCOUNTING SYSTEM

Corkins[9] blames the accounting structure for the continued use of the vertical organisation, as most accounting systems are still organised by function. Managers are measured primarily on how well they meet their budgets. In this case, the goal setting mechanism prolongs the use of a system that no longer functions effectively. Therefore an alternative to a functionally organised accounting system should be considered.

DIVISION OF LABOUR

Duck considers that the functional system was due to the ideas perfected by F. W. Taylor, industrial engineering pioneer, who considered that work should be broken up and analysed in increasing detail. Although a simplistic view of Taylor's work analysis theories, Duck points to the concentration of expertise in functions, not processes as being the cause of retaining functional silos. Therefore the accountabilities of a tactical manager should include satisfying the customers of a process.

C.1.3 Summary of the functional organisation

To summarise, vertically oriented organisational designs tend to be weakened due to:

- Lack of awareness of the needs of other functions;
- Lack of communication between peers across different functions;
- Unproductive rivalry between departments;
- Inappropriate performance goals and work incentives;
- Lack of clear accountability of the process;
- Bureaucracies within the functions to manage the links between departments.

From the above the root of the issues of the functional, vertically designed organisation can be identified: how the system is viewed. If the system is viewed as a group of departments, the focus of improvements and management will focus on departmental issues. If the system is viewed as a group of processes linked to create value, then improving the value-generating system will be the focus. Many of these problems are eliminated by simply viewing the system as interdependent processes. This leads to the next issue: the lack of recognition that the mining operation is a system, as seen in Figure 6-8.

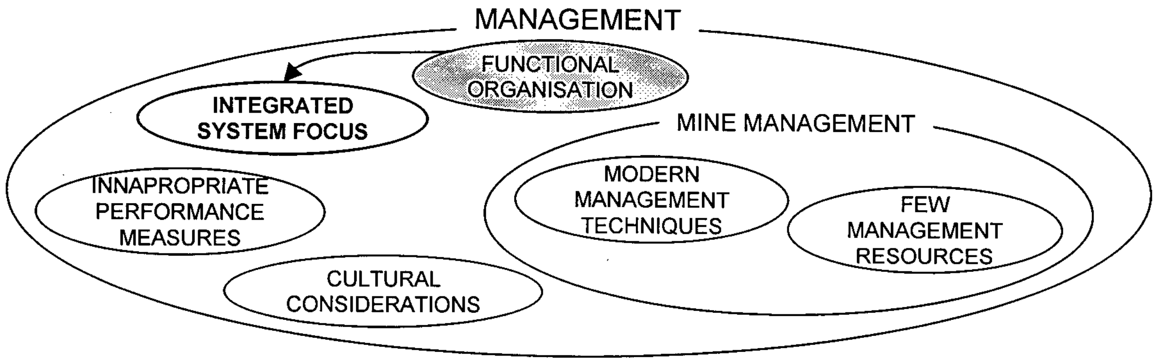

Figure 6-8: Progression of Discussion - from Functional Organisation to Integrated System focus

C.2 Viewing the System as Interdependent Processes

As discussed above, vertically designed organisations result in independent functional units that set their own goals on how to create the product or service the company provides. Each function within an organisation is intended to produce certain outputs that add benefits along the value chain. As a result of the independence of the functional units, inefficiencies and waste will be induced. Virtually all modern management tools, from reengineering to Total Quality Management (TQM), have a component of systems analysis where processes are studied in relation to the overall system.

C.2.1 Effect of not Viewing the System as Interdependent Processes

POOR INTEGRATION

Campbell describes a situation at an Australian mine where several chronic problems with the production system were identified. Bureaucracy and buffers between work units were creating inefficiencies, including:

- Vague production planning (engineering and operations);
- Slow assay turn-around (lab and engineering);

- Co-ordination difficulties for equipment moves (maintenance and operations);
- Marginally adequate equipment availability and reliability;
- Low service levels at the centralised parts stores (logistics and operations);
- Mismatching of the flow rates from one operation to the next (mine to mill);
- Slow communications with excessive bureaucracy amongst the different departments.

These are common effects of poor integration between processes. Campbell discusses a case study where a manager with a background in manufacturing, reengineered a surface mine in Australia, resulting in significant economic benefits from the resulting changes.[10]

LACK OF UNDERSTANDING

Inefficiencies derived from a lack of understanding of the overall value chain are often caused by a lack of effective awareness of the production system. Hawkes discusses the effect of a mine increasing its burden and spacing to create larger fragments when blasting.[11] This decreases drilling and blasting costs but causes adverse effects on the process downstream, especially in the mill, resulting in decreased profit.

PERSONAL SYSTEMS

Senge, a strong advocate of systems thinking, discusses seven learning (individual or as an organisation) disabilities that are caused from a lack of systems thinking:[12]

- "'I am my position" – this translates to the loyalty one has for their functional units. "When asked what they do for a living, most people describe the tasks they perform every day, not the purpose of the greater enterprise in which they take part." (p.18)
- "The enemy is out there" – a by-product of the "I am my position", and the non-systemic ways of looking at the world that is fosters, this type of mentality limits the ability to see the overall system.
- The illusion of taking charge. – 'proactiveness' can be 'reactiveness' in disguise. True proactiveness comes from seeing how individuals contribute to their own problems. (p.21)

- Fixation on events: the primary threats to our survival, both organisational and of societies, tend to come not from sudden events but from slow, gradual processes. Generative learning cannot be sustained in an organisation if people's thinking is dominated by short-term events.
- Parable of the boiled frog: the internal apparatus for sensing threats to survival is geared to sudden changes in environment, not to slow, gradual changes. It is important therefore to learn to see the gradual processes.
- Delusion of learning from experience: "We each have a 'learning horizon', a breadth of vision in time and space within which we assess our effectiveness. When our actions have consequences beyond our learning horizon, it becomes impossible to learn from direct experience.
- The myth of the management team – "most teams break down under pressure."

Overall, the most important detriment to a lack of systems thinking or analysis approach is the inability to accurately predict the effect of a particular inefficiency or of a planned improvement.

C.2.2 Root cause of a lack of system focus

Trahant[13] discusses the lack of process focus in business systems, where designers and operators work in functional vacuums characterised by unanticipated problems and increased cost. Roberts[14] lists other deficiencies that are limiting process thinking which include:

- Modern mining technology that encourages economies of scale and therefore reinforces the attitude that one must fully utilise that particular expensive asset;
- Poor measuring, analysis and reporting systems, that are really legacy systems from outdated management and business principles;
- Poor data collection and distribution methods that induce frustration at the flood of data resulting in little to no information;
- Use of the accounting system to measure performance instead of an activity-based accounting method;

- Corporations have no solid methodology for improving productivity.

C.2.3 Summary of the lack of integrated system focus

To summarise, a lack of a system focus on managing an operation tends to result in:

- A lack of understanding of the true causes of inefficiencies
- A lack of ability to predict the effect of improvement initiatives
- A short term view of the operation and management focus
- Gradual decrease in productivity that remains unnoticed until too late.

The performance measures are the primary tool by which management can understand the system and accurately represents the manner in which management views its goals. When performance measures focus on functions, so does management. Similarly, if performance measures are inappropriately designed, then little understanding of the production system can be engendered. This leads to the next issue: the lack of adequate performance measures as shown in Figure 6-9.

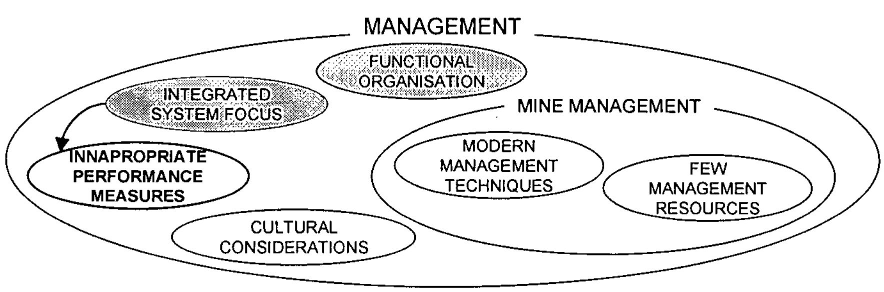

Figure 6-9: Progression of Discussion - from Integrated System Focus to Inappropriate Performance Measures

C.3 Inappropriate Performance Measures

Those who work in the mining industry are familiar with the two traditional performance measures: tonnage and mine costs. Most operations have both a cost and performance measurement system. Measurement is one of the most important tools in management since decisions on how to improve or maintain production should be based on accurate pertinent information. Traditional accounting systems are still required in most mines for financial reporting purposes in the payment of taxes or equity trading.

C.3.1 Measuring Performance Inappropriately

TONNAGE HOISTED AS PERFORMANCE MEASURE

Dietze[15], discusses how the mining industry uses the single variable of tonnage hoisted as the primary cost driver, yet he suggests that other cost drivers are better indicators of cost variance. Dietze claims that only 25 to 30 percent of the costs are driven by tonnage.

ACCOUNTING SYSTEM AS A PERFORMANCE MEASURE

In a discussion related to Activity Based Costing in an underground gold mine, Smith discusses the inappropriateness of traditional cost accounting systems for performance measurement.[16] Tipping clearly summarises the problems discussed by the authors mentioned above.[17] The traditional reporting and management mechanisms are primarily through financial systems and final output, usually measured based on the functional departments (e.g., final output for mining operations is commonly tons). Tipping lists and describes what he considers are the seven main problems of performance measurement in most businesses (only those not mentioned above are shown):[17]

- No indication of cause and effect: Performance drivers are rarely used to derive what caused the increases or decreases in performance.
- A blurring of key issues. Management teams rely on a variety of information sources. Interpreting this myriad of reports, in various formats, is time-consuming and confusing, resulting in mostly

superficial analysis. Hence critical issues may be missed due to the way the data is presented and/or the mechanism of analysis.

- Unreliable or inaccurate data. This issue deals with the common occurrence of 'ad hoc' reporting systems. Reports are commonly outputs of spreadsheets or data collection mechanisms that have the potential to produce inaccurate data.
- Time consuming and costly. The assembly of data and converting that data into reports can be costly in both time and resources.
- Results can be 'filtered'. Individuals presenting information can choose to highlight certain items, ignore, or even misrepresent others. In informal data collection and interpretation systems there is ample opportunity for individuals to report that they are performing well when the opposite may be true.
- No linkage to performance management. Mining performance measures simply report what happened, and have no link to what will be done to improve. The 'improvement' pressure is usually assumed to be obtained from the incentive system. Unfortunately, the incentive systems are set up to track traditional measures that are usually short-term objectives.

C.3.2 Root Cause behind the use of Inappropriate Production Performance Measures.

History is the primary reason this problem exists. Accounting systems and performance management systems used in the mining industry predate the information age. As is discussed below, costing systems were originally used for financial reporting purposes, and are unlikely to provide effective management information without changes. Performance management in terms of production reporting has not changed significantly in the mining industry as today's variance reports are strikingly similar to those of thirty years ago.

ONE ACCOUNTING MECHANISM IS NOT ENOUGH FOR ALL PURPOSES

Kaplan,[18] a very respected author on performance measurement systems, discusses the core issues of traditional costing systems employed by most corporations. According to Kaplan, cost systems are employed for three important purposes[18]:

- "Valuation of inventory and measurement of the cost of goods sold for financial reporting
- Estimation of the cost of activities, products, services, and customers; and (more recently)
- Providing economic feedback to managers and operators about process efficiency. "

It seems unlikely that all of the above information can be provided by a single cost measurement system.

PERFORMANCE REPORTING

Mining primarily uses monthly variance reports to measure performance. There are usually three components to mining variance reports: production, costs, and safety. These values are usually listed beside a budgeted or planned amount of costs or tonnage. For example, a variance report from Anvil Mining Corporation[19] from 1971 presents virtually the same information as an INCO variance report in 2001. This demonstrates how performance measures in mining have not significantly changed in the past 30 years despite advances in information technology or business systems in other industries. Mining companies rely on incentive systems for managing the behaviour of their employees.[20] There are not direct incentives for managers or workers to improve performance of the overall system. Poorly designed incentives systems result in behaviour contrary to the goals of the company.

C.3.3 Summary of the Performance Measure Issue

To summarise, inappropriate performance measurement systems can result in or are the result of:

- Assumptions that incentive systems alone induce the desired behaviour from employees;
- Traditional costing systems may not provide the type of information needed for all managerial decision making since they were designed primarily for financial reporting purposes;

- Performance information is reported along the vertical organisation structure instead of the system-process views;
- Performance information can be filtered, with little direction provided to a manager on how to improve.

From the above and prior discussion, the roots of the issue of performance information can be identified: the management systems, data infrastructure, and performance measures. Behaviour is frequently overlooked in management as it is assumed that incentive systems ensure that people behave accordingly. How frequently these systems (including incentives) are evaluated for effectiveness also plays a role. Mines have traditionally given priority to safety regulations, however, the published evidence (or lack thereof) suggests that management systems for production control may not have received as much attention.[21] Auditing the management system may be important, as shown in Figure 6-10,.

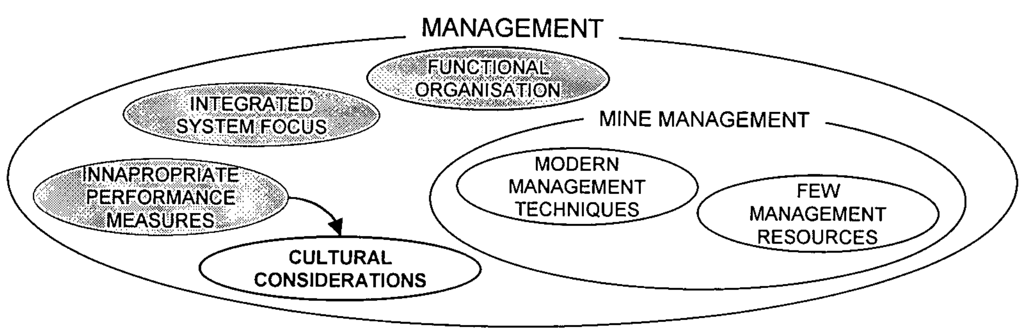

Figure 6-10: Progression of Discussion - from Performance Measures to the Incorporation of Cultural Considerations

C.4 Incorporation of Cultural Considerations

Cultural considerations are difficult to incorporate into mine management systems. Michael Hammer and other reengineering pioneers are quoted to have underestimated the importance of the cultural aspect of organisations when devising the 'Reengineering' management method[22]. By overlooking cultural issues in management systems, improvement initiatives and even performance can suffer.

C.4.1 Effects of not Incorporating Cultural Considerations in Management

According to Goodman, some mine managers rely almost exclusively on the incentive systems for gaining productivity improvements. [23] This may not result in great improvements as the culture of the organisation does not foster an active desire to improve. Managing culture is often referred to as 'change management' because in most management publications culture is discussed as being in need of change. It would be ineffective to list all the problems existing when the culture of a business is poorly aligned to its goals, due to the sheer volume of literature. The long history of the mining industry has created a complex and ingrained culture. Schaffer[24] mentions the common cultural barriers faced by managers when attempting to improve a production system:

1. **Psychological Myopia:** The tendency to view the work in ways that are psychologically comfortable and personally reassuring.
2. **Wasteful Work Patterns:** The tendency to shape one's activities so as to stay busy with familiar routines and avoid anxiety-provoking challenges
3. **Weak Performance Expectations:** Avoiding risk by asking subordinates for less than is really possible or permitting them to escape from real commitments and consequences.
4. **Misuse of Work Management Disciplines:** The tendency to be casual, careless, or cynical about work planning, measurement, and tracking procedures
5. **Invisible Conspiracy:** The Underside of Corporate Culture. The unique tangle of debilitating patterns that are reinforced by formal and informal institutional mechanisms.

A further barrier that is frequently mentioned anecdotally in the mining industry is a focus on short-term objectives. Managers tend to focus on the tonnage target for that month. This may be a factor of the mechanism by which performance is measured. According to The Standish Group[25] the failure to consider the effect of culture when implementing change is the primary source of failure for most improvement projects. Therefore, culture should be considered when implementing any improvements.

C.4.2 Root Cause for Underestimating Cultural Issues

Culture may be overlooked due to its esoteric nature, the difficulty in its management, or even due to the nature of managers in the mining industry. Cavender considers that many improvement opportunities are overlooked due to the professional inclinations of management.[26] For example, considering that most managers in mining were engineers by training, improvement opportunities are more likely to be based on technical innovation rather than social engineering.

C.4.3 Summary of Cultural Issues

To summarise, the inability to take culture into account in mine management systems can result in or is the result of:

- The difficulty in measuring cultural attitudes
- Technical focus of mine management
- Reliance on incentive systems to address cultural issues
- Little emphasis on communication and human interaction abilities
- The difficulty in managing culture.

From the above list and prior discussion, the roots of poor culture management lie in the nature of the management systems and the inherent difficulty in managing culture. Much has been published on changing culture and a considerable amount of research has been dedicated to that end in other industries. Most research on mining culture has been focused on increasing the safety culture. According to Bell[27], virtually no research has been undertaken on cultural effects on mine production.

As mentioned by Cavender above, improvement opportunities are frequently characterised by past successes.[29] Mining has had great success in applying technical improvements in the past, particularly in economies of scale. This cultural tendency leads into the next issue, namely, the over-reliance on economies of scale for continued profitability, thereby missing potential improvement opportunities brought about by alternative management techniques, as seen in Figure 6-11.

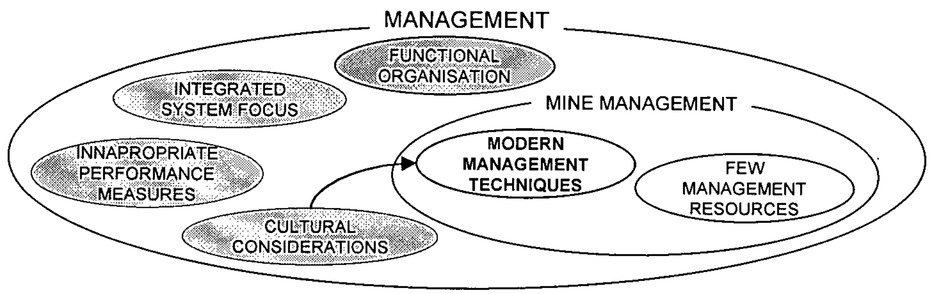

Figure 6-11: Progression of Discussion - from the Incorporation of Cultural Considerations to Modern Production Management Techniques in Mining

C.5 Modern Production Management Techniques in Mining

The issues discussed previously are managerial issues current to all businesses. The remaining discussion focuses on issues specific to mining. An important weakness in current mine management is the apparent lack of use of modern management systems. This has been an issue brought up by several authors indirectly since, as discussed before, frank discussion of mine management issues are politically difficult. Advanced management tools can range from scientific methods such as linear programming to more conceptual business models such as Business Process Redesign. Figure 6-2 shows the evolution of business systems and some of the mining industry's areas of acceptance. Some applications of operations research (OR) have been adopted, along with Total Quality Management for those companies that require ISO9000 certification.

