# Joint Enhancement of Mine Operations and Maintenance: A Structured Analysis Approach

by

Paul A. Roman

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## ABSTRACT

A good working relationship between the operations and maintenance departments is fundamental to the overall success of a mine. Unfortunately, the need for high productivity, coupled with a usually harsh physical environment that pushes a mine's equipment to the limits of its design capacity, result in a high-stress work environment making cooperation between these interdependent groups difficult. Rather than trying to resolve these issues through the blind application of new technology, this research suggests that a shared understanding of the joint information requirements of these two groups is a prerequisite step necessary to improve their business processes. Without this understanding, decisions concerning the application of new technology to the mining industry will continue to be based on functional boundaries that may improve departmental efficiency, but reduce overall mine effectiveness.

Using the Case Study approach, the structured analysis methodology is shown to be an effective way to gain this understanding. The methodology is applied to heavy truck maintenance and the production planning process for an open pit mine. In both cases, qualitative and quantitative benefits resulting from improvements made to these processes are presented. The most significant improvements are based on better communications through shared information. Generalisations on how this methodology can be applied to mining situations, other than open pit, are also included.

# TABLE OF CONTENTS

ACKNOWLEDGEMENTS ..... II

ABSTRACT ..... III

TABLE OF CONTENTS ..... IV

LIST OF FIGURES ..... viii

LIST OF TABLES ..... x

LIST OF ACRONYMS ..... XIi

**CHAPTER 1** ..... 1

1. INTRODUCTION ..... 1

1.1. OPERATIONS AND MAINTENANCE RELATIONSHIPS ..... 1
1.2. THE IMPACT OF THE INFORMATION REVOLUTION ..... 5
1.3. STRUCTURED ANALYSIS AND DESIGN TECHNIQUES ..... 7
1.4. RESEARCH OBJECTIVES ..... 9
1.5. SCOPE ..... 9
1.6. OUTLINE ..... 10

**CHAPTER 2** ..... 11

2. OPERATIONS AND MAINTENANCE RELATIONSHIPS IN MINING ..... 11

2.1. INTRODUCTION ..... 11
2.2. THE TIME MANAGEMENT MATRIX ..... 11
2.3. CONFLICTS BETWEEN OPERATIONS AND MAINTENANCE ..... 15
2.4. KEY PERFORMANCE INDICATORS IN OPERATIONS AND MAINTENANCE ..... 17
2.4.1. The Availability/Utilisation Conflict ..... 20
2.4.2. Maintenance Costs ..... 22
2.5. SUMMARY ..... 23

**CHAPTER 3** ..... 24

3. COST IMPLICATIONS OF CURRENT EQUIPMENT TRENDS IN MINING ..... 24

3.1. INTRODUCTION ..... 24
3.1.1. Economies of Scale ..... 25

3.2. INTRODUCTION - HAULAGE CAPACITY EXAMPLE ..... 29
3.2.1 Estimating Downtime Costs ..... 31
3.3. DESCRIPTION OF SIMULATION EXAMPLE ..... 33
3.4. SENSITIVITY ANALYSIS ..... 35
3.5. RESULTS ..... 36
3.6. CONCLUSIONS AND RECOMMENDATIONS ..... 38
3.7. SUMMARY ..... 40

**CHAPTER 4** ..... 41

4. MINE OPERATIONS PLANNING & MAINTENANCE MANAGEMENT ..... 41

4.1. INTRODUCTION ..... 41
4.2. THE OPERATIONS PLANNING PROCESS ..... 42
4.2.1. Establishing Grades and Volume Requirements ..... 45
4.2.2. Equipment Selection/Mine Design ..... 47
4.2.3. Scheduling Mining Activities ..... 50
4.3. EMERGING TECHNOLOGIES – MINE PLANNING AND OPERATIONS ..... 51
4.3.1. Advanced Mining Management Information Systems ..... 52
4.3.2. On-board monitoring systems ..... 54
4.3.3. Mining Automation ..... 56
4.3.4. Evaluation of Emerging Technology ..... 60
4.4. MAINTENANCE MANAGEMENT ..... 61
4.4.1. Preventive Maintenance ..... 64
4.4.2. Reliability Centred Maintenance ..... 67
4.4.3. Predictive Maintenance ..... 69
4.4.4. Maintenance Management Information Systems ..... 72
4.4.5. Equipment (Asset) Management ..... 73
4.5. THE ROAD TO AN ENTERPRISE WIDE MINING INFORMATION SYSTEM ..... 76
4.6. SUMMARY ..... 83