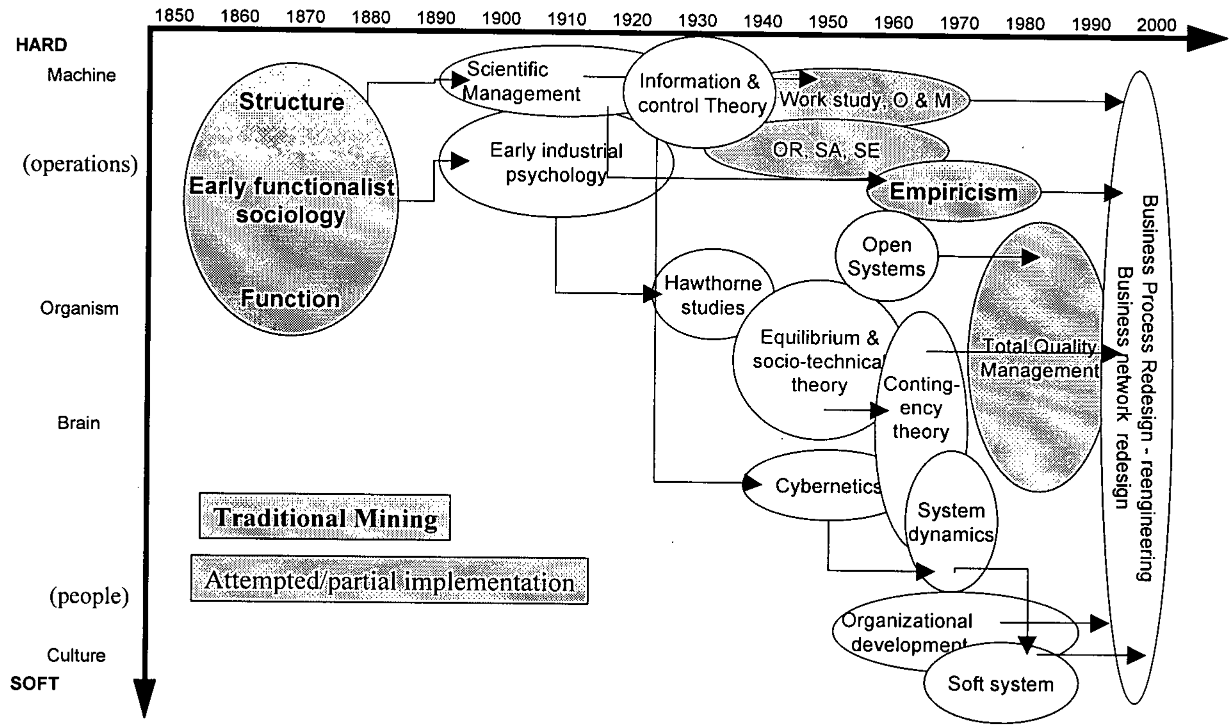

Figure 6-12: Evolution of Business Systems and Mining's Areas of Acceptance, modified after Peppard[28]

C.5.1 *Effect of Few modern Management Techniques in Mining*

The results of the lack of use of these new business systems is simply the loss of all the benefits the techniques can potentially contribute.[29]. In discussing the hurdles to the implementation of mining automation, Dasys[30] discusses how most automation initiatives fail because these improvements are usually devoid of process management improvements. Process based improvements are a key component to virtually all modern business systems. The process focus is a central aspect to the TMMS methodology developed in this thesis.

C.5.2 *Root Causes behind Mining's Lack of Management Techniques*

Pauley[31] described the attempted use of advanced management systems in a surface mine. When applying some of the management techniques in Figure 6-12, the mine manager expressed "irritation" and "tension" throughout the process of implementation. The management expected the improvement systems to be a "black-box", whereby improvements would be automatically determined through computerised simulation models.[31]

The management techniques require education and the direct intellectual involvement of employees within the mine.[31] Education and lengthy intellectual involvement consume mine employee's time, a very limited resource. Hence, significant leaning towards a black box approach has been prominent in mine culture. Table 6-1 shows a list of views of mining executives in comparison to the desired management views required for using modern management techniques. This shows obvious cultural differences. Another reason for lack of interest in new management techniques discussed by Pauley is the difficulty of transferring tools developed in other industries, into mining.

Table 6-1: View of a Group of Mining Executives[31]

Mining Executive Views		Preferred Views
Cost cutting mentality	→	Making the best use of existing resources
Functional thinking	→	Systems thinking
Strive for local optima	→	Strive optimum system
Paralysis by Analysis	→	Focused, results motivated, project management
Grand, impersonal initiatives	→	Experimentation and learning, incremental implementation
Benchmarking	→	Know theoretical and practical limits
Many performance measures	→	Meaningful performance measures

Cavender[29] considers that the mining culture is the most important factor in the use of modern management techniques. He uses the example of a traditional cost reduction project to illustrate:

- **Past success in mines**: Mines tend to rely on past initiatives at the operation or in the industry as a guide on how to improve.
- **Professional inclination**: Managers tend to search for improvements within the confines of their own profession. For example, if the mill manager has been promoted to being the overall operations manager (mine and mill), improvements are more likely to be focused within the mill. Similarly,

mines would be less likely to search for improvements in an industrial engineering sector as most managers in mining have a mining or mineral processing background.

- **Economies of scale**: Past successes in mines have included spectacular increases in economies of scale. For example, bulk/massive mining, large equipment and processing facilities, have all kept mining operations profitable. As Hustrulid[32] discusses, systematic or optimisation improvements in mining have primarily focused around exploiting economies of scale instead of modifying the mining system itself. Process improvements are not sought since economies of scale have met with such success in the past. Hustrulid also mentions the diminishing effectiveness of economies of scale as machines and operations become ever larger, compounding the need for more process improvement initiatives.
- **Education**: One of the roots of this cultural limitation is education. Scoble and Daneshmend[33] have conceded that mine engineers need to broaden their knowledge in other disciplines especially in the engineering sciences. As it is implied, education in process improvement methods is virtually never covered in any mining engineering curriculum. Professional development, either through university[34] or professionally[35], is similarly driven by industry demands and culture, which have not identified tactical management as a source of potential improvement mechanisms.
- **Negative experiences**: Attempted implementations of new management techniques have failed result in cultural resistance to these types of improvements[36]. This is the result of improper implementation techniques and a lack of recognition of the differences between mining and those industries where these new business systems were developed.
- **Information technology**: is the key enabler for most modern business systems[37]. Devine[38] clearly lays out the importance of information technology planning for competitiveness, especially how it relates to advanced business systems. Buying the technology is not enough, new methods of using the technology is where the true value lies. These systems are not black boxes. Imrie[39] describes how the information systems of most mining companies have evolved over time into a patchwork of systems. The data is too often inconsistent, in various storage formats and versions, and infrequently carries over operational boundaries.

C.5.3 Summary of Management Techniques in Mining.

To summarise, the lack of use advanced management tools in the mining industry results in or is the cause of:

- reduced information technology planning, utilisation, or recognition of its potential
- focus tends to be on short term goals, economies of scale, a preference for traditional improvements, and is often limited to the educational background of the manager.
- managers and workforce tend to be jaded by poorly implemented business systems that were applied without significant change from their original concepts usually based in manufacturing.
- The overall result is the lack of benefits that these tools bring which may include increased profitability and long-term stability

Business concepts can be well explained, documented, and discussed but developing those concepts into a functional mine management system is where the challenge lies. Once tactical management techniques have been modernised, strategic systems should be more amenable to improve. Furthermore, since management decisions at higher levels are based on decisions and information supplied from lower levels, a dependable tactical management system is needed to make effective strategic decisions. Figure 6-13 shows how this discussion on tactical management issues is completed in the next sub-section. Appendix C and Appendix G describe the use and abilities of modern management techniques, as evidence that applying those systems can result in improved management abilities. The past discussion simply reveals the issue resulting from a lack of use of these techniques.

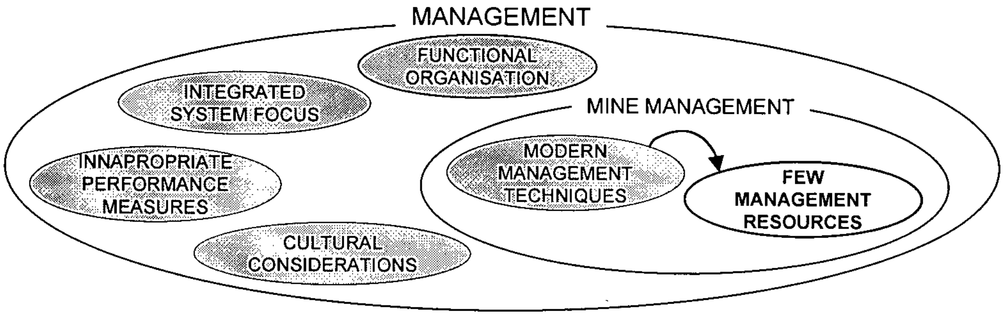

Figure 6-13: Progression of Discussion - from Modern Production Management Techniques in Mining to Tactical Management Resources

C.6 Tactical Management Resources

Direct published reference to a formal tactical mine management system was not found in the literature review. Supplementary training for frontline supervisors, isolated process improvement applications, and expert systems have been implemented at different operations. The discussion below reviews past tactical management tools for mine management.

C.6.1 Effect of Few Mine Management Resources

DATA TO FEED THE MANAGEMENT SYSTEMS

Universal Scheduling Consultants[40] (USC) undertook a 1.5 year analysis and development of a tactical management system that focused on mine schedules, benchmarks, and capacity tracking. The system called for every miner to account for the time and productive units achieved throughout their shift, including delays. This data was collected, benchmarked, and tracked. Formal scheduled meetings were to be held on a regular basis where Total Management Quality (TQM) tools were to be used to determine methods of improving the processes using delay and capacity information that had been collected. Upon a change in upper management (superintendent), relatively soon after the tactical management system was complete, the system was abandoned. Without support from the manager, who had not been present during the justification and system development, the system was dropped. One acknowledged weakness of the system was the data collection method that was too labour intensive.

INCO had identified an integrated information system that would automatically collect and calculate trends/capacities. This IS would have greatly simplified the collection, calculation, and analysis of the production information for the USC system. Several additional Mine Information Management System (MIMS) modules were purchased in an attempt to integrate all cost, maintenance, and production information into a common database, enabling the eventual use of the integrated system for tactical management and improvement.

OVERBURDENED FRONT-LINE SUPERVISORS

Mining operations rely heavily on front line supervisors for enforcing safety, workplace compliance, productivity, crew planning, maintenance choices, and a host of other critical decisions.[41] These front-line supervisors have heavy managerial burdens. Some companies may provide skills training for front-line management, however, very little has been published on this practice. Modern management techniques require education, skills at visualising the mining system and clear accountability. Increasing management's visible accountability and ability is a potential source of controversy.[42] Furthermore, the mining environment is a difficult system to manage, for example mines tend to have:

- dispersed workplaces;
- poorly understood geological conditions;
- low equipment reliability;
- highly labour intensive processes;
- supplies and output bottlenecks (main ramps, shafts, etc…);
- hazardous conditions.

The supervisors must visit the workplace (face), consuming time when underground, to ensure that the miner is working safely and efficiently. Tactical managers are also expected to manage all mechanical, manpower, workplace, and supplies resources. The managerial decisions have to be made quickly.

C.6.2 Root Causes of allocating few resources for tactical management

Due to the nature of tactical mine management, namely controlling daily, weekly, or monthly production and costs, little time can be dedicated to the systematic problems affecting the production system. Changing s TMMS can only be a long term process requiring substantial foresight, time, and strategic (non-tactical) vision.[43]

TRAINING FOR FRONT-LINE SUPERVISORS

Feilder[44] describes a demonstration project in an underground mine where leadership training for frontline supervisors resulted in increases in productivity and safety. The training sessions consisted of education in sociological techniques called leadership match, supervisory skills training, and behaviour modelling. After a two year and then five year assessment of the program's effectiveness, productivity at the mine face increased by approximately 30%, while safety incidents were reduced by more than 50%. It was acknowledged that over such an extended period of time, the additional training may not have been exclusively responsible for the improvements.

Althouse[45] describes another front-line supervisory improvement program where a series of workshops were undertaken with all supervisors at a mine, accompanied by guideline texts (for participating supervisors) in the following subjects:

- Human relations skills at work: inter-personal skills
- Managing a section: planning, time management, worker management
- Complying with safety regulations: the U.S. mining regulations were explained

- Conducting training in-house: characteristics of the adult learner, instructional methods, using visual aids, lesson plans
- Elements of management planning: operations planning and control, formal training in management practices
- Managing maintenance: building maintenance plans, tips to carry out maintenance and housekeeping procedures;
- Development of comprehensive safety plans.

None of the frontline supervisors had received formal training in any of these topics prior to the workshops. The benefits of the workshop training were limited. According to the author, the observations of the study suggested that there was little reason to expect the area foremen to change their behaviour or work patterns, unless explicitly directed to do so by the manager.[45] Training was seen as cumbersome and the texts were never read.

Bell[27] describes a similar improvement program sponsored by the U.S. Bureau of Mines and undertaken at the Hecla Mining Company. The president and mine manager supported the program that focused on creating team-based problem solving as part of the tactical management system. Five years after instituting this program, a 50% improvement in mine productivity and 78% improvement in safety was partly attributed to the program (other efforts to improve productivity and safety were undertaken over that 5 year period). Bell, Althouse, and Feilder referred to the front-line supervisor as in need of additonal training and resources to accomplish their allocated tasks.

WORKPLACE AS A NECESSARY VARIABLE IN MINE MANAGEMENT SYSTEMS

Grayson[46] describes a mine manager's primary responsibility as "to manage the productive output of men and machines in the most cost effective way subject to a host of constraints" which can be categorised as:

- Reliability and availability (utilisation)
- Changeable and hazardous conditions

- Regulation and work agreements
- Isolation
- Design limitations
- Self imposed limitations

The unpredictable and reduced asset or workplace utilisation, as mentioned above, is a common source of focused mine management efforts at a tactical level. Renstrom[47] discusses the use of a simulation model used to analyse various scheduling scenarios on the cut and fill processes at a Boliden mine in an attempt to optimise asset (equipment, labour, and workplace) utilisation. This prototype process control mechanism is a successful example of a tactical management tool that uses production and delay information for system improvement. Vary[48] describes a similar tool which tracks the activities and delays in a cut and fill mine in order to identify areas for improvement. The focus of this tactical management tool was the motivation and productivity of the crews.

NO METHODOLOGY TO CREATE A TMMS

The above discussion attempts to show some published evidence of research ontactical management systems. There is little evidence of an integrated formalised methodology for tactical management system development. An integrated formalised methodology is a set of instructions necessary to develop a TMMS. This lack of methodology may stem from the fact that the importance of the development and maintenance of a TMMS is receives little recognition.

One purpose of this section is to show a lack of the existence of adequate management tools. It should be noted, however, that this is not a criticism of the industry or those managers currently working in mining operations. Little academic or professional focus has been dedicated to the design or analysis of integrated tactical management systems. There have been some isolated yet successful applications of modern management tools in the past decade.[49] Mines at present are not without tactical management systems since a mine would be unable to function or maintain safety standards without such systems. The points raised in the discussions of this subsection relate primarily to the issues related to these systems (structure, modernity, and flexibility). Planning and structure are important for any tactical management system. According to Soganich, the following disadvantages should be expected if planning and structure of a TMMS are inappropriate:[50]

- Ambiguous accountabilities for maintaining or improving production
- Reduced ability to identify systematic process issues
- Short-term outlook on production
- Inability to comply with the plan or budget
- Many production corrective actions
- Inaccurate production reports ("paper tons")
- Confused production recording; (multiple data entries, sources, data stores, and report versions)
- Decisions made on unreliable and old information

LACK OF TIMELY TACTICAL INFORMATION

A more focused reason for the lack of TMMS may relate to the limited accurate information that is available for decision makers.[51] Detailed specific production information is difficult to collect, compile, and use since there are many activities. These activities are complex and subject to frequent changes throughout the shift. These changes are often as a result of the foreman's decisions. Several surface dispatch and underground communications suppliers provide technology that can collect and automatically interpret production information[52]. These information systems are not industry norms, as much of the incentive, productivity, and process control measurements are still undertaken by paper-bound labour intensive mechanisms that do not provide the information in a manner needed for tactical management (productivity, delays, inputs, organised according to accountability and process).

C.6.3 Summary of Issues regarding few mine management resources.

To summarise, the lack of use of structured formal tactical management systems in the mining industry results in or is the cause of:

- A lack of information despite the abundance of data;
- The difficulty of supervising the work or collecting incremental production or process information of the activities being performed (especially underground);
- Overburdened front-line supervisors;
- Few instances of training/education (published evidence is lacking);
- Desirability (or lack thereof) of having one's decisions be more visible, and being more accountable to those decisions;
- The difficulty of accurately predicting, planning, and managing a system subject to so many unknowns and unreliable systems;
- Lack of methodology to develop a TMMS.

As the most important part of the overall mining process, the production system warrants the most comprehensive and involved performance monitoring system. However, as discussed, few tactical management tools exist, relating to the various issues mentioned in this appendix.

C.7 Synthesis

The primary output of this appendix is the identification of the issues which a new TMMS design should address. The broad categories of the issues of current management mechanisms include:

- Effects of the functional silos;
- Recognition of the systems elements of an operation;
- Poor performance measures and mechanisms;
- Disregarding the influence of culture;

- Inadequate use of modern management systems;
- Shortage of information and adequate measures;
- No formal tactical management structure.

The following appendix will follow the design, implementation, and assessment of a methodology developed to design a TMMS system that attempts to address the issues identified in this Appendix.

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Appendix D. Thesis Evolution

The evolution as discussed in this Appendix, charts the research directions which were explored in seeking to meet the objectives of the thesis. The ultimate evolution (decades from now) of this work will be to support the introduction of automation and robotics into mining. Aiding the implementation and use of advanced technology requires a production system that is well understood and tightly controlled. Increased control over the production system can be achieved by introducing more effective front-line management.

Figure 6-14 shows how the limited success of advanced technology in mines has tended to be due to a lack of focus on the mining system, whereby the design of the technology did not fully incorporate the issues involved in managing the mine's production system. Therefore the objective should be to design and implement the ideal mining system and if the technology is appropriate, it can be included, otherwise a sub-optimal system would result. However, designing the ideal mining system is too broad. A more feasible option would be to develop a methodology resulting in a management system that aids the mine to achieve its goals. These three phases of concept evolution are discussed in this appendix.

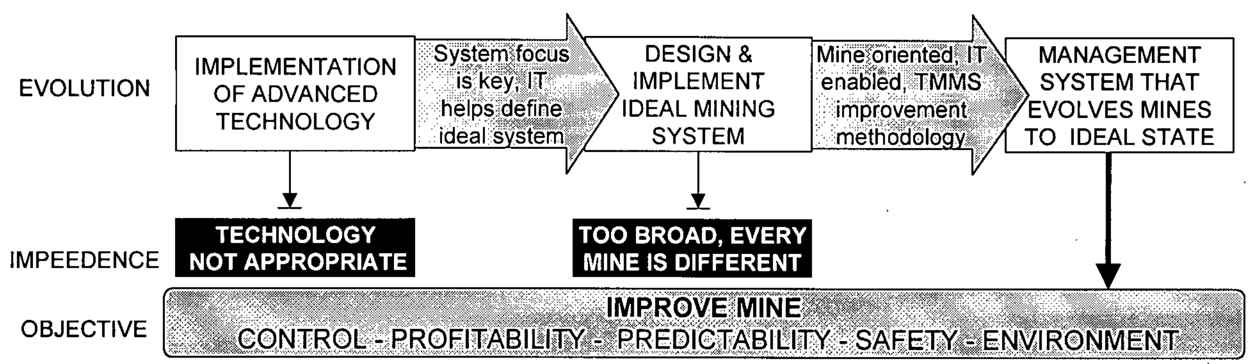

Figure 6-14: Thesis Concept Evolution

D.1 Technology Implementation

The original concept behind this body of work was to develop a methodology that would aid the integration of advanced mining technologies (mainly automation) into mines. This was first inspired by personal experiences with INCO Mines Research's Mining Automation Program (MAP). The group leader's vision was to fully automate an underground mine.[1] Despite well recognised prototype success, very few pieces of automated equipment as yet have been successfully implemented into the production systems of INCO mines.[2]

Substantial background research in technology implementation strategies and in-depth analysis of the technology challenges in a mining environment, changed the focus from the technology to the system where the technology was being implemented. The goal of any change should be to create the ideal system, not to implement a piece of technology into a system in an attempt to fully utilise the technology (sometimes to the detriment of the system). Therefore if the ideal system requires such technology, then it should be used.

Background research also indicated that this ideal system can be determined and would be managed through information technology. Thus one should first identify the ideal system then implement the is most appropriate technology. Resistance by mine employees and sub-optimisation will result if a piece of technology is implemented into a system that cannot take advantages of its benefits. Figure 6-15 shows the first phase of this evolution within the context of the overall concept.

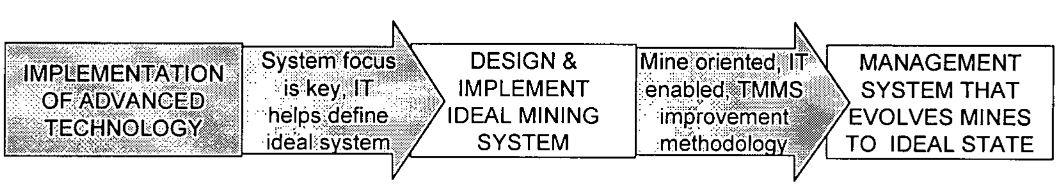

Figure 6-15: First Phase Leading to the Identification of the TMMS Concept

D.2 Design the Ideal Mining System

An extensive literature review indicates that the most common approach used by the manufacturing industry is to design (or redesign) the processes to align along set goals such as increased profitability, flexibility, consistent and positive cash flow, maximising throughput, environmental compliance, and/or safety. If advanced technology is included in the final 'ideal' process, then it should be implemented. Therefore advanced technology is not the change element, it is an element that enables the change to be made. However, in order to reengineer these processes, the current and ideal system must be clearly understood and controlled.

Operations management techniques such as reengineering were developed in manufacturing and service industries to identify and implement the optimal production management system. A potential option for improving the production system in mining is to apply reengineering theories to determine an ideal mine management system. Two issues posed barriers establishing a standard mine management system. Firstly, the topic was too broad and unrealistic in its goal of reengineering all possible mining systems. Each mine is different in technical and cultural terms and a common reengineered management structure may not be suitable for all mines. Secondly, many of the reengineering tools that had been implemented in mining did not take into account the industry's particular culture or lack of adequate IT infrastructure. Figure 6-16 shows how these impediments further developed the research direction of this thesis.

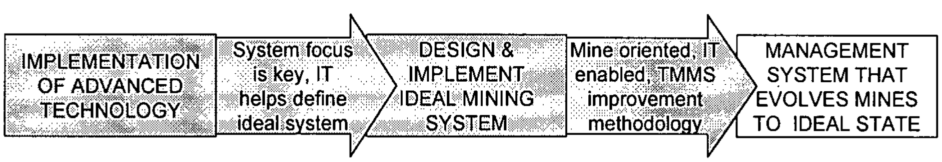

Figure 6-16: Second Phase Leading to the Identification of the TMMS Concept.

D.3 A Tactical Mine Management System Leading to the Ideal Mining System.

Appendix C discusses how the production control and management mechanisms in many mines are in need of modernisation. Several issues are identified related to the industry's inadequate IT infrastructure, use of modern management techniques, and audits of management systems.

The manufacturing industry profits from information rich environments, where work processes can be monitored and controlled electronically. Using such automated production information management, techniques can be applied such as operations research (OR), the theory of constraints (TOC), and other process improvement tools. Recent technological acquisitions by mining companies in terms of enterprise integrating networking systems have created the potential for creating inexpensive, easily accessible and timely information. Easy access to information should enable mining operations to embrace the new process optimisation techniques developed and perfected in the manufacturing industry. Unfortunately, several constraints to these techniques appear to exist. Firstly, not all of the techniques are applicable in every situation. Hence, the particularities of the techniques must conform to the system in which they are applied. A second constraint to such optimisation methods is that they are not applicable to mining in their pure forms. The mining environment is different from manufacturing in terms of resource consumption and planning, production control, manpower requirements, process inputs, and culture.

Modifications to manufacturing management techniques are required. The development of a methodology that includes modified-for-mining management techniques is the focus of this thesis. It should be noted that many mining companies and international mining research institutions are beginning to focus on this 'process' approach to overall system improvement and recognise that IT is the primary enabler of the change. However, the key to the success of other industries was that it was not an individual business tool, technology, or bit of information providing the dramatic improvements, but the synergy derived from using combinations of all three.

Therefore, the evolution of this thesis was motivated by the desire to develop implementation methodologies to aid the implementation of technology. Management techniques such as reengineering were possible frameworks from which to build the ideal mining system which would allow the full use of advanced technology. The final evolution in the concept is toward a methodology that would result in a management system that steers changes in the mining system toward the development of the ideal mining system.

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Appendix E. Foundations of Production Management

Appendix D discusses the evolution of the concept for this work. This Appendix establishes develops concept to develop a methodology that produces a TMMS integrating information technology and modern management techniques. The methodology should also recognise the lack of IT infrastructure and awareness of alternative management techniques in mining. Therefore the challenge addressed has been to:

- identify the most appropriate management techniques in other industries and in mining
- modify the techniques to suit underground mining
- characterise the IT infrastructure needed for such a TMMS.

Figure 6-17 shows how this discussion is associated to the other thesis components. As can be seen, the evolution of productivity management in other industrial sectors is reviewed so that industry best practice can be determined. Production management techniques in mining are also considered since it is important to understand the current state fully before considering a new design. These two issues are discussed in this Appendix. The key aspects that make mining unique and the alterations necessary for the successful application of modern management techniques are analysed in Chapter 2 . These various discussions are used in Appendix E in the distillation of a framework for a TMMS.

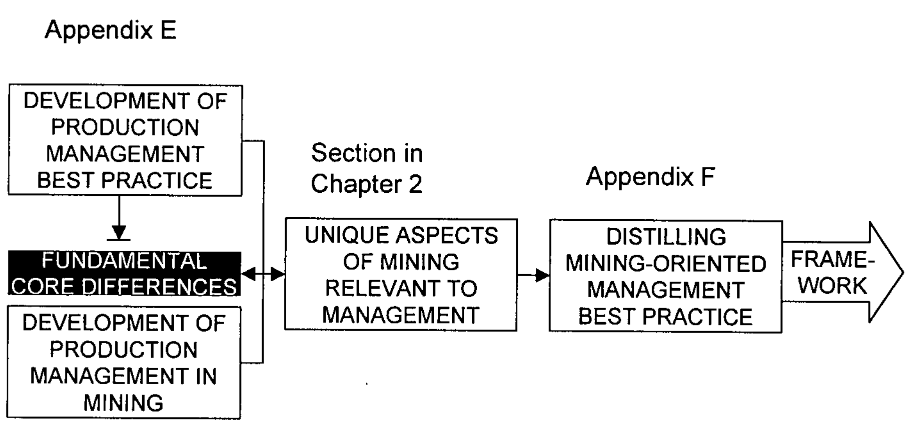


Figure 6-17: Relationship of Analyses in the Formulation of a Framework.

E.1 Productivity Management

The origins of productivity management lie in the industrial revolutions that have evolved in the last 300 years in the Western world. Michael Hammer theorised in 1993 that the great improvements in the evolution of the corporation, and hence, human productivity, were in four phases[1]. The initial phase began with Adam Smith's Division of Labour theory. The next phase was the creation of large bureaucracies to manage the large corporations formed in the 1820s during the construction of America's large railway networks. The third phase was epitomised by the division of large corporations into small regional divisions by General Motor's Alfred Sloan. This enabled a large corporation to provide regional service and marketing abilities while maintaining the advantages of a large manufacturer. Corporate managers were therefore able to manage the large company by reviewing financial data coming from the divisions. The final phase in the evolution of the corporation was the development and widespread use of industrial engineering tools for planning and control. The primary operations management tool developed over this period is basically the application of the scientific method to improve industrial activity. It was the micro computer and associated networks that then allowed these tools to achieve large gains in intellectual, managerial, and industrial productivity.

E.1.1 Early Production Theorists and Theories

Modern operations management can trace its roots back to the pin factory as described by economist-philosopher Adam Smith in his "Treatise on the Causes of the Wealth of Nations."[2] In this series of essays he espoused several theories of management such as the principle of the Division of Labour. This was derived from the observation that a number of specialised workers, each performing a single step in the manufacture of a pin (which was the term for a nail at that time), could make far more pins than the same number of generalists engaged in making whole pins. This simple tactical management philosophy, of breaking down work into a series of manageable activities, allowed the development of economies that enabled the West to dominate the World's economy into the present.

E.1.1.1 Origins of the Corporation

The growth of the United States into its Western frontier and the transportation networks required, particularly the railroad, brought about the development of the bureaucracies of large organisations. Corporations spread over large distances required bureaucracies that would allow them to centralise strategic decision making while allowing informed local managers to make decisions involving day-to-day operations. These railroad companies were given land-use rights, allowing them to develop the resources in the areas though which the railroads traversed. These rail companies would form smaller companies that were associated through a common diversified corporation. Organising such a large company resulted in massive increases in bureaucracies that produced and analysed information so that informed business decisions could be made.

The next major phase of the development of manufacturing were the advances made by the early automobile pioneers namely Henry Ford and Alfred Sloan (while working for Chrysler). Ford built upon Smith's Division of Labour by creating a moving assembly line, where the work of each specialist was brought to him. Sloan, as president of GM, further enhanced Ford's system by decentralising divisions further into management specialisation. For example, according to Sloan, corporate executives needed expertise in mainly financial areas, not engineering or manufacturing. This created the functional departments where expertise such as engineering, operations, or administration was in more formalised organisational units.

E.1.1.2 Industrial Engineering

Use of scientific method by individuals throughout England brought production management one step further. This was a relatively uncoordinated group who were aspiring to derive increased profit from their stockholdings. Charles Babbage (1791-1871) is often credited with developing the early computer and wrote "The Economy of Machinery and Manufactures", which is considered to be the first work on operations management.[3] At the end of the nineteenth century and the beginning of the twentieth, a body of management knowledge began to emerge as a result of the efforts of several individuals, mainly Americans including Frederick Taylor, Henry Gantt, Frank and Lillian Gilbreth, and Harrington Emerson.[4] It is interesting to note that a key figure in the development of modern management theory was the French mining engineer, Henri Fayol.[5] In 1925 Fayol proposed that the manager's job was to plan, organise, command, co-ordinate activities, and control performance. Fayol's principles of management were:[6]

- Specialisation of labour: encouraging continuous improvement in skills and methods.
- Authority: the right to give orders and the power to exact obedience.
- Discipline: forbidding slacking, bending of rules.
- Unity of command: each employee has one only one boss.
- Unity of direction: a single mind generates a single plan and all play their part in that plan.
- Subordination of Individual Interests: when at work, only work things should be pursued or considered.
- Remuneration: employees receive fair payment for services.
- Centralisation: consolidation of management functions where decisions are made from the top.
- Scalar chain (line of authority): a formal chain of command running from top to bottom of the organisation.
- Order: all materials and personnel have a prescribed place, and they must remain there.
- Equity: equality of treatment (but not necessarily identical treatment)
- Personnel tenure: limited turnover of personnel. Lifetime employment for good workers.
- Initiative: thinking out a plan and executing it.
- Esprit de corps: harmony, cohesion among personnel.

As can be seen, these principles have changed relatively little over the past century. The difficulty remains the same: developing the measures, procedures, and mechanisms to allow all these things to happen.

The work of these pioneers was aided by the American Society of Engineers that eventually became the Society for Advancement of Management. Periods of resistance by organised labour to the concept of scientific management permeated the development of this field of study. The most important period of resistance was in the 1920s where poorly trained "efficiency experts" used pseudo-scientific methods of analysis, mainly to find cost savings for management, without truly understanding the processes that were suggested for change[7]. A proliferation of efficiency experts and their harmful activities caused a widespread disillusionment of the field of study and eventually caused the term management science to be replaced with "operations research" and "industrial engineering". It is interesting to note that a proliferation of modern day "efficiency experts" has for the past decade applied a form of reengineering to the point where the media tends to relate the term "reengineering" to corporate greed and a rapacious business community. Most management theorists have also begun to refer to reengineering as Business Process Redesign/Design (BPR or BPD).

E.1.2 Modern Production Management

The more recent history of production management can be characterised by increases in competition and the ubiquity of computers. The use of computer controlled machines allowed factories to be more automated. Computers also facilitated the reduction in bureaucracies that held the large corporations together as many of the tedious tasks of data processing are now automated. Competition for customers seeking quality and price created the need to maintain close control and measurement of productivity and product reliability. Competition and computers were the catalysts that enabled the expanded use of tactical management tools. Quality management, logistical planning and control, new accounting methods, and overall business reengineering philosophies were the major developments in production management. These last two developments, new accounting and business redesign, are discussed in depth as they are considered to be particularly important when discussing the future of production management in mining.

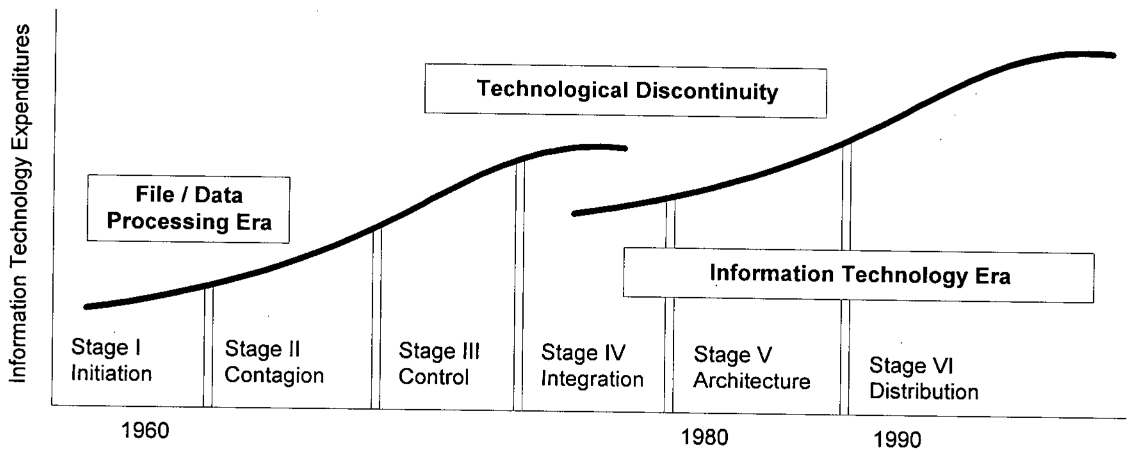
E.1.2.1 Basic Improvement in IT: the Database

The improvements in management tools are frequently associated with developments in information management.[8] The development of relational databases allowed for improved analysis and communication of data. Traditional systems were called file processing and when computerised, used their own data sets. Therefore, if the same data was required for another application, then the data had to be re-entered into a separate data file for each application. The database approach uses data modelling and systems planning to develop a common repository of data which all applications can share. The data has to be formatted in a fashion allowing all applications to function. Table 6-2 reviews the disadvantages of file processing and the advantages of the database approach. Figure 6-18 provides a view of the evolution of information technology over the past four decades.

Table 6-2: Comparison between Traditional File Processing Data Handling and the Database Approach[8]

Disadvantages of File Processing	Advantages of Database Approach
Uncontrolled Redundancy When each application has its own files, the data needed to be re-entered into disparate applications.	Minimal Data Redundancy A single repository of data is the core of a database.
Inconsistent data When the same data are stored in multiple locations, inconsistencies in the data are inevitable.	Consistency of Data By eliminating redundancy, inconsistency is reduced.
Inflexibility The file processing system effectively reports only those reports that were anticipated in the original design.	Integration Data Within each database, data models are created that allow data entities to be linked to each other through common attributes.
Limited data sharing Each application would usually have it own files and format that may not have been useable by other applications	Sharing of data All authorised users have the ability to extract the data so that everyone is using the same information.
Poor Enforcement Standards As each organisation and application was unique, few standard data modelling rules were defined.	Enforcement Standards Database management theory and a centralised approach allow for effective standards.
Low Programmer Productivity As the various data formats were different, a programmer would have to write different code for each application.	Ease of Application Development Since the data formats and models are well defined, far less time is needed to develop applications.
Excessive Program Maintenance Descriptions of files, records, and data items are embedded within individual application programs, therefore any changes would require considerable rework.	Reduced Maintenance As long as the data formats and models remain intact, changing elements within the database is relatively easy.

The costs of the database approach include new specialised IT personnel, the need for backing-up mainframe data, and organisational conflict.



Stage I: Initiation. Computer data processing is introduced.

Stage II: Contagion. Computer uses spreads rapidly, automating basic applications.

Stage III: Control. Management institutes control mechanisms to stem the rapid escalation of data processing costs.

Stage IV: Integration. Organisation seeks to integrate stand-alone applications.

Stage V: Architecture. Organisation develops common data models to support current and future applications.

Stage IV: Distribution. The enterprise distributes its data and processing throughout the organisation.

Figure 6-18: Stages of Growth in Information Systems[8]

E.1.2.2 Total quality management

From the seventies through to the nineties, American manufacturers were faced with the encroachment of foreign manufactured goods that were usually of better quality, more practical and cheaper. High quality, imaginative products were becoming the norm. Foreign competitors were using different management philosophies to develop management systems that created manufacturing systems resulting in higher quality at lower cost. These philosophies, called total quality management (TQM), consisted of both hard and soft methods for improving the production and control system. Early developers of TQM include American quality experts such as Joseph Juran and Edward Demming who applied their concepts in the 1940 and 50's Japan. [9] Their efforts aided the Japanese manufacturing industry to gain a large market share in the West. TQM concepts were largely rejected by Western manufacturers until the mid-1980s.[10, 11] The basic tenets of TQM include[12]:

- Visionary and inspiring leadership
- Teamwork
- Risk-taking to make improvements
- Emphasis on training
- Understanding the underlying processes that make up the system
- Use of statistics to evaluate processes.

E.1.2.3 MRP to ERP

TQM forced a re-visitation of traditional industrial engineering (IE) tools which were at that time focused on the processes that make up the system, not the management or control of the support mechanisms. In the 1980s, computers were used for solving complex planning and scheduling using IE algorithms. Master production scheduling was formally established by the early 1980s in following the tenets laid out in Joseph Orlicky's 1974 book Materials Requirements Planning (MRP)[13]. Figure 6-19 shows the MRP closed loop system popularised by pioneers such as Oliver Wight.[14] MRP lead to the development of MRPII then to enterprise resource planning (ERP) by the mid-to-late 1990s. Eli Goldratt, conceived an offshoot of MRP, called the Theory of Constraints (TOC).[15] TOC has proved superior to traditional manufacturing and industrial engineering optimisation tools when applied to a complex production system.[16] Despite TOC's promise of better results, it has not been adopted to the extent of MRP.[17] Other manufacturing scheduling initiatives also were slow in being accepted such as Just-In-Time manufacturing (JIT). These were only adopted several years after their widespread acceptance in the Japanese manufacturing industry.

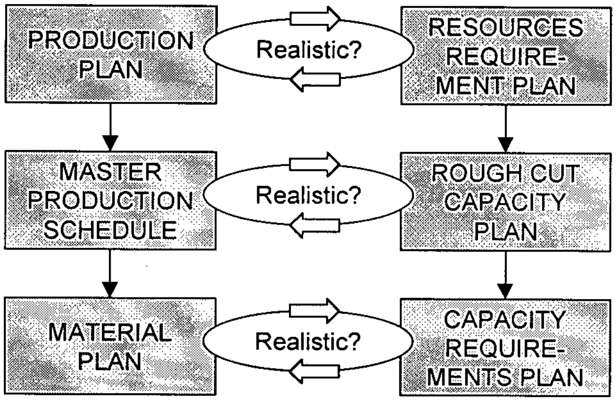


Figure 6-19: Closed Loop MRP[18]

E.1.2.4 Activity Based Costing

American manufacturers were unable to regain their absolute dominance over their own markets, even following the general acceptance of the TQM philosophy ,the partial adoption of JIT, and other operations management tools. Business leaders began looking at other causes, such as how accounting information may be inappropriately applied in the decision-making processes. In the early 1980s, many companies began to realise that their traditional cost accounting systems induced decisions detrimental to the company.[19] Cost structures were changing where overhead and indirect costs were increasingly displacing the traditionally dominant labour and material costs. This was primarily caused by the increasing variation of products and services offered, along with new technologies. Additional factors also related to the level of competition faced by many companies, where the margin of error could induce severe profitability fluctuations.

Johnson and Kaplan[20] were the first to suggest reporting costs to decision-makers along process lines as opposed to cost elements (labour, materials, etc…). ABC had been suggested as a accounting method than traditional financial reporting systems long before the large data requirements that make this method feasible were available[21]. Information systems were not yet widespread and therefore data was expensive to collect and analyse. Enterprise information systems were the key enabling technology behind ABC, however, an even more popular yet controversial business improvement method would take advantage of this new cheap source of data, and was known popularly as reengineering.