**CHAPTER 5** ..... 86

5. THE STRUCTURED ANALYSIS METHODOLOGY ..... 86

5.1. INTRODUCTION ..... 86
5.2. STRUCTURED ANALYSIS DEFINED ..... 91
5.2.1. Styles of SA ..... 92
5.3. MODEL SYNTAX AND USAGE ..... 92
5.4. THE MODELLING PROCESS ..... 100
5.4.1. Knowledge Acquisition ..... 100
5.4.2. Documenting Acquired Knowledge ..... 101
5.4.3. Model Validation ..... 102
5.5. AUTOMATED SUPPORT ..... 103
5.6. SUMMARY ..... 104

**CHAPTER 6** ..... 106

6. A STRUCTURED ANALYSIS OF HEAVY TRUCK MAINTENANCE ..... 106

6.1. CASE STUDY PART I - INTRODUCTION ..... 106
6.2. DESCRIPTION OF THE HTMBU ..... 107
6.3. CASE STUDY SCOPE ..... 108
6.4. SELECTING THE APPROPRIATE VIEWPOINT ..... 111
6.4.1. The Team Leader's Viewpoint ..... 112
6.4.2. The Maintenance Team Viewpoint ..... 115
6.5 ANALYSIS AND RESULTS ..... 117
6.5.1. Opportunity 1 – Breakdown Maintenance Data Collection ..... 118
6.5.2. Opportunity 2 – Breakdown Maintenance Cost Data Collection ..... 121
6.5.3. Opportunity 3 - Streamlining Loss Management Reporting ..... 123
6.5.4. Opportunity 4 - Alignment of Pay and Rewards with Team Performance ..... 125
6.6. SUMMARY OF IMPROVEMENTS ..... 126
6.7. CONCLUSIONS ..... 127

**CHAPTER 7** ..... 129

7. A STRUCTURED ANALYSIS OF OPERATIONS AND MAINTENANCE ..... 129

7.1. INTRODUCTION ..... 129
7.1.1. Selecting an Appropriate Viewpoint ..... 130
7.2. SCOPE ..... 131
7.3. DESCRIPTION OF THE "AS-IS" TRUCK/SHOVEL PRODUCTION PLANNING PROCESS 132
7.4. ANALYSIS AND RESULTS ..... 134
7.4.1. Improved Information Flow for Decision Making ..... 135
7.4.2. Improved Short-term Production Planning Process ..... 139
7.4.3. Improved Long-term Production Planning Process ..... 146
7.4.4. Cost Control Strategy ..... 149
7.5. SUMMARY OF IMPROVEMENTS AND RECOMMENDATIONS ..... 152
7.6. CONCLUSIONS ..... 154

**CHAPTER 8** ..... 156

8. STRUCTURED ANALYSIS OF MINING – A BROADER CONTEXT ..... 156

8.1. INTRODUCTION ..... 156
8.2. SA APPLICATION TO OTHER OPEN PIT OPERATIONS ..... 156
8.3. APPLICATIONS TO HARD ROCK UNDERGROUND MINING ..... 158
8.4. INTEGRATION OF MINE AND MILL PLANNING ..... 159
8.5. IMPROVING RELATIONSHIPS WITH EQUIPMENT/SOFTWARE VENDORS ..... 161
8.6. USING SA MODELS FOR ACTIVITY BASED COSTING ..... 162

**CHAPTER 9** ..... 165

9. CONCLUSIONS ..... 165

9.1. SUMMARY OF ORIGINAL CONTRIBUTIONS ..... 165
9.2. BENEFITS ..... 166
9.3. FUTURE WORK ..... 168

REFERENCES ..... 170

APPENDIX A ..... A-1

APPENDIX B ..... B-1

APPENDIX C ..... C-1

APPENDIX D ..... D-1

APPENDIX E ..... E-1

# LIST OF FIGURES

## CHAPTER 1

Figure 1.1: Maintenance Program Satisfaction Survey ..... 3

## CHAPTER 2

Figure 2.1: The Time Management Matrix ..... 12
Figure 2.2: Factors Influencing Equipment Productivity ..... 18

## CHAPTER 3

Figure 3.1: Trends in Haul Capacity for Open Pit Mines ..... 27
Figure 3.2: Effects of Larger Capacity Equipment on Downtime Costs ..... 32