E.1.2.5 Reengineering – BPR - PI

Simply stated, Business Process Design (BPD) may be defined as the fundamental rethinking and radical redesign of business processes to bring about dramatic improvements in performance. This method is typically processed-based where errors incurred through handoffs between functional departments are eliminated by structuring work and accountability according to processes. This management tool has also been referred to as Reengineering, Business Process Redesign (BPR), and Process Innovation (PI). The seven principles that sparked a decade-long attention to this management method are:[22]

- Organise outcomes, not tasks
- Ensure that those who use the products of the process have a say in how the process is performed
- Subsume information processing work into the real work that produces the information
- Treat geographically dispersed resources as though they were centralised
- Link parallel activities instead of integrating their results
- Put the decision point where the work is performed and build control into the process
- Capture information once and at the source

Large amounts of experience-induced changes and evolution has refined reengineering. Many authors discuss the low-level operations management tools used in reengineering and even more discuss how to successfully implement this difficult improvement method. This management technique is the culmination of the tools, thought and productivity technology of the past century. The many tools used in BPR include:

- Project management tools
- Co-ordination tools
- Modelling tools

- Business Process Analysis
- Human Resources Analysis and Design,
- Systems Development

Many researchers have commented that reengineering is simply a regeneration of existing management systems. Figure 6-20 shows the intellectual inheritance of reengineering, where the reasoning and technical aspects of many different management techniques are part of the foundation for BPR. What makes this new management technique so powerful is the use of IT in its application.[23] Information technology has enabled the development and widespread success of modern management tools.

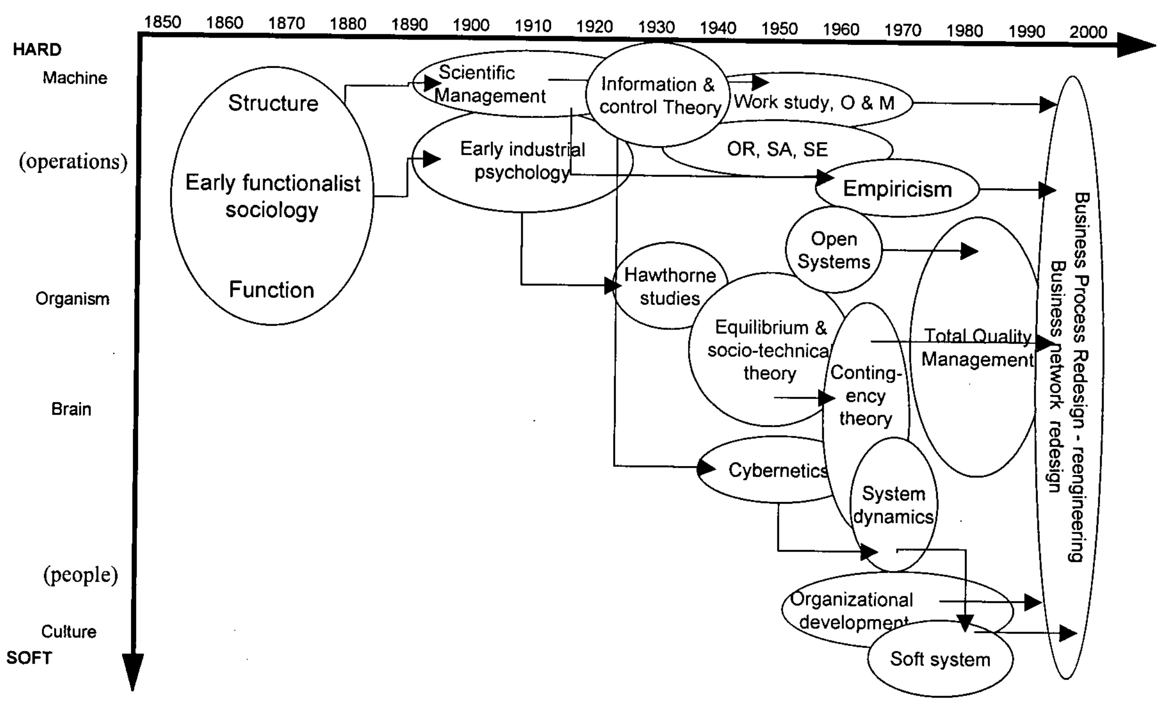


Figure 6-20: Intellectual Inheritance of BPR, Modified after Peppard[24]

E.1.2.6 Overall Enabler: Information Technology

In the mid-eighties, Porter (developer of "Porter's five forces of competition") referred to IT as enabling a revolution in businesses.[25] Porter discussed how, before the IT revolution, most of the progress principally affected the physical component of what businesses do (build, assemble, excavate). Information technology is now advancing faster than the technologies for physical processing. However, the technological transformation is expanding the limits of what companies can do faster than managers can explore the opportunities.[25] Since the eighties, many companies have harnessed the power of IT, using the tools mentioned previously. IT is still in the process of penetrating the mining industry. The evolution of mine production management, however, has yet to undergo the IT-use revolution experienced in other industries.

E.1.3 Synthesis of Production Management Best Practice.

This Appendix resolved to uncover how production management best practice has evolved over time and to focus on the important developments. Figure 6-21 summarises a chronology of modern management evolution. The early pioneers of production management had to contend with the rapid expansion of both technology and market economies. The period from Smith's division of labour to Taylor's use of science in management (industrial engineering), dealt with increasing productivity. Industrial engineering developed into a wide-ranging field to include logistics and human factors. However, information technology driven by increasingly more powerful and less expensive computer systems would allow the great advances in production management witnessed in the last quarter-century. Cheap computational power facilitated the use of IE. The performance information from the production systems enabled a more detailed analysis and closer control over production systems enabling the use of MRP and TQM. Linking production databases (production information) with support databases such as accounting (cost information) enabled the development of ABC. Reengineering, as shown in Figure 6-20, was the conglomeration of all these systems whereby the ideal system is designed and implemented using any production management or technology available.

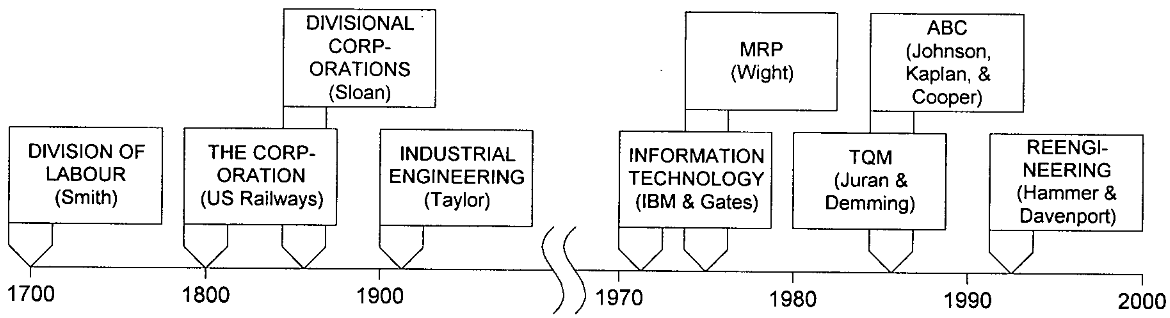


Figure 6-21: Best Practice Production Management Timeline

Most of the above tools have not been successfully implemented into mine production management. As was mentioned previously, there are certain aspects about mining systems that impede the effectiveness of these management techniques from being widely successful in mines. This Appendix aims to help derive a framework for an alternative TMMS, it is important to understand the how the current state of mine production management evolved and currently exists.

E.2 Mine Production Management.

The previous section highlighted the components of production management that should benefit mining. Before proposing a TMMS methodology, the current state of production management (PM) and how it has developed is analysed.

E.2.1 Early Mining

Georgius Agricola's De Re Metallica, first published in the seventeenth century, was the first mining engineer's 'handbook' and was used as a textbook for many centuries.[26] It discusses the management of mines and mine production including crew management, financial issues of the era, and technical aspects of extracting metal from the ground. It was functional until the later half of the twentieth century, when scientific processes became far more advanced than the technology presented in the book.

The development of new management techniques were indistinguishable from the change arising from new technology. For example, upon the introduction of the first pneumatic drills in the late 1800s, as many as ninety percent of miners found themselves unemployed[27]. Little anecdotal or factual evidence exists of mine managers actively developing new management techniques. One example of the use of scientific methods to improve productivity of a core mining process is that of the Swedish Mines Authority between 1760-1770. [28] This state-funded research improved the ergonomics of the hand-drilling process, making Sweden the world's rock drilling expert. Even following the introduction of the pneumatic drill in the late 19th century, the hand drilling process was so well designed that hand drilling was being used in Europe up to the first World War.[28] This method of research was popularised by F.W. Taylor, and became known in the industrial engineering field as Motion Study, over a century after being introduced to mines.[29]

E.2.2 Transformation of Work 1880-1930.

In a comprehensive discussion of miners, engineers, and the transformation of work in the Western mining industry from 1880 to the 1930, Hovis and Mouat provide a chronology of change, both technical and organisational that transformed the mining industry in the early part of this century. [30] The essential element of this phase of evolution was the shift from reliance on the mechanic and miner to a professional engineer. The main driving factor for change in this period was the widespread depletion of high grade deposits, increasingly competitive markets, and the adoption of new mining methods, tools, and mineral processing technology.

From the 1500's to the late 1800's, the miner was an artisan whose skill was founded on apprenticeship and practice. A miner required good judgement as well as industriousness, with skills passed down from father or fellow workers and "jealously guarded." [30] As the size of operations grew, then mines applied Smith's theory of the Division of Labour, however, the miner was usually capable of undertaking a variety of functions.

According to Hovis and Mouat, mining technology developed faster than downstream activities such as milling, transportation and marketing. [30] By 1870 technologies such as machine drills, high explosives, powered hoists, and pumps were used to mine deeper and with greater speed, however, the need to mine selectively worked against these developments. Mining had to be selective because the milling was slow and the concentration process was usually limited to gravity separation. Hence, most mines of the time were high-grade deposits, where mining had to remain on a small scale when removing ore, and where picks and bars were used to remove the ore from the face. Thus the core transition from hand to machine drilling was a gradual process that evolved from 1880 to 1910.[30]

Emerging into the 20th century, a drill crew would not only be drillers but mechanics, drill pattern designers, logistics (nipping or delivering consumable supplies), and blasters. An external change forced a de-skilling of miners. New metal products and inventions requiring electricity created a demand for increased metals, especially copper. Larger mines were needed to fulfil demand, therefore lower-grade massive deposits began to dominate. These mines began to resemble factories, where specialised people and equipment were used in relatively continuous operations. Equipment was no longer repaired by operators whilst specialised drilling crews loaded and shot the rounds. This specialisation can be seen as equivalent to Smith's Division of Labour. The complexity of continuous operations required centralised control therefore engineers began to be responsible for the success of the mine. However, relatively few changes in the levels of employment were caused by these changes. Until the 1920s' the workforce increased in direct proportion to output. The advantage of using these methods was to enable the mining of lower grade but larger deposits. Economies of scale were enough to offset the increases in the cost of the new machines and technical experts. However, it was not the new machine alone that enabled the huge increase in productivity but the integration of labour and machinery into a single unit geared for mass production. [30]

The use of scientific management methods to control mining costs increased the importance of the engineer. The new demographic of workers: specialised miners in specific tasks that were to be organised by the engineer, required new incentives and payment methods. Contracting and the bonus incentive systems were needed for each process. Mass mining and milling techniques, as well as the successful application of engineering principles to the organisation of labour, integrated both people and machines into a controllable engineered system. [30] Mines and their unions fought every innovation that tended to dilute the skills needed to mine or that shifted payment from daily work to piecework. [30] The incentive system was the primary source of production data and control. Therefore incentive data had to be measured accurately so that the miners were paid what was due. Engineers would continue to dominate the intellectual aspect of the success of the mine until the end of the twentieth century through a continued trend toward mechanical technology, diverging somewhat from scientific management methods.

Hoover, a well respected authority on mining engineering (and a former president of the United States), listed the five major factors that influence the output of a mine as:[31]

- Cost of equipment
- Life of the mine
- Mechanical inefficiency of patchwork plant
- Over production of base metal
- Security of investment.

Note that many of these factors are still important to mine management, although few focus on the tactical issues of management. The central factor in tactical management was the efficiency of workers. The mine officers' (supervisory staff) primary tasks were to control, stimulate, and inspire the "men" (miners). The efficiency of the man was considered to be a factor of three variables: skill, intelligence, and application. Note that training or standard procedures were not yet considered to be a factor. Furthermore, social concepts of the time were not egalitarian. For example, "two to three men …of a low mental order, such as Asiatics and negros" were equal to one white man.[31] This example of lack of social equity downplayed the important effect that training and management played in mine productivity. This is an important factor when now considering the role of mining in the process of globalisation.

Frontline management was often poorly educated and infrequently able to write legibly, making the collection of data difficult. Committing the information to memory was at times inaccurate. In order to overcome these difficulties, reports in the form of punch-cards were used to keep track of the number of men, sticks of explosives, tons and various other variables.[32] This data was used primarily for the calculation of incentive rates. Run charts of the productivity of each miner was sometimes used to instil rivalry, in getting miners to work harder; "to get mining costs as low as is compatible with good mining it is essential to instil a healthy rivalry among men and let them know that the mine superintendent and everyone in authority on the job, knows how much work they are doing."[32]

E.2.3 Post WW II: Economy and Technology

A new, rapidly expanding economy at the end of the second World War resulted in increased demand for minerals. New metals came to the forefront, such as aluminium and uranium. New technology and increased demand for fossil fuels stimulated the development of longwall machines in Britain. The massive increases in productivity brought about through the use of larger and more complex machines resulted in considerably more output per man. Figure 6-22 shows the increase in miner productivity over time and the influence of various technological improvements.

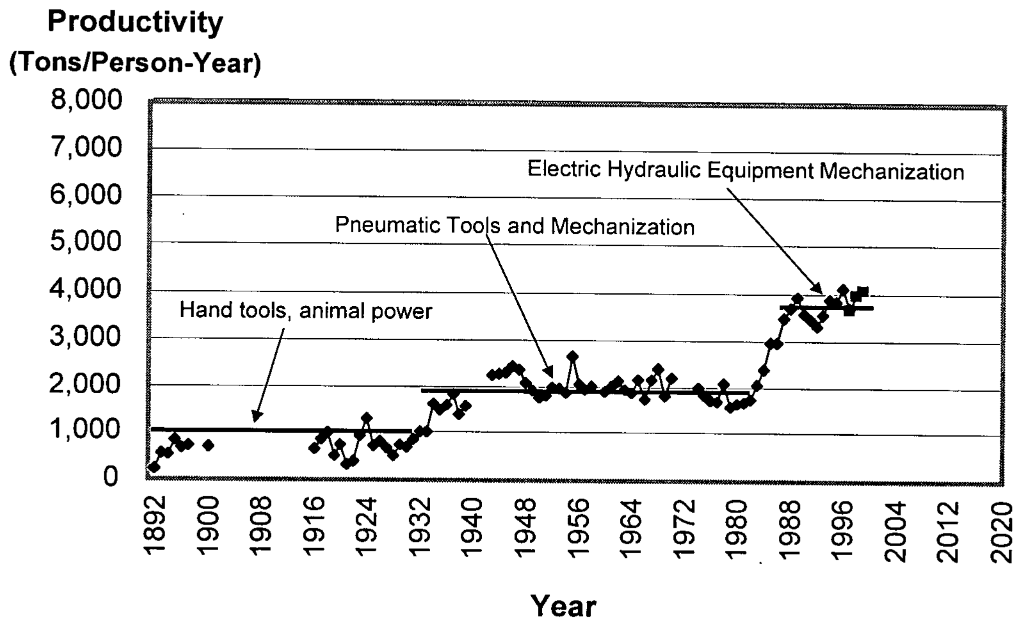


Figure 6-22: Productivity as a Factor of Technology[33]

The move from the tracked captive level mine to a more flexible, rubber-tired, ramp-accessed mine occurred in this period. The manager and administrator in mines began to use scientific principles and technology that were developed during the Second World War for mining and exploration. [34] Finance however, remained the domain of the accountants as it was perceived that financial accounting was: "the process of gathering all financial data so as to know the overall financial picture of the mining organisation."[35] Hence, cost information was seen to be primarily for the senior corporate officers and board of directors. This excludes the modern concept of costs as being used by tactical managers for process optimisation or performance measurements.[35]

E.2.4 Current State and Future State of Operations Management in Mining

Globalisation, environmental compliance, loss of capital and record-low commodity prices are currently changing the mining industry fundamentally. Market price trends in the past decade have shown steep declines for some core mineral products. [36] With the exception of construction material, commodity prices are obviously continuing to decrease despite a strong economy through this period. Mining companies therefore have had to find ways to further decrease the cost of mining.

Mining companies continue to invest in information technology to reduce costs. Strategic initiatives such as new metal marketing mechanisms,. supplier relationships, and contract bidding tools have become available, powered primarily through the Internet. [37] Computer aided design (CAD) software has been used by the industry for decades. Mines are investing in enterprise wide resources where operation and corporate integration promise to increase flexibility and strengthen control. Figure 6-23 shows the highly advanced Enterprise Mining Solution currently marketed by Mincom. Enterprise Resource Planning systems (ERPs) are strategic in scale, however, the tactical element in this example is the Minestar system. This system was developed by the Caterpillar Mining Solutions Alliance and is designed to provide vehicle health and production information over a wireless network. Included in the system is the ability to compare scheduled against actual production. The technology suppliers state that this technology allows mines to "reengineer a mining process, maximise the productivity of a system, and increase operator morale."[38] What is not mentioned in the promotional brochures for such products is the need for a management system capable of developing information from the data provided by such systems, and decision making procedures that would induce the required changes that result in improvements. (Note that the Minestar system is currently only available for surface mines.)

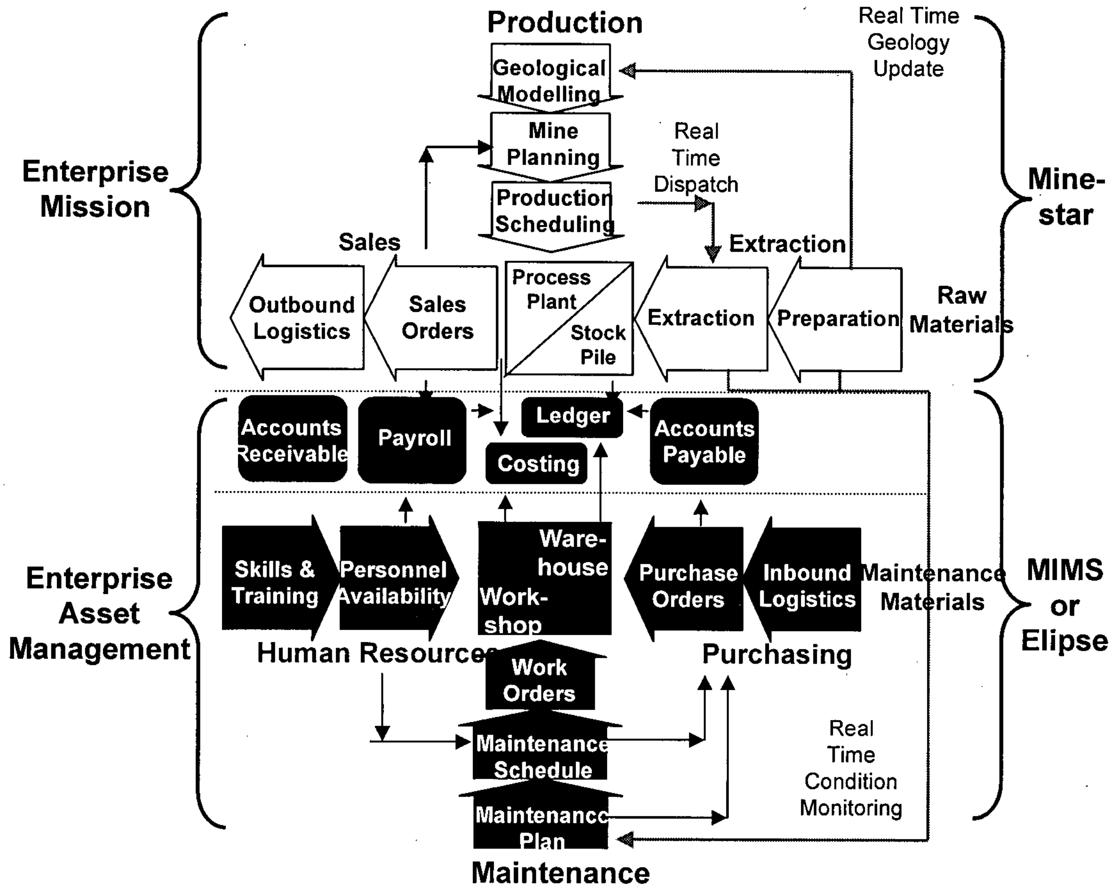


Figure 6-23: Enterprise Mining Solution Marketed by Mincom[39]

MINCOM's Enterprise mining solution aims to provide large amounts of information about the mining system. The core challenge remains to use the information to maintain and increase production.

Some published evidence suggests that attempts have been made to introduce operations management tools in mining. The modern OM tools that have seen great success in other industries appear sporadically in mining technical literature. The broad categories of modern OM in other industries, discussed previously include:

- Industrial engineering
- Total Quality Management
- Materials Resource Planning, Enterprise Resource Planning, and Theory of Constraints
- Activity Based Costing

- Reengineering

Industrial engineering (IE) tools and algorithms are widely used in dispatch systems, and computerised planning software. The field of IE is large and frequently used in dispersed applications throughout the mining industry. Some examples include the use of expert systems,[40] operations research, and systems analysis[41]. However, examples of more traditional IE in modern mines are lacking. For example, there have been very few applications of workflow analysis, (observation and optimisation of the ergonomics of tasks actions when someone performs a manual activity). Taylor's original work analysed the motions involved in laying bricks, and determined the most optimal motions. The motions he determined at the beginning of the last century are still used today in brickwork construction.

TQM has been applied where downstream mineral consumers require a product with very specific requirements. Kelly describes the process required for compliance with ISO 9002 in an IOC Iron mine in Labrador.[42] The emphasis was on quality of product rather than quality of management. Publicised widespread use of MRP, and ERP remains uncommon, although the Theory of Constraints has been applied in a limited fashion. Pauley discusses an example of such an application where considerable positive returns were experienced when bottlenecks in a surface mine were identified and removed.[43] However, considerable resistance was encountered at one operation where management wanted a black-box tool that would automatically use the IT to derive opportunities.

Activity based costing has been attempted in several mines. Smith discusses the use of ABC in an underground gold mine to determine cost drivers for more accurate cost of the various mining processes.[44] Studies of the application of ABC in the same functions as used in manufacturing (product costing) have determined that there is no benefit to using this management application since mines typically have only a single product.[45] Manufacturing originally used ABC primarily for product differentiation, where the exact costs of producing a particular product is calculated, thereby eliminating unprofitable products. However, ABC has been used in mining to determine cost drivers thereby benefiting decision making.

Reengineering has to date only been applied in a limited context to mining operations.[46] Campbell discusses one application of reengineering at an Australian mine, where a manufacturing manager was hired as mine manager.[47] The reengineered system reportedly eliminated twenty million dollars in costs in addition to increasing flexibility and customer (mill) satisfaction. Despite the benefits of these management tools, application and acceptance in mining remain limited.

E.2.5 Synthesis of Mine Production Management

Mine production management evolved in parallel with mining equipment and methods. Few fundamental changes in equipment or methods have been experienced in the mining industry in the past quarter century. Other industries however, are being transformed through IT and new management techniques. This review considered the few applications of these techniques in mining and revealed their current lack of widespread acceptance. Mine production management would benefit from applying production management best practice. The current state of production management in mining can be improved by determining the aspects that make the mining system unique then designing a methodology for TMMS that compensates for these unique aspects.

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Appendix F. Establishing a TMMS framework

The following provides the reasoning behind the TMMS methodology's development. The discussion begins by distilling a reengineering model from successful models found in published documentation. This leads into a list of the required aspects of a mining operation prior to the application of the TMMS methodology. This discussion concludes by using the issues raised in the previous appendices to develop the framework from which the TMMS methodology was established.

F.1 Reengineering Tactical Mine Management

Reengineering is a term that could broadly describe the numerous process innovation methodologies proposed over the past decade of management in the Information Age. This management technique borrows from the many other methodologies proposed by numerous authors. A common feature among most authors is that reengineering is simply the integration or evolution of other management tools, as presented in Figure 6-20. This appendix distils a reengineering technique from more "traditional" reengineering methodologies by taking mining's uniqueness into account. Therefore several reengineering models are discussed then assessed for appropriateness to mining.

Aggrawal[1] provides a simple description for a process: "a set of activities to fulfil the needs of internal or external customers." This particular author suggests a nine step reengineering methodology to implement process redesign from an assessment of twenty reengineering case studies:

- **Think big**: changes in the organisational structures, management systems, job redesigns, and rewards.
- **Appoint a steering committee**: a group of the best managers should be responsible for overseeing the reengineering project. This committee should outline a specific strategy and set of goals for the change.

- **Committee to sell the idea**: Communication is the most important function as a sense of urgency, focus on critical targets, and preparing employees for changes will help the workplace culture to absorb the required transformation.
- **Rengineering team**: A team of experts need to map out the business in terms of customer requirements, outputs of the processes, workflow, and setting baselines for performance.
- **Design backward**: Starting with the final ideal output, the system is reverse engineered. This new system needs to include out-of-the-box thinking, helpful ideas, and have the approval of the process managers.
- **Plan implementation**: Roughly six months are allocated for the design phase whereupon a detailed implementation plan should be formulated. Here is when IT alternatives are evaluated. Application of formal operations improvement techniques such as JIT and TQM can also be considered.
- **Implement**: During the implementation process, managers and workers pinpoint checkpoints where new training, reward systems, and career paths are to reinforce support for the redesigned process.
- **Management supervisions**: The cost of outside consultants and purchases of IT should be closely monitored by management as these typically spiral out of control.
- **Monitor progress**: The progress on the reengineering efforts should be monitored and correlated with the envisioned objectives outlined in the first few steps.

The method above depends on the ability to design backward through the production process. This would require close participation between internal suppliers and customers and very good understanding of the needs of the customer. The concept of internal customers is not yet widely understood in mining. For example, the maintenance department infrequently sees the operations department as its customer. These support processes are usually managed by individuals accountable to the top manager at the mine, not the individual he services. More importantly, the measures of output quality are unknown and information to produce measures non-existent. Cheney[2] discusses a much simpler methodology:

- Design mission statement from corporate vision statement;

- Define actions characterising the mission using concept mapping technique known as Soft Systems Methodology (SSM);
- The activities defined in the concept model are then compared to current situation;
- The activities are then broken down into workable pieces whereupon a needs of the processes and customers involved are further described;
- Key measures are defined to control the new processes
- The IT needs for the new system are accounted for;
- Organisational structures are defined to conform to the new measures.

This methodology is simpler however,. it assumes that information exists from which to derive key measures, that management has the ability to use conceptual tools such as SSM, and that customer needs are understood. A more basic methodology is needed. The simplest methodology may be provided by Davenport[3], one of the pioneers of process innovation/reengineering:

- Identify processes for innovation;
- Identify change levers;
- Develop process vision;
- Understand existing processes;
- Design and Prototype the new process.

Klein also provides a basic yet complete methodology, rich in the use of low-level management techniques and has the essential element of social design in parallel with technical design, as seen in Figure 6-24.[4] This technical design element, and some of the tools listed in the various steps can be used in a mine management reengineering scenario, although the required IT infrastructure is assumed to be already present. The methodology may be too involved and complex for an industry unfamiliar with these types of changes and tools.

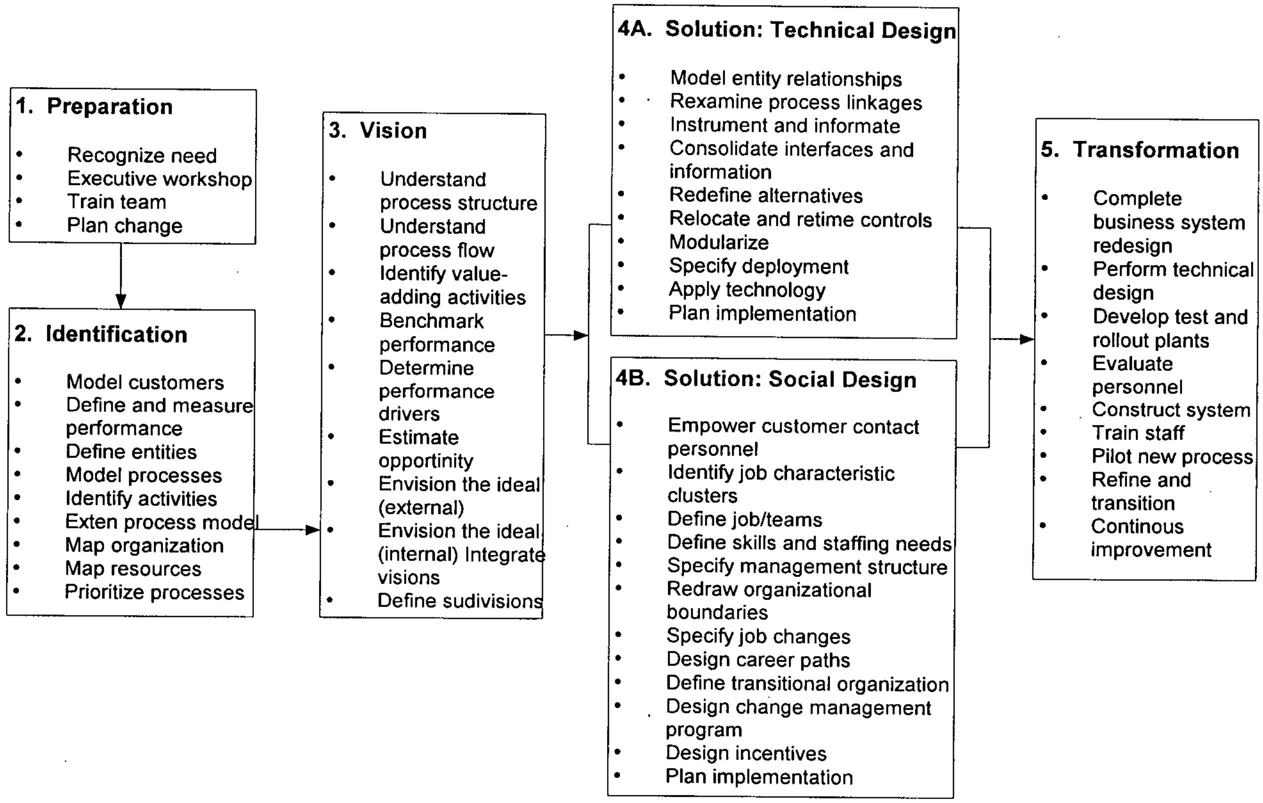

Figure 6-24: A methodology for Business Process Reengineering.[4]

Elzinga *et. al.* also describe a generic improvement methodology, rich in the use of operations management:[5]

- **Preparation**: The enterprise's vision, mission, and goal statements are studied so that Critical Success Factors (CSFs) cab be selected. CFS selection is a methodology which systematically identifies those action that are necessary to enable an enterprise to achieve its goal. This requires input from the top management and quantifiable measures to track progress.
- **Process Selection**: Using techniques called the Analytical Hierarchy Process (AHP), Benchmarking, cause and effect diagrams, and process mapping tools such as IDEF0, critical processes are identified and mapped.
- **Process Quantification**: Tools such as Value Chain analysis and Activity Based Costing (ABC) are used to characterise processes quantitatively.

- **Process Improvement Selection**: Using TQM tools such as cause-and-effect diagrams, Pareto charts, and AHP, ideal processes are designed that better conform to the CFSs, resulting in a mapped "TO-BE" design.
- **Implementation**: Using change management, the "TO-BE" system is implemented.
- **Continuous Improvement Cycle**: Once the ideal process, the inertia of change should be continued by establishing a principle of continual improvement. This phase can be aided through benchmarking competitors and other industries for best practice.

This methodology is appropriate for companies familiar with some of these tools, for executives who support and understand the future needs of the company, and that have established information systems. The simplicity of many of the tools mentioned and of the methodology itself would make many parts appropriate to a mining situation. The IT infrastructure and systems thinking needed for the application of ABC and mapping tools infrequently exist in mines but are extremely important. Another aspect of this methodology that would be important is the preparation phase where team members are selected and management change planned.[6]

The focus of IT within the methodology cannot be underplayed. Figure 6-25 shows how Bustard recommends an incremental approach to BPR where the business system evolves incrementally to a new business system and accompanying computer support development. Hence, the IT infrastructure evolves with the management and production systems.

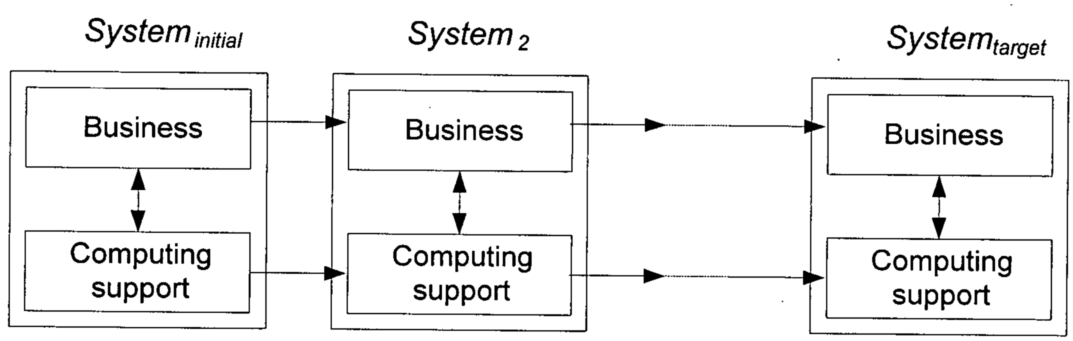

Figure 6-25: Co-evolutionary System Concept[7]

Appendix C discusses how mining is infrequently managed as a business. Instead, a technical approach is taken where focus is on the tools and equipment that break and move rock. The procedures and control systems are secondary. The incremental approach mentioned above would address mining's lack of business focus by building incrementally on successive successful business systems. Mine IT infrastructure is similarly incapable of servicing advanced business systems and hence would also require incremental growth. Finally, this approach also conforms to improving the operational processes incrementally. By increasing the control and managerial insight, operational opportunities should also reveal themselves.

The aspects of the generic reengineering models that conform to mining distilled from the above discussion include:

- The need to build business and supporting IT infrastructure incrementally;
- The need to use simple operations management techniques and providing the training on how to use the more modern tools;
- A preparation phase where team members are chosen, trained and inspire
- Focus on processes in the value chai
- All systems have a visualisation, design, and implementation phase;
- Change management issues should be addressed throughout the process;
- A social design element is key when designing management systems;

- Reengineering is a team effort involving experts for every key process;
- Many of the generic reengineering methodologies assume an existing strong IT infrastructure. An IT infrastructure centred on processes need to be designed and built. The IT infrastructure is then evolved alongside the management systems.

F.1.1 Mining Reengineering Models

The methodologies described until now were designed for industries in the service and manufacturing sectors that felt the need to alter their processes for competitive reasons. With some exceptions, such as Suncor and Syncrude, mining companies have yet to widely consider reengineering. Critical key inputs needed for the above methodologies are adequate IT infrastructure and managers with knowledge of modern management techniques. A few mine reengineering models exist. Ormerod describes an attempted application of process innovation models using many complex operations management techniques attempting to define an information systems strategy for Rio Tinto, (at Richards Bay processing plant[8] and Palabora mine).[9] The lack of familiarity and pre-existing IT infrastructure frustrated the managers involved and did not result in a positive outcome.

Pauley and Ormerod applied a similar reengineering model at a South African RTZ mine and a much simpler, more tactical model at an American RTZ mine.[43] There was considerably more tactical production data at the American mine which allowed the implementation of the simple management techniques which were successful.

Roberts, in various publications, describes operational mine management as frequently reacting to symptoms rather than addressing the core problem.[10, 11] Roberts takes a TQM approach whereby the variability of the mining processes are monitored. If problems exist, the statistical process control tools can easily identify the faulty processes and TQM tools applied to find the core problem. This is difficult in mining as scheduled production and priority shifts can alternate between work areas, creating "planned noise". Furthermore, the IT infrastructure needed to collect and assess the variability of all critical processes does not exist. Finally, managers are frequently unfamiliar with statistical process control.[12] However, the systems (flowcharting the process) and mechanistic approach to problem solving of the Roberts method have proven successful. Figure 6-26 represents the approach though diagrams.

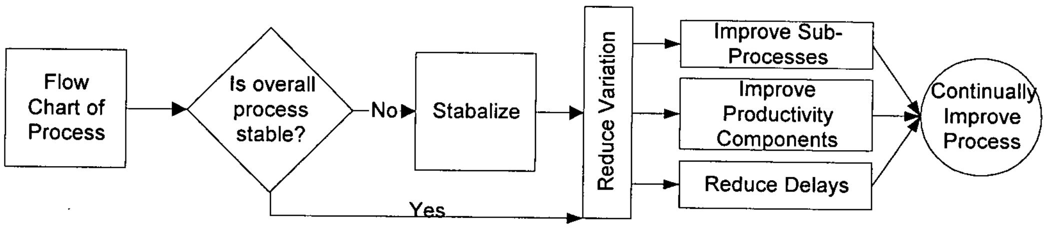

Figure 6-26: Robert's method of Improving Processes (Roberts, 1996)

The steps from the figure above are:

- Make a flowchart of the process and give it an owner
- Determine whether the process is stable and if not, stabilise it.
- Reduce natural variation
- Attack productivity components
- Attach out-of-process delays
- True continuous improvement
- Introduce higher capacity equipment (invest)

Roberts presents a basic yet powerful idea for understanding processes, as seen in Figure 6-27. The inputs and resulting output of a process must be measured in order to gain better understanding. Therefore mining IT must be capable of linking inputs with their resulting outputs. Processes also require understanding and therefore should be charted in a manner that conveys how the inputs are converted into outputs through the various decisions and procedures.

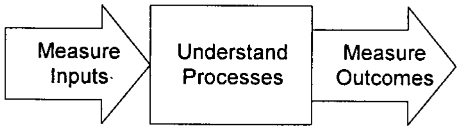

Figure 6-27: Measure and Correctly Analyse Outputs, Inputs, and Processes[13]

Roberts also identified the need for a shift in management culture. [14] He notes that effective qualitative measurements and analysis are infrequent in mining resulting in reduced accountability. The lack of measures may be attributed to the reduced understanding, structure, and utilisation of IT. Roberts also notes a distinctive lack of formal improvement systems whereby improvements are identified, planned, implemented, and measured. Finally, the need for dynamic and energetic leadership to combat the highly destructive tendencies of some union delegates is also mentioned. Communication and looking for win-win improvements are the key.

F.1.2 Distilling a reengineering model appropriate to mining

Virtually all reengineering models have a process of first, outlining the vision of management change, second, visualising the business processes, third, designing the ideal business processes, and implementing the improvements. Many suggest the institution of a continuous improvement process. These more generic methods assume that the information technology, management technique familiarity, and executive management support already exist. A mining methodology will require a redesign of IT prior to the redesign of a management system. Furthermore, the lack of familiarity among typical mine employees will require education in the use of initially simple tools and procedures. Finally, the lack of executive management support will not allow the six months-to one year redesign time suggested by the generic methods. Therefore a more tactical scope is needed.

Therefore, the basic requirements of a reengineering model for mine management are:

- Systems planning process
- Data that can be organised into a relational database

- Construction and evolution of an IT infrastructure
- Establishing measures (and thereby accountabilities)
- A mechanistic process of improvement
- Tactical level improvements (prior to strategic as here is where the data is collected and first processed)
- Clear measurable accountability that is easily understood
- A process that considers the effects of culture in any potential implementation.
- A system that evolves as needed and as capable

These basic requirements for a mine management model to be successful may already exist in some operations. A more formal description of the type of mine needed to be capable of adopting such a reengineering model is described in the next section. This brief description should allow mine managers (including engineers) to consider if their mine is ready for a new TMMS.

F.2 Mine Operation Prerequisites needed to introduce informed mine management.

Using the above requirements for a mine management model, some basic building blocks in terms of technical and cultural infrastructure are needed. These components are usually present in most mines in Australia, North America, and Europe. The basic premis in this dicussion is that the TMMS methodology would be most applicable in a mine that has:

- adequate traditional mine engineering output (mine schedule, diligent safety design)
- adequate human resources (volume)
- an empowered educated workforce (quality)
- basic data that is easily retrievable, computerised, and networked.