## CHAPTER 4

Figure 4.1: Scope of the Operations Planning Process ..... 43
Figure 4.2: The Operations Planning Process ..... 43
Figure 4.3: From the Model to the Mill ..... 46
Figure 4.4: Embedded Production Monitor/Controller ..... 55
Figure 4.5: Schematic diagram for a tele-operated video control system LHD ..... 57
Figure 4.6: Possible Maintenance Policies ..... 63
Figure 4.7: Simplified RCM Logic ..... 67
Figure 4.8: Conventional Condition-Based Maintenance ..... 69
Figure 4.9: Embedded Model-Based CBM ..... 71
Figure 4.10: Mining Enterprise Information System ..... 81
Figure 4.11: The Mining Enterprise Solution ..... 83

## CHAPTER 5

Figure 5.1: The SA Box ..... 93
Figure 5.2: Sample Context Diagram ..... 94
Figure 5.3: Sample Level 0 Diagram ..... 96
Figure 5.4: Bitumen Production, Syncrude/A1 ..... 98
Figure 5.5: Mining, Syncrude/A11 ..... 99

## CHAPTER 6

Figure 6.1: Context Diagram (MT-1) ..... 109
Figure 6.2: Context Diagram – Team Leader's Perspective (TL-1) ..... 113
Figure 6.3: Level-0 Diagram from Team Leader's Perspective (TL-2) ..... 115
Figure 6.4: Level-0 Diagram from Maintenance Team Viewpoint ..... 116
Figure 6.5: Categories of Downtime ..... 119

## CHAPTER 7

Figure 7.1: Context Diagram – Truck/Shovel Production Planning (as-is model) ..... 131
Figure 7.2: Level-0 Diagram for the as-is Model ..... 133
Figure 7.3: Sample Mean Chart for Truck Availability (793 Fleet, 1/10/98 – 31/3/99). 138
Figure 7.4: Daily Planning (as-is) ..... 140
Figure 7.5: 0815 Production Coordination (as-is) ..... 141
Figure 7.6: 0815 Production Coordination (to-be) ..... 144

## CHAPTER 8

Figure 8.1: Cost Behaviour over the Life Cycle of a Mine ..... 163

# LIST OF TABLES

## CHAPTER 3

Table 3.1: Mobile Equipment Costs IOCC ..... 30
Table 3.2: Results of RAPTOR™ Simulation ..... 37

## CHAPTER 4

Table 4.1: Ratio of Maintenance Costs to Total Value Added Costs ..... 63
Table 4.2: Top six reasons for IT Project Failure ..... 80

## CHAPTER 7

Table 7.1: Availability Improvements Based on Improved Short-term Planning ..... 154

# LIST OF ACRONYMS

| | |
|---|---|
| ABC | Activity Based Costing |
| AGM | Annual General Meeting |
| BPwin™ | Business Processes for Windows |
| BS | British Standard |
| BU | Business Unit |
| CAD | Computer Aided Design |
| CASE | Computer Aided Software Engineering |
| Cat 793 | Caterpillar's 240-ton haul truck |
| Cat 797 | Caterpillar's 360-ton haul truck |
| CBM | Condition-Based Maintenance |
| CECAM | Computerised Equipment Control and Monitoring |
| CFS | Cut and Fill Stoping |
| CIM | Canadian Institute of Mining, Metallurgy and Petroleum |
| CIM | Computer Integrated Manufacturing |
| CM | Corrective Maintenance |
| CMC | Co-ordinated Motion Control |
| CNS | Communication Network Slave |
| CWA | Contract Work Order |
| DMMS | Distributed Mine Management System |
| DSS | Decision Support System |
| EVA | Economic Value Added |
| FG | Focus Group |
| GPS | Global Positioning System |
| HTMBU | Heavy Truck Maintenance Business Unit |
| IAS | Intelligent Antenna System |
| IAW | In Accordance With |
| IRR | Internal Rate of Return |
| IOCC | Iron Ore Company of Canada |
| IDEF0 | Integrated Definition Language (Ver. 0) |
| IT | Information Technology |
| KBS | Knowledge-Based System |
| KPIs | Key Performance Indicators |
| LAN | Local Area Network |
| LCR | Loss Control Report |
| LHD | Load-Haul-Dump (Vehicle) |
| LHS | Longhole Stoping |
| LM | Loss Management |
| MIS | Management Information System |
| MMIS | Maintenance Management Information System |
| MMS | Maintenance Management System |
| MTBF | Mean Time Between Failures |
| MTTR | Mean Time To Repair |