TRADITIONAL MINE ENGINEERING OUTPUTS

Examples of basic engineering outputs include a mine plan, budget, and safety system. Safety and environmental issues should not dominate a manager's time. Though important, the manager should focus on the profitability of the production system (core of the business). Through careful engineering and well structured control mechanisms, environmental and safety issues can be brought under control, freeing time to directly manage productivity of the core processes.

HUMAN RESOURCES

Not every mine has the capability to adopt new management techniques. The requirements for any successful implementation always includes a workforce that has the ability to learn and change. This type of management reengineering will not work in mines that have understaffed and overworked technical and supervising personnel. Management change and improvements require a workforce willing to learn and apply OM techniques, but also has the time to adapt and learn.

EMPOWERED EDUCATED WORKFORCE

A literate miner workforce is needed to provide information related to equipment health and work accomplished. Many management techniques also require input from the experts within the system, which may include miners. For example, if undertaking a redesign of the development process, input from the development miner would be crucial. The cultural acceptability of managers interacting with workers is therefore required. This statement is not intended to imply that miners in Australian, North American, South African, or European mines are illiterate. However, mines located in third-world nations may have an illiterate workforce and where workers are not free to interact with management.

COMPUTERISED DATA AVAILABILITY

Examples of raw data found at mining operations and where information systems are used for compilation and documentation include:

- operational and historic parameters that are measured by sensors on equipment;
- financial transactions that are kept for fiscal reporting purposes;

- personal input from individuals within the operating system;
- output from simulations that model an existing or proposed system.

Rivard describes a survey study of the construction industry's use of IT.[15] As there as not been a study on the state of computerisation in the minerals industry, conjecture will be used to infer assumptions from the aforementioned survey of the construction industry. Some of the most common areas that use IT include:

- **Materials control / purchasing**: This area is known to be computerised in the mine industry, however, the stocking of underground storage areas are rarely managed through IT. The MIMS system from Mincom and the mySAP from SAP are some of the core IT suppliers.
- **Scheduling**: Software such as PS7 or Microsoft project is reported to be widely used in the construction industry. It is assumed that such software is also used in mining as production plans must be planned years in advance yet updated monthly
- **Design** (CAD): Virtually all design is currently undertaken using computer aided design (CAD) tools.
- **Costing and budgeting / Invoicing / Bookeeping**: This category of business system is the most widely computerised in the construction industry. This may be similarly true for the mining industry as bookkeeping and accounting software has been developed in other industries and can be easily adopted.
- **Maintenance**: The Mincom system was originally a maintenance management system where the meter-hours from equipment were compiled so that preventative maintenance (and eventually predictive maintenance) could be more effectively planned.

Other computerised areas particular to mining include:

- **Incentive systems**: Mines need to compile the vast amounts of data in order to calculate the incentive payments. This data is infrequently collected automatically as surveyors, foremen or miners must provide daily assessment of work accomplished. Surface mines are introducing new technology that allows production data to be collected automatically. The same data is often the primary method of tracking performance within a production system.

- **Geology / metal inventory**: Geographic Information Systems are used in the construction and mining. However, mines use orebody models to determine the value of the ore for evaluation and accounting purposes.

From the discussion above, it seems that many of the business processes in mines are computerised. The unfortunate aspect is that these systems are frequently independent. The data is used separately in necessary functions such as financial reporting or mine planning. The value of integration is not yet widely understood. Data integration would allow the creation of valuable information for management.

SYNOPSIS OF THE PREREQUISITES FOR APPLYING TMMS

To summarise, a reengineered TMMS can be applied in mines that first have adequate traditional mining engineering outputs. Secondly, the proposed TMMS requires participants in the production system that can give time to designing, implementing, and executing a new management system. The third requirement is a miner workforce (miners) that are literate and culturally empowered to interact with management. The final necessity, is the availability of data, preferably computerised and with the potential to be integrated. These are the core requirements to apply the framework as presented in the next section.

F.3 TMMS Framework

Appendix C discusses the broad categories of managerial issues in both mining and other industries. Appendix E provides the history of how these management techniques were devised and evolved to suit the changing business and technological environment thereby eliminating managerial issues. A section in chapter 2 highlights an important reason for mining's lack of use of management techniques: the unique nature of mining. It is assumed that these differences can be circumvented once understood. Rough guidelines for a reengineering model are distilled in the first section of this appendix. This leads to a discussion of the basic components of a mine that would be capable of adopting modern management techniques. The last section of this appendix will provide the framework for a TMMS that attempts to address the weaknesses of current mine management.

Figure 6-28 represents the conceptual framework for a TMMS empowered by information technology and taking industry best managerial practice into account. The four components are the building blocks needed to set-up an informed management system. This same framework needs to be revisited on occasion to maintain the validity and effectiveness of an established system. These are the four building blocks for strong tactical management. Each of these components use OM tools to produce their intended output.

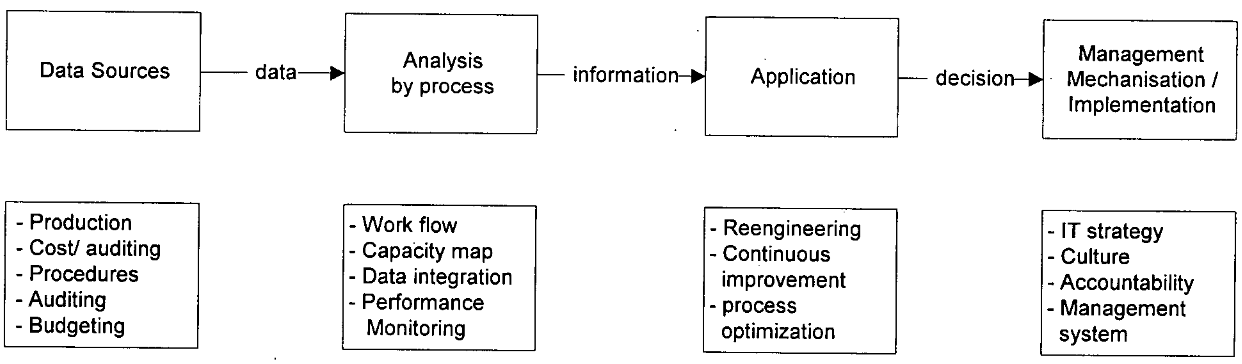

Figure 6-28: Conceptual Framework for a new TMMS

Data: Raw data is the conceptual representation of the outputs of the production system.

Analysis: Data alone provides no real value, as it had to be refined into information representative of the system. Modern management techniques suggest that data should be organised according to the processes within the system. This precipitates the need to define the system.

Application: Understanding and being informed about the production system of a mine does not result in improvements. The application of knowledge, production system redesign strategies, and operations management techniques would result in options which can lead to improving the system.

Management Mechanisation: The will and means to effectuate process redesigns are important, however, in order to improve the productivity of an operation, a strong mechanised method of actively designing and implementing improvements is needed.

This framework was distilled through a literature review of modern process innovation techniques in other industries. The following features were common to virtually all modern management systems:

- Process focus;
- Data Integration (linking input and output data according to process);
- Phased Integration;
- Assessing the impact of culture;
- Data is generated at lower levels;
- Tactical management;
- Formal mechanism.

In the conclusions of Appendix C, the issues of modern mine management were listed. Table 6-3 presents the elements which address the weaknesses of current tactical mine management.

Table 6-3: the Framework's Elements Addressing Managerial Weaknesses

Issues	Element of the Framework
• Effects of the functional silos • Recognition of the systems elements of an operation • Poor performance measures and mechanisms • Disregarding of ignoring the influence of culture • Insufficient use of modern management systems • Shortage of formal mechanised integrated tactical management tools	• Process focus • Data integration • Phased integration • Cultural sensitivity • Data accuracy • Tactical focus with OM tools • Formal mechanism

A framework alone does not induce change. A pragmatic approach to applying this framework is therefore needed. Chapter 3 proposes a methodology resulting in the required components of a TMMS. Appendix Gdescribes the low-level management techniques that are used within the TMMS.

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Appendix G. Management Techniques within a TMMS

Modern management techniques play an important part in the development and use of a TMMS. It is not within the scope of this thesis to provide the theoretical and practical background or in-depth discussion of the wide-range of management techniques available to be used in the various phases of development or in the use of a TMMS. This appendix is important, however, in providing an overview of the techniques mentioned in Chapter 4 and guidance for those interested in learning more about the modern management techniques that would be useful in building and using a TMMS.

Virtually all modern-day mines use spreadsheets, communications, group-ware, and project management tools. Groupware is an all-encompassing term used by Davenport[1] to describe all tools that facilitate group tasks including:

- Group brainstorming, decision making and structured discussion;
- Group communication via teleconferencing, electronic mail, and electronic bulletin boards;
- Group preparation of documents;
- Group scheduling of meetings and facilities;
- Group access to database records;

For example, Project Scheduler by Scitor™ or Microsoft Project™ are software applications that can help plan and implement complex changes that will occur during the development of a TMMS. It should not be assumed that tactical managers are familiar with these tools. Easy to learn and use, the basics of these tools can be taught in a matter of days and tactical managers can gain proficiency through use and access to experts who can be tutors.

G.1 Systems Planning

The systems planning phase is intended to provide a picture of the current state of production management, an ideal state of production management, and a roadmap of how the management system should evolve from the current state to the ideal state. This is a typical reengineering visualisation process that is common in virtually all process innovation endeavours. The previous chapter mentioned the many tools available for visualising processes and process change. Creativity tools to promote out-of-the-box thinking have been used to visualise the ideal system.[2] The main technique in this phase of TMMS development is process modelling, (also known as System/Process/activity/workflow mapping). The tool is essentially a mechanism to represent, usually graphically, the series of actions, data, rules, and procedures that occur in accomplishing work. A brief review of process modelling along with mining examples is provided here.

G.1.1 Process Modelling

There are many process mapping techniques. One of the earliest and most thorough process modelling tools is Systems Analysis and Design Technique (SADT).[3] Another popular standard has developed from SADT roots, namely IDEF0. This modelling technique is used for analysing whole systems as a set of interrelated activities or functions.[4] IDEF0 is explained below to provide an example of a process mapping tool's basic rules, input requirements, and outputs.

IDEF0 is a structured analysis technique developed for systems design and analysis for the US Air Force Integrated Computer Aided Manufacturing (ICAM) program. There are several tools within ICAM definition (IDEF) techniques and they have been assigned numbers, therefore the basic technique is IDEF0 (IDEF – zero). Structured analysis techniques are methodologies that can map out a network of activities and processes within a system. Once an accurate workflow map has been laid out, analysis on various levels can be effectuated. The method is widely used in mapping systems for information system design, factories and even bureaucratic systems. This modelling technique is used in the TMMS development to map out the existing production and management systems (known as the AS-IS system) and to accurately define the desired systems (known as the TO-BE system). This allows the design team to visualise, understand, analyse, and improve the final design.

G.1.1.1 Basic Box

As with most structured analysis techniques, processes are represented by boxes, and interfaces represented by arrows as seen in Figure 6-29. An active-verb phrase inside the box distinguishes the different processes. Figure 6-30 provides an example where the operational process of 'produce drill pattern' is presented. Arrows indicate information flows (such as geological information) or physical objects (such as drills or miners) and these arrows are accompanied by noun phrases (the 'names' example: engineering personnel, drilled holes). The direction of entrance and exit from the box indicates the type of information or physical object being conveyed. The arrows entering and leaving the boxes horizontally are the inputs and outputs, respectively. Inputs represent elements that are needed to produce an output. Outputs express the data that is produced from the function. Therefore the function transforms the inputs into the outputs. Arrows entering the box from above indicate controls (elements that constrain or govern the function). Bottom entry arrows are mechanisms which can be considered the people, device or machines that perform functions.

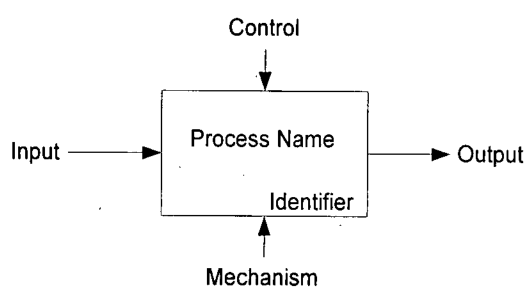

Figure 6-29: Basic Elements in Process Mapping

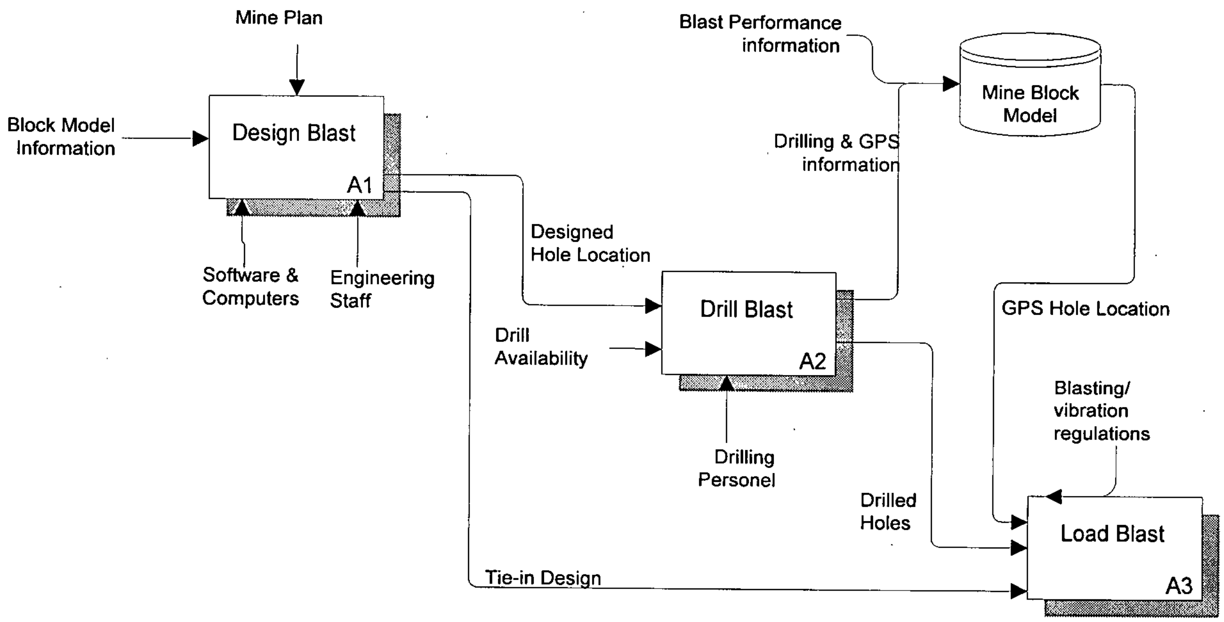

Figure 6-30: Operational Process as an IDEF0 Diagram.

G.1.1.2 Decomposition

An IDEF0 model is made up of several diagrams that increase in complexity when increasing in hierarchy. This is similar to the hierarchy of work as shown in Figure 2-1. Figure 6-31 shows how a more detailed diagram is derived from a single box on a more general diagram. The process of describing a box in more detail is called 'decomposing a function'. The top most and most generalised diagram, also called the context, is labelled A-0. This diagram summarises all the information needed to understand the overall model. Subsequent diagrams usually contain 3-6 numbered boxes. Numbers identify which diagram is being viewed, for example, in the figure below the A0 diagram is decomposed in diagram A2. Box 3 in diagram A2 is decomposed into diagram 23. Each diagram is labelled with a prefix 'A' to signify activity. Each arrow leaving or entering a diagram must also be shown entering or leaving a diagram on the lower or upper diagram.

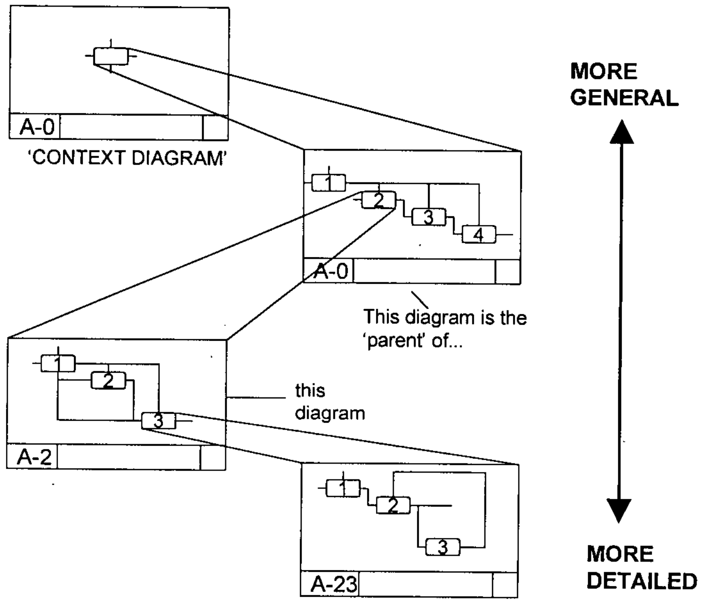

Figure 6-31: Decomposition of an IDEF0 Model[5]

G.1.1.3 IDEF0 Example

Figure 6-32 is provided, to show a more formal example of a computer generated IDEF0 model. The example is obtained from a paper which describes the 'reengineering' of Syncrude's Heavy Truck Maintenance Business Unit (HTMBU). In performing the structured analysis, several sources of valuable information were identified and opportunities for improvement were uncovered. Many of these opportunities lay in measurement and motivational issues, pointing to the need to map the influences and effect of culture. Systems Thinking is used as a tool to model the variables that affect motivation or other less specific processes.

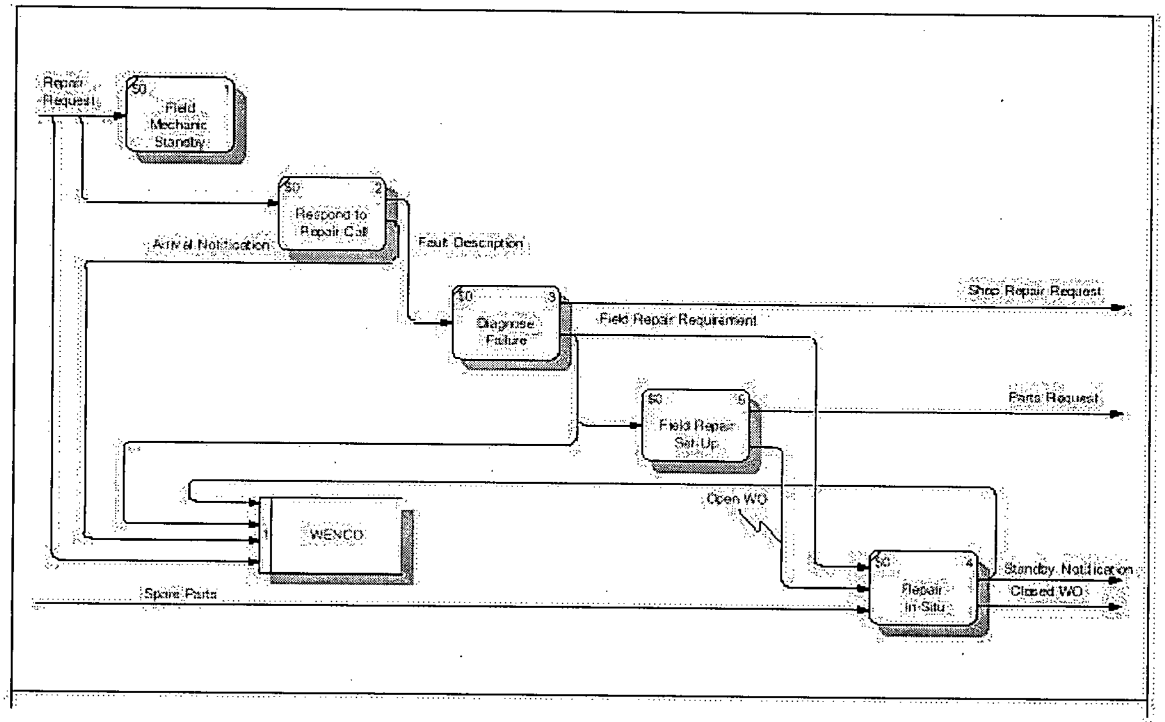

Figure 6-32: A0 of Syncrude's Heavy Truck Maintenance Business Unit, example of IDEF0

G.1.2 Systems Thinking

Systems thinking originated in the writings of Senge in the Fifth Discipline.[6] Systems thinking is a method devised to represent complex systems that are best evaluated as whole systems interacting with each other.[7] The complex systems influencing cultures and behaviour are best represented graphically through influence diagrams. Systems thinking is somewhat graphical whereby 'causal loops' or 'feedback loops' are used to represent various systems influencing each other. The various types of relationships these systems can have are organised into a classification scheme called archetypes. The two most common are discussed below.

Figure 6-33 shows the 'Limits to growth' archetype. This is a reinforcing process that is set in motion to produce a desired result but creates secondary effects eventually slowing the success. Therefore to change behaviour of the system, you must identify and change the limiting factor.

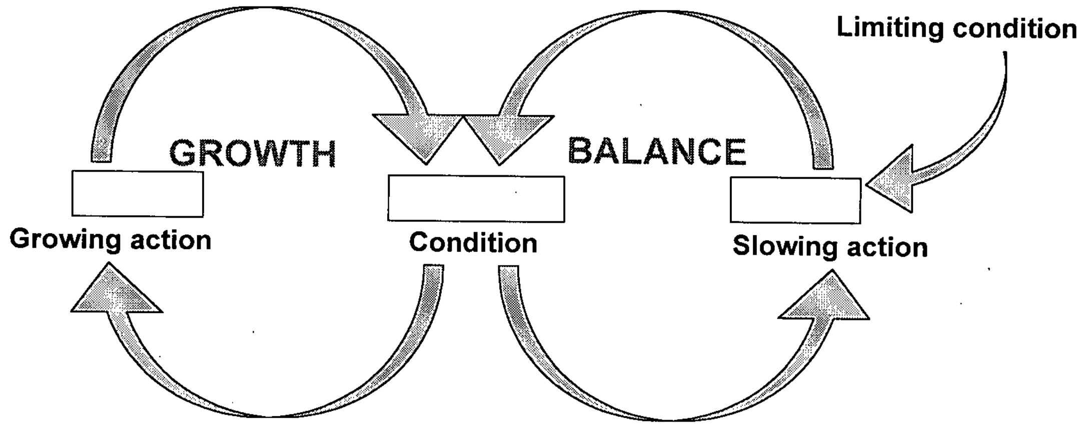

Figure 6-33: 'Limits to Growth' Archetype

Figure 6-34shows the 'Shifting the Burden' archetype. These represent easy fixes that usually leave the underlying problem unaltered. Because the symptoms apparently clear up, the system looses whatever abilities it had to solve the underlying problem. Leverage can be achieved by strengthening the fundamental response and weakening the symptomatic response.

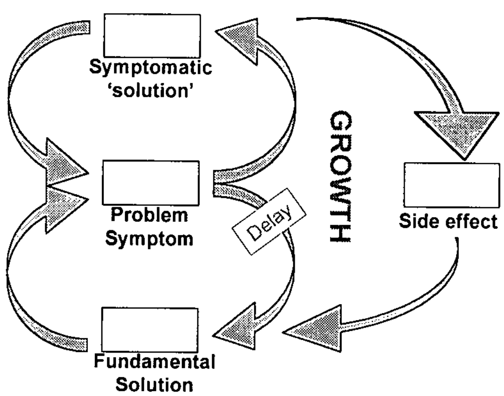

Figure 6-34: Shifting the Burden Archetype

G.1.3 Ethnography

As discussed in Chapter 3, ethnography is the fundamental research method of cultural anthropology and the written text produced to report ethnographic research results.[8] Ethnography is a qualitative research method and product that is not quantitative, public policy, or journalistic. This characterisation method aims to gain a view of a group of people and can be guided by the following basic questions:

- How do members of a particular group perceive or understand social or cultural phenomenon?
- How is a certain social or cultural practice socially constructed among members of a certain group?

Ethnographers participate in the cultures under investigation to gain insight into cultural practices and phenomena. Useful and reliable notes documented throughout this research process typically constitutes the major part of the data on which later conclusions will be derived. Other data sources include site documents and interviews. The following list are some variables that should be included in field notes:[9]

- Date, time, and place of observation;
- Specific facts, numbers, details of what happens;
- Personal responses to the fact of recording notes;
- Specific words, phrases, summaries of conversations, and insider language.

Throughout the data collection process, the data is analysed. There are no official canonical ways to approach ethnographic analysis although the following points can be used to arrive at conclusions:[36]

- Determine patterns, connections, similarities or contrastive points in the data;
- Use software specifically designed for ethnography including Nud/ist, ATAS/ti or Ethnograph;[10]
- Use "respondent validation" which is explaining or developing conclusions with the individuals you are studying.

G.1.4 Systems Planning Management Techniques within the TMMS

Three systems modelling techniques were mentioned above. Multi-layered scientific descriptive modelling methods such as IDEF0 is the single most important tool within the development and use of a TMMS since operational processes must be understood and characterised. Process modelling is used to communicate a common understanding of a particular system. However, the particular method used to represent a process is not important. The ability to see links between inputs and outputs, workflow, constraints, and organise is important. The IDEF0 method is involved, complex, and unfamiliar in mining. Simpler methods such as flowcharting are suggested although a more detailed structure mechanism may be needed by software developers when building data infrastructure. Several process models will need to be created when building a TMMS. These may include:

- **Work-process process/activity/task map(s)**: here the various actions undertaken by personnel is organised according to the work undertaken.
- **Workplace map**: the various locations and the processes which will take place are mapped.
- **Change process**: the various inputs and outputs along with specific tasks are presented in a process modelling format.

Cultural characterisations are even less familiar to mining than process modelling methods. Understanding workplace culture and motivational issues are key to controlling workers and managerial decision making. Garnering a modicum of understanding of the organisational culture and labour/management behaviours is important prior to making any final decisions in the planning of a TMMS. [11] Similarly, in using the system, the cultural impact of any changes or measures should be evaluated before any system or improvement is implemented. For example, if technology designed to track the miner workforce underground is perceived as a major infringement on the privacy of the worker, perhaps the technology should not be implemented.

Figure 6-35 shows other tools that may facilitate the systems planning phase though planning and creativity enhansing. Couger et al provide several creativity enhancing techniques specifically geared towards reengineering type improvements.[12] A list of these tools can be found at the end of this chapter in Table 6-5. The TMMS design team should be made aware of management techniques such as total quality management (TQM) so that a systems plan can include potentially powerful system components in the TMMS evolution. [13] Since these improvement techniques will not actually be used until the TMMS is complete, they are not discussed until the "Using the system" phase is discussed.

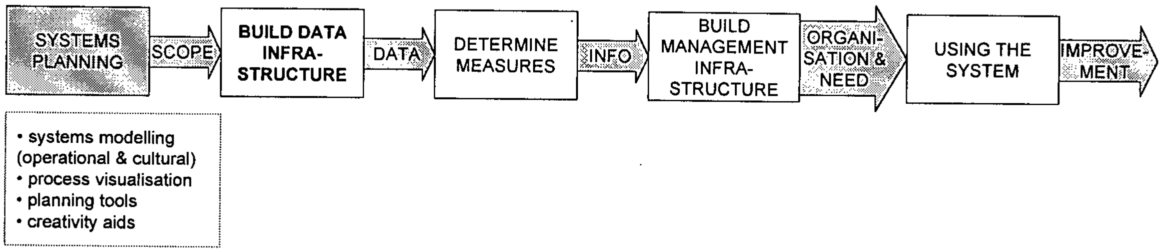

Figure 6-35: Structure of Chapter 5 Showing the Key OM Tools of Systems Planning.

G.2 Data Infrastructure

Planning and constructing data infrastructure will be undertaken primarily by IT professionals familiar with the coding, database languages, and applications development platforms. Automated electronic data entry through hard technology such as sensors or controllers will be best handled by electrical or electronic engineers. In this phase, mine managers will be concerned with developing the required data collection activities and participate in data modelling with the IT programmers. Data modelling was explained in the previous chapter and is therefore not repeated here. Data collection may include creating jobs tasks that consists of entering and auditing information, training employees at completing the information slips, and managers at auditing the slips prior to data entry. Training aids such as on-line tutorials, flowcharts on bulletin-boards, and teaching sessions are used to ensure employee participation. The development of a data collection system is aided by process modelling or a flowchart of the data collection tasks undertaken by each employee. Evaluating the effect of culture on different data collection techniques may also be beneficial. Therefore systems modelling plays an important role in this phase.

Figure 6-36 shows how database design and data modelling are a core aspect to developing data infrastructure. Mine employees however, will still need to apply systems analysis to design, implement, and educate employees in the data collection activities.

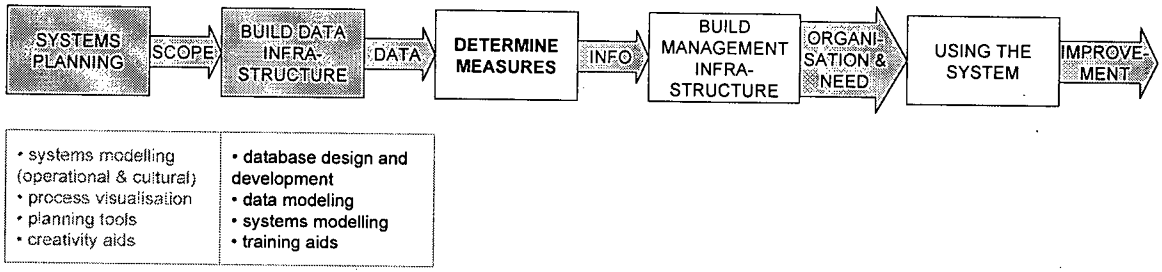

Figure 6-36: Structure of Chapter 5 Showing the Key OM Tools of Data Infrastructure Development Phase

G.3 Determining Measures

Determining measures is an involved process that employs many management techniques. As discussed in the previous chapter, activity based costing (ABC) is used as a model for the basic building block for all measures. Performance management is the most important aspect of measurement and is an entire field of study. Examples of these performance measurement techniques include Balanced Scorecards, theories of motivation, non-financial measures, and Key Performance Indicators (KPI). Setting goals is another area of performance management rife with techniques such as budget development, or comparative tools such as the Analytical Hierarchy Process (AHP). Diagnostic measures are popular in manufacturing where techniques such as control charts are used to measure the health of a particular process. Another area important to measurement is information presentation techniques such as variograms, Pareto Charts, the software tools such as Excel or PowerPoint, and the human factors important to the communication of technical information. It is unfeasible to explore the entire breadth of these techniques therefore only ABC, Balanced Scorecard, and Process Control Charts are discussed. Interested readers are encouraged to explore the many references available at the end of this chapter.

G.3.1 ABC

The background and use of ABC within the development and use of a TMMS was discussed in previous chapters. There are three key aspects of ABC that are important to developing measures within TMMS. Firstly, all data collection and measures are linked by a common process. For example, all measures of drilling output and input are linked to the drilling process. Secondly, all inputs, including overhead and workplace inputs are also linked to a particular output so that all costs can be attributed to processes along the value chain. Finally, measures of production (output) are developed that most closely correlate to how costs fluctuate, these are more formally known as cost drivers. Some of the basics of ABC are discussed below.

G.3.1.1 Process as an Integrator

Traditional accounting systems typically allocate costs according to expense types such as labour, supplies, or equipment. Figure 6-37 compares the traditional cost reporting with ABC reporting. It can be seen that traditional accounting does not provide managers with a clear picture of the process costs. It only provides information about the inputs used to produce the final output.

Current accounting	
Mining Department	
Salaries	$1,600,000
Consumables	$300,000
Equipment costs	$5,700,000
Utilities	$10,000
Services	$140,000
Contractors	$1,500,000
Total	**$9,250,000**

What is spent

Use Resource cost drivers

ABC accounting	
Surface Mining Department Acitvities	
Designing drill & blast pattern	**$54,000**
Drilling pattern	$76,000
Rock breaking	$1,025,000
Production Planning	$105,000
Loading	**$2,268,300**
Hauling	$4,862,000
Mine road maintenance	$590,000
Train Employees	$76,000
Supervise Employees	$193,700
Total	**$9,250,000**

How it is spent

Figure 6-37: Traditional vs. ABC Cost Reporting[14]

G.3.1.2 ABC Nomenclature

Considering the popularity of ABC, many books, magazine articles, and are available, although, this popularity results in many different versions of ABC. The term cost driver and activity driver are often used interchangeably. Brimson's version of ABC focuses on performance management (as opposed to product mixes).[15] Figure 6-38 shows how, according Brimson, the components of an activity can be separated into several elements:

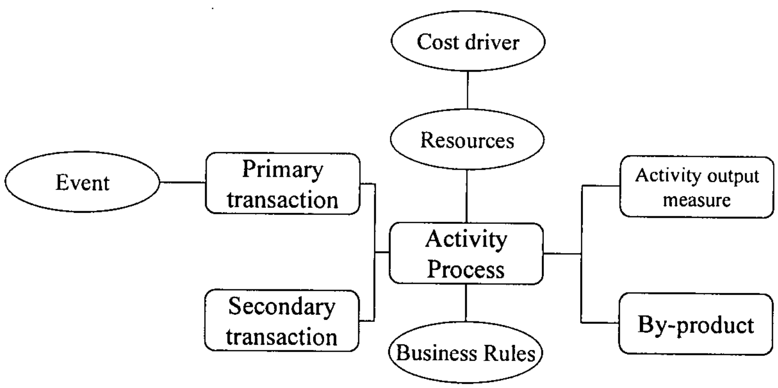

Figure 6-38: Activity elements[15]

The following points describe the activity elements represented in the figure above.

- **Event**: the consequence or result of an action external to the activity. Events trigger the execution of an activity. The two primary types of events are clock event and external event. A clock event occurs regularly. An external event occurs outside the activity.
- **Transaction**: is a document associated with the transmittal of information. The document serves as evidence of the transaction. The receipt of a work plan, for example, would trigger an order entry activity.
- **Resources**: are the factors of production employed to perform an activity such as labor, technology, travel, consumable or equipment availability.

- **Cost driver**: is a factor that creates or influences cost. Cost driver analysis identifies the cause of cost. A positive cost driver results in revenue, production, or support-related activities that generate profit. A negative cost driver causes unnecessary work and reduced profitability
- **Output**: is the culmination (product) of the transformation of resources by an activity. It is important to distinguish the output from the goal (the goal is profit).
- **Activity measure**: is how the activity is gauged in terms of "number of activity occurrences per period"
- **Business rules**: control activities, define the goals, strategies, and regulations governing the activity. Rules take the form of policies, procedures, rules of thumb, and algorithms.

Many of the variables mentioned above can be tracked. For example, a development drill round is initiated by an engineering design delivered to the workers. The inherent idea in ABC is that resources are consumed by activities at a measurable rate called a resource driver. Activities are consumed by customers. ABC is a translator, not a replacement for accounting information, where decision makers use ABC for decisions and accountants use traditional accounting systems for their needs. ABC is considered socio-technical tool that, if the information is shared, would empower employees to improve their work practices.[16] An ABC system facilitates the creation of performance measures.

G.3.2 The Balanced Scorecard

The Balanced Scorecard is both a tactical and strategic management technique. It is strategic in scope yet applies to front-line and upper level management. It is a mechanism that links the strategic vision and strategy with measures at all levels of management.[17] Using both financial and non-financial measures, the balanced scorecard translates a business unit's mission and strategy into tangible objectives and measures that represent a balance of external measures for shareholders and customers, and internal measures of critical business processes, innovation, learning and growth. Figure 6-39 shows how the balanced scorecard provides a framework to translate strategy into operational terms.

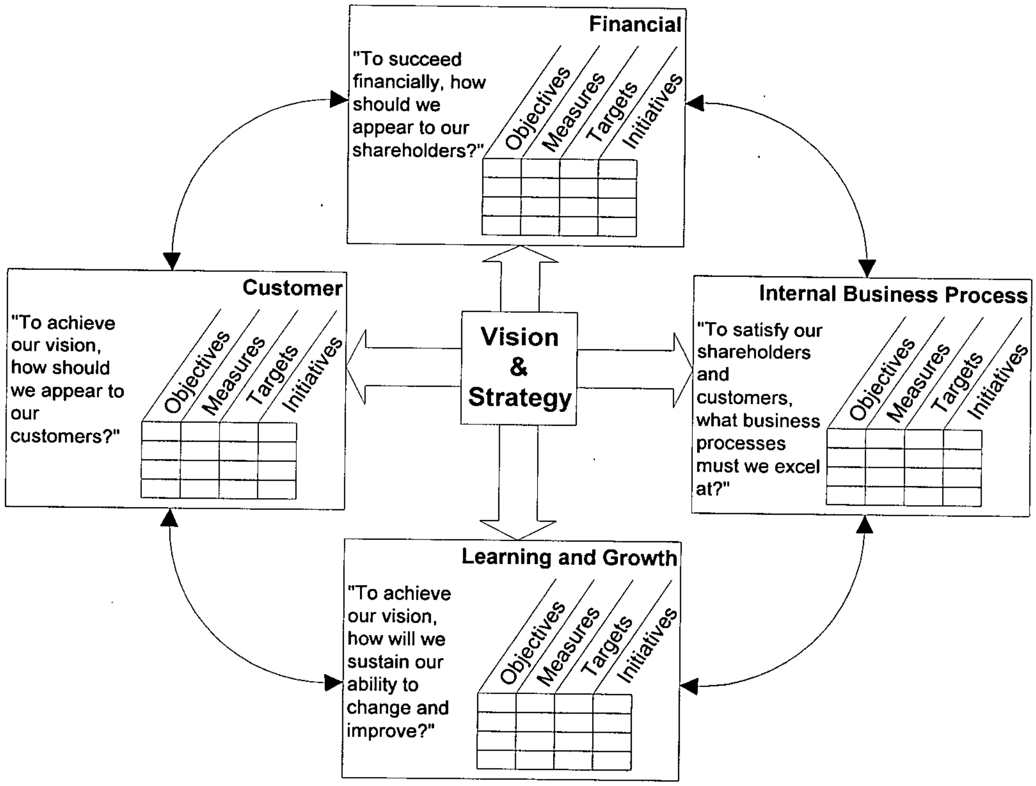

Figure 6-39: Balanced Scorecard – a Framework to Translate Strategy into Operational Terms[17]

An information infrastructure is needed in the development of Balanced Scorecards for every level of the organisation. The advantage of the TMMS methodology is that the basic performance measures collected in the data infrastructure can be conglomerated into increasingly higher levels of management as prescribed in the systems model and the hierarchy of work. Each individual being measured by a balanced scorecard must understand:[18]

- What accomplishments are expected of him/her personally
- What accomplishments are expected of his/her work-teams and business unit collaboratively
- What procedures he/she should be using to achieve these personal and group accomplishments.

Considering that tactical mine management is unfamiliar with quantitative measurement of performance, the Balanced Scorecard may not be an appropriate performance measurement system when first developing a TMMS. The use of less complex measures at first may help develop the tactical manager's understanding and acceptance.

G.3.3 Process Control Charts

Control charts were developed in order to distinguish between chance variation and variation caused by the system being out of control, called assignable variation.[19] The type of control chart used depends on the measures monitored. $\bar{x}$ and R charts are used when monitoring continuous processes and a p chart is used for discrete data. Processes that are under control are those whose process averages lie within the upper control and lower control limits (UCL and LCL respectively).[20] Figure 6-40 shows an unstable process while Figure 6-41 shows a stable process.

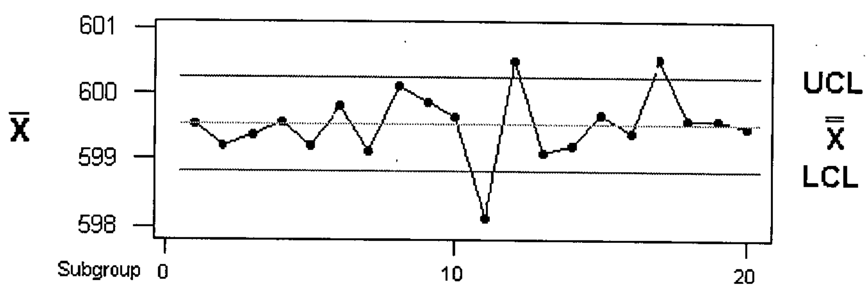

Figure 6-40: Unstable Process – Points Outside the UCL and LCL.

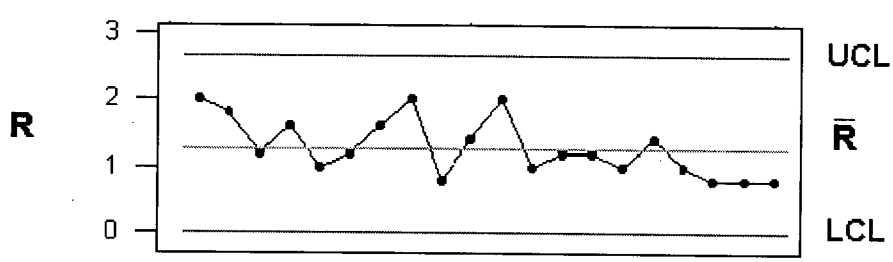

Figure 6-41: Stable Process

Process control such as seen above has been used in the mining industry where quality aspects of the product is very important such as Iron ore production[21] or in improvement initiatives based on TQM theory (ass discussed at the end of this appendix).[22] From the field studies, INCO had considered process control as an important improvement tool and provided managers with training.[23]

G.3.4 Management Techniques in the Development, Calculation, and Presentation of Measures

This section reviewed three modern management techniques among the many tools used to develop, calculate, and present performance measures. ABC was reviewed because it is a key concept in this thesis when establishing logical links between process inputs and outputs. The Balanced Scorecard was discussed as an example of a performance measurement technique that relies upon a detailed integrated information system that can be organised into higher or lower levels of management. Process control charts were reviewed as an example of a mathematical technique that can be used to diagnose the degree of control over a process. The manner in which the measures are presented is also important. The medium of communication used (example: paper, computer, oral) may directly affect how well the information is absorbed. Human factors for the communication of technical information is area of research that may provide ideas as to how the information is to be presented. Figure 6-42 shows the various uses of management techniques when determining measures and the examples that were considered.

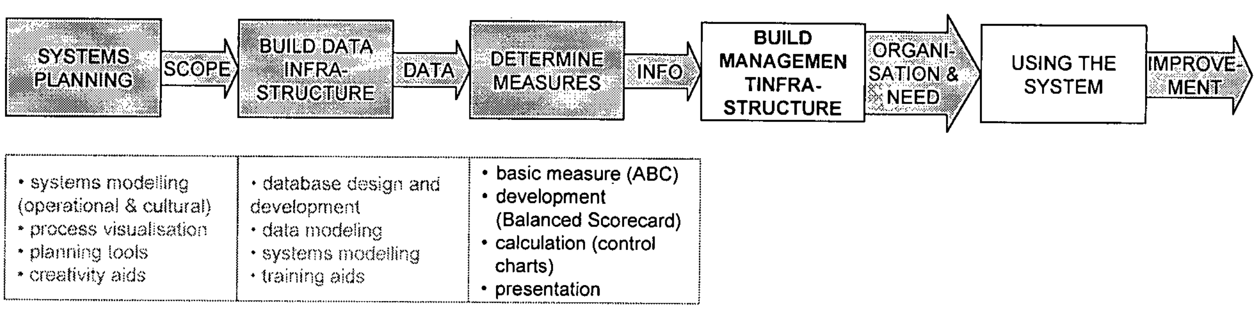

Figure 6-42: Structure of Chapter 5 showing the key OM Tool Categories for Determining Measures.

G.4 Management Infrastructure

Management infrastructure is basically the design and development of organisational activities resulting in a particular outcome such as motivation, participation, and/or action. Knowledge of the field of Organisational Sesign is the key to designing an appropriate management system. Some basics of organisational design are presented below.

G.4.1 Organisational Structure

An organisation is defined as "the planned co-ordination of two or more people who, functioning on a relatively continuous basis and through division of labour and hierarchy of authority, seek to achieve a common goal or set of goals."[24] An organisation's structure can be interpreted as having three components: complexity, normalisation, and centralisation.[25]

- **Complexity**: the degree to which organisational activities are different and to which integrating mechanisms are utilised to co-ordinate and facilitate the various components
- **Formalisation**: the degree to which an organisation relies on rules and procedures to direct the behaviour or the people
- **Centralisation**: the degree to which an organisation's decision making power is diffused downward within the hierarchy.

G.4.2 Organisational Design

Organisational design is the design of an organisation's structure to achieve the organisation's goals and involves:[25]

- Identifying the system's goals
- Making explicit the relevant measures of organisational effectiveness (OE), weighing them, and using these measures as criteria for evaluating alternative structures

- Systematically developing the design of the three major components of organisational structure (complexity, formalisation, centralisation)
- Systematically considering the system's technological, cultural, and relevant external variables as moderators of organisational structure
- Deciding on the general type of structure for the system.

Developing the goals and measures of the TMMS was undertaken in the first three phases of the TMMS methodology. Organisational effectiveness is an important consideration when choosing measures and structure. Table 6-4 is a list of criteria for organisational effectiveness.

Table 6-4: Criteria for Organisational Effectiveness

Technical	Cultural
• Overall effectiveness	• Accidents
• Productivity	• Absenteeism
• Efficiency	• Turnover
• Profit	• Job Satisfaction
• Quality	• Motivation
• Growth	• Morale
• Control	• Conflict/cohesion
• Planning and goal setting	• Control
• Flexibility/adaptation	• Planning and goal setting
• Stability	• Flexibility/adaptation
	• Participation
	• Goal consensus

G.4.3 Organisational Design as an OM Tool in Developing a Management Infrastructure

New organisational designs have been inspired from the development of information technology. Organisations with flattened hierarchies or management hierarchies based on processes are becoming more popular due to the visibility and monitoring ability of IT.[26, 27] Basics of organisational design and models of new organisations should be investigated prior to designing the management infrastructure in a TMMS. As the development of a TMMS is suggested to start small and altered when necessary an expertise in organisational design may not be necessary. However, understanding and using the guidance provided in this field of study may facilitate the creation of an appropriate data infrastructure. Figure 6-43 shows the primary tasks in designing an organisation.

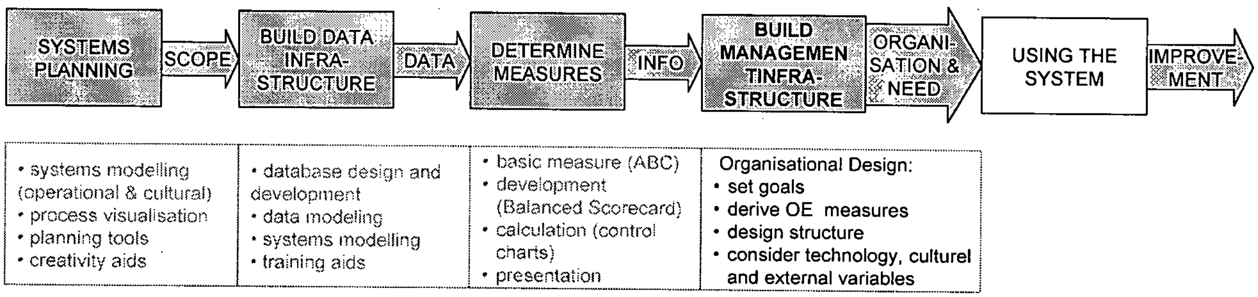

Figure 6-43: Structure of Chapter 5 showing the Steps in Organisational Design for Developing Management Infrastructure.

G.5 Using the System

The objective of this work is to produce a methodology resulting in a TMMS that motivates tactical managers to improve. It also provides the data and structure needed to undertake and sustain improvement initiatives. The development of an IT infrastructure provides the data needed to produce performance measures for performance management, which initiates the motivation to change. The IT infrastructure and determine measures phases also produce information that is readily available for use in today's modern management techniques. Using the system generates the motivation to improve. The management techniques described in this section can facilitate process improvements including:

- **Product and Transformation System**: improvements focusing on the core production processes.
- **Resource Management**: improvements focusing efforts on the structure and inputs of the processes.
- **Product Supply**: improvements focusing on the support processes of the system.

There are too many improvement techniques to provide an exhaustive list or descriptions. Two simple examples will be discussed. The first example will describe an application of the Theory of Constraints

(TOC) as a resource management and product supply improvement. The dual nature of this technique is derived from its ability to increase productive capacity while reducing work in process inventory.[28] The second example is an application of Forcefield Analysis as an example of a very simple improvement technique for quality management.

G.5.1 Theory of Constraints.

This method is designed to enhance profits, cashflow, and return on assets by increasing productive capacity while reducing unit input. This capacity improvement technique was developed by Eli Godratt[29] and widely accepted by others.[30] TOC focuses on three operational measures: throughput, operating expense, and inventory to provide feedback to decision-makers.[31] Throughput is defined as revenue minus cost of the raw materials based on the units sold (not produced). An expense is considered the cost of the raw materials needed to produce a unit of output, all other costs are considered operating (fixed) expenses.[32] This includes labour as Goldratt considers that labour is fixed in the short term. Inventory represents the cost of all the raw materials that have not yet been sold plus all capital assets. The goal is the maximisation of the system's throughput. The first step is to analyse the production system to identify the constraining process(es). Once the production system has been analysed, five steps of 'focusing' attempt to increase the throughput while minimising operating expense and inventory. These five steps are presented below.

1 - Identify the constraint: A constraining process can be typically identified by the amount of work-in-progress material waiting to be processed. For example, if a substantial amount of muck is waiting to be mucked in several stopes, the constraining process is mucking. If that muck is waiting because the ore passes, crushers, and loading pockets are full, the constraint lies in the hoisting process.

2 - Exploit the constraint: consists of squeezing the most throughput out of the resources paid for by the operating expenses. Consider the example where mucking was the constraint. No additional resources would be required if increased supervision time was spent at the mucking process, ensuring that the operating time was well spent.

3 - Subordination: In this focus, excess capacity in other processes is used to reduce the burden on the constraining process. For example by improving drill and blast design, the dilution can be decreased, leading to reduced inventory but more throughput (of the intended goal, metal). A different operator could also run the scoop while the regular scoop operator is on break ("hot-seat over break"), thereby increasing throughput without increasing operating expense.

4 - Elevation: The fourth step is to invest in added capacity by increasing operating expense, inventory, or both. For example, if an additional scoop is leased, the operating expense is increased but mucking process increased.

5 - Inertia: This element of TOC is simply a reminder to continue finding and reducing constraints in the production system. Reducing or eliminating a constraint in one process will increase the capacity of the overall system but will result in a different process becoming the bottleneck. For example, if the constraint of the mucking process is designed out of the system, perhaps another constraint will appear upstream or downstream of this process. For example, if mucking improves to such a degree that stopes are being emptied faster than they can be filled, perhaps the drilling and blasting processes need attention.

An application of the TOC technique requires substantial information input.[33] The TMMS provides that information and a method to track the improvements generated from applying this improvement tool. These types of continuous improvement tools can be made a permanent part of the TMMS whereby managers meet on a regular basis to find and eliminate constraints. This improvement method was found to be the best of all known optimisation techniques at improving productivity in complex operational systems.[34]

G.5.2 Force Field Analysis

Force Field Analysis is a technique to identify the forces that are present in a situation. This method is similar to the Systems Thinking technique whereby the driving and restraining forces are listed in order to gain understanding and to find solutions. This technique compares the dynamic forces of change and resistance in an attempt to reach a more desirable state. Figure 6-44 shows the primary elements of force field analysis within a mining example. A problem is proposed where a change from the current situation to an ideal situation is required. Only when the driving forces are stronger than the restraining forces will change occur. The process in the force field is as follows:[20]

- A small group of people is assembled to identify a situation which need changing;
- Brainstorming is used to identify driving and restraining forces;
- Consensus is reached about the most important restraining and driving forces;
- An action plan is formulated to strengthen driving forces and weaken restraining forces.

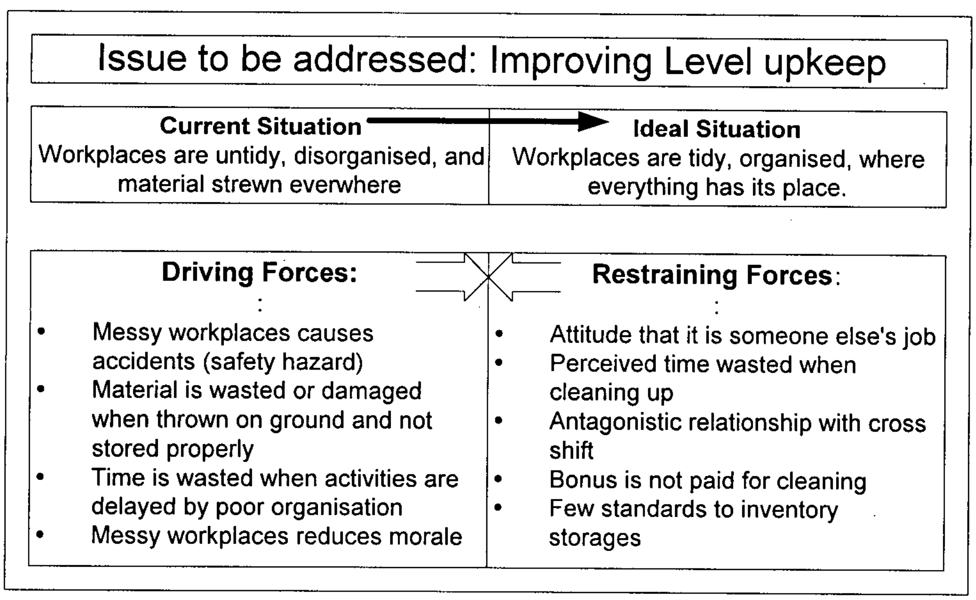

Figure 6-44: Force Field Analysis example

G.5.3 Management Techniques when Using the TMMS

Using a TMMS that was developed using the methodology proscribed in this thesis would provide the data and structure needed to apply modern management techniques in a mine. The capacity, inventory, cost, and throughput monitoring needed for TOC are easily provided by the ABC and performance aspect of the measures. The organisational structure needed for undertaking a force field analysis is provided by the management infrastructure. The impetus for initiating an improvement to the production or management systems is provided by the performance management mechanism within the TMMS. The essential element to systems planning, and using the system is knowledge of the various management techniques available. This is a process of education that will require development of the mine operation's managers. The process of educating front-line supervision should become common in mining.[35] Figure 6-45 shows the four categories of improvement initiatives that are enabled by developing a TMMS as prescribed in this work.

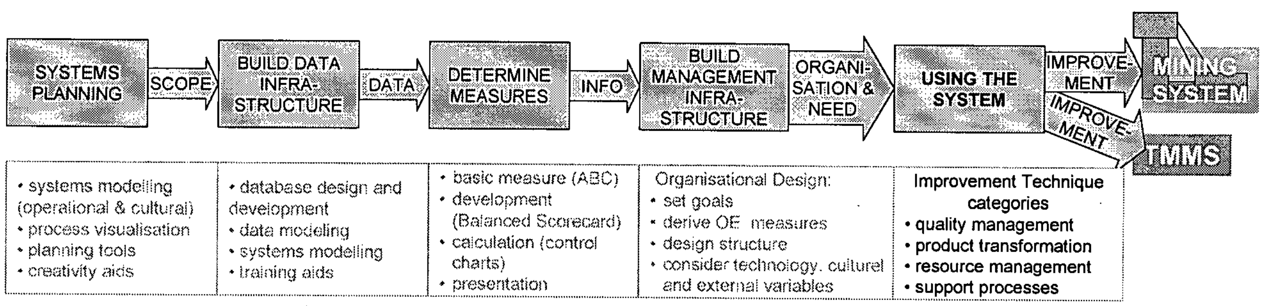

Figure 6-45: Structure of Chapter 5 Showing the Categories of Improvement Techniques.

G.5.4 List of Management techniques.

The following table attempts to classify the many different modern management techniques uncovered, described, studied, and/or applied in the course of undertaking this doctoral work. Table 6-5 is a list of modern management techniques showing their various uses. Systems modelling, improvement tools, and measures are self-explanatory. The 'strategic planning' category are tools which can be used in the development of a systems plan (and incidentally in strategic improvements). Implementation tools can be used to aid in the implementation of improvement initiatives or when developing a TMMS. It is beyond the scope of this work to provide a description of each technique however this table can be used to identify areas of interest for further research.

Table 6-5: OM techniques classification

OM Technique	System Modelling	Improvement Tool	Measures	Strategic Planning	Implementation	OM Technique	System Modelling	Improvement Tool	Measures	Strategic Planning	Implementation
Action Science		X		X		Mirror technique		X			
Activity Based Costing (ABC)	X	X	X	X		MRP / MRP II	X	X			
Analytical Hierarchy Process (AHP)			X		X	Multi-Skilling		X			X
Automation		X				Network logic	X				
Balanced Scorecard			X	X		Options Pricing	X				X
Benchmarking		X	X			Okuno's Five Techniques		X			
Brainstorming		X		X	X	Optimization		X			
Business Process Re-engineering (BPR)	X	X		X		Object-oriented programming	X				
Business Process Simplification and Improvement (BPS/I)	X	X		X		Process redesign decision support system (PRDSS)	X	X	X	X	
Change Management				X	X	PadeS Design sim		X			X
Cognitive Mapping	X			X		PERT		X			
Computer Aided Softare Engineering (CASE)	X					PC-based prototyping tools		X			X
Computer Integrated Engineering (CIE)	X	X	X			Organisational Design	X	X	X	X	X
Concurrent Engineering (CE)		X				Porter's five forces		X		X	
Conferencing		X		X		Process analysis	X	X	X	X	
Continuos Improvement (Kaisan)		X				Process design assitant		X			
Conventional programming		X				Process modeling tools	X	X	X		
Core process technique		X				Plant Layout		X			
Creative Problem solving (CPS)		X		X	X	Process Value Analysis	X	X	X	X	
Critical Success Factors (CFS)		X	X	X	X	Programmable databases and spreadsheets		X	X		
Data gathering and analysis tools		X	X			Project management tools		X		X	X
Decision analysis software		X		X	X	ProSim (simulation)		X			
Delphi		X				Prototyping;		X			X
Design for Assembly (DFA)		X				Quality Functional Deployment (QFD)		X	X		
Desktop graphics tools		X	X			Rapid systems development techniques		X			

OM Technique	System Modelling	Improvement Tool	Measures	Strategic Planning	Implementation	OM Technique	System Modelling	Improvement Tool	Measures	Strategic Planning	Implementation
DFD data flow diagram	X	X	X			Root Cause Analysis		X			
Employee Empowerment		X		X	X	Scenario analysis		X		X	
Error Free Manufacturing		X				Search conference				X	
Esprit project 8162 QUALIT		X	X			Simulation	X	X			X
Executive Information Systems		X	X	X		Skill Based Pay					X
Expert Systems			X	X		Socio-technical concepts	X	X		X	X
Fifth Discipline	X	X	X	X	X	Soft systems methodology	X				
Flowlines	X					Source Matrix		X			
Focus Theory		X				Statistical Process Control (SPC)		X	X		
Force Field analysis		X			X	Storyboarding				X	
Gantt Chart		X			X	Strategic Choice Approach				X	
General communications technologies		X			X	Strategic cost management				X	
Graphical modeling	X					structured design and analysis technique (SADT)	X				
Group decision-support systems (GDSS)			X	X		Supply Chain Management		X		X	
Group support systems (GSS)				X		Systemigram	X				
Hypermedia	X	X				Team effectiveness training		X		X	
Idea generation tools		X				Technology trend databases				X	
IDEF0	X					Theory of Contraints	X	X	X	X	
Influence diagrams	X	X	X	X	X	Time and Motion Studies	X	X	X		
Information engineering	X	X	X	X		Time window		X			
ISO 9000		X		X		TQM	X	X	X	X	
Just In Time (JIT)		X				Transfer pricing			X		X
Kanban		X				Transition management team				X	X
Key Performance indicators			X			Value analysis			X	X	
Learning organization	X	X	X	X	X	Value chain analysis		X	X	X	
Mass Customization		X				Very high level languages	X				
Measuring Change tolerance					X	Visible factory		X			

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