| | |
|---|---|
| NPV | Net Present Value |
| OEM | Original Equipment Manufacturer |
| PHM | Proportional Hazards Modelling |
| PKS | Pay for Knowledge and Skills |
| PM | Preventive Maintenance |
| RAPTOR™ | Rapid Availability Prototype Testing for Operational Readiness |
| RCM | Reliability Centred Maintenance |
| RFI | Requests for Information |
| RTF | Run-to Failure |
| SA | Structured Analysis |
| SCL | Syncrude Canada Ltd. |
| TBF | Time Between Failures |
| TF | Task Force |
| TMS™ | Total Mining System |
| TTR | Time To Repair |
| VIMS | Vital Information Monitoring System (Caterpillar Inc.) |
| WO | Work Order |

# CHAPTER 1

## 1. Introduction

### 1.1. Operations and Maintenance Relationships

A good working relationship between the operations and maintenance departments in both open pit and underground mines is fundamental to the overall success of the organisation. Although this statement describes the ideal situation, unfortunately, this is not usually the case. Short-range production targets dominate the day to day management of the mine resulting in a high-pressure working environment. This, in turn, often results in a strained relationship between these two equally important departments. For example, Bostwick and Buchanan (1993) report on American Barrick Resources efforts to achieve an aggressive 415,000 tons per day mining program at their Goldstrike operation in Nevada. In their efforts to economically push production output to such high levels, mines are expecting corresponding increases in the productivity of their mine mobile equipment. To the maintenance manager, the high production targets are translated into correspondingly high levels of required equipment availability needed to achieve the production targets in a cost-effective manner. The point is that the requirement to meet the aggressive targets can lead to short-term focus that recognises the efficiencies associated with delaying scheduled maintenance. Eventually, however, short-term neglect will result in long term problems. The result of pushing the mine's equipment to the limits of its design capacity and beyond is equipment failure. Since these failures were not planned, they have an even greater impact

than if the scheduled maintenance had been performed. In particular, failure maintenance results in a loss of production. Since this decrease in production capacity was not part of the production plan, these failures often end with targets being missed or achieved only through expensive alternatives such as contract mining. From the production manager's perspective, failures are a maintenance responsibility and it becomes easy to shift the blame to the maintenance manager.

In most cases, it is unlikely that the maintenance manager will fully accept responsibility for lost production due to equipment failure. After all, his technicians were not the ones operating the equipment when it failed. Furthermore, the maintenance manager can probably produce a list of all of the scheduled maintenance actions that were missed because operations refused to release the equipment. This particular scenario is fictional, but not uncommon. When production managers do not meet their quotas, the finger is often pointed at maintenance. As a result, a confrontational culture can develop between the two organisations resulting in a lack of cooperation that exacerbates the problem.

A recent survey by Coopers and Lybrand provides some insight into the strained relationship between operations and maintenance (Campbell, 1997). The survey was distributed to production managers in the mining industry. A summary of the responses to the question: "Are you satisfied with the current maintenance program?" is provided in Figure 1.1. The figure shows that from a production manager's perspective, few seem totally satisfied with their current maintenance program. Combining those who responded no (24%) with those who responded sometimes (53%) suggests that over three-quarters of those

surveyed (77%) believe there is room for improvement in their respective maintenance programs. The following survey statements given by the production managers as to why they were dissatisfied further support this. These are:

(a) Chronic equipment failures.

(b) Conflicts between production and maintenance.

(c) Excessive maintenance costs.

(d) Unnecessary preventive maintenance.

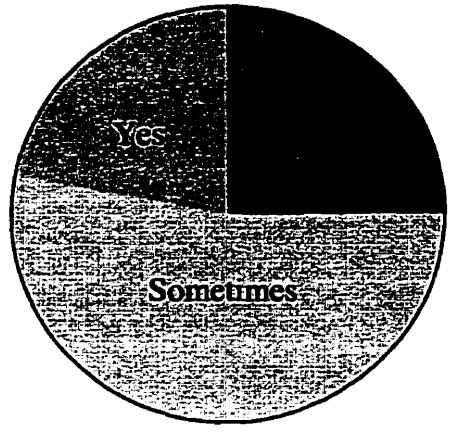


**Figure 1.1: Maintenance Program Satisfaction Survey (Campbell, 1997)**

These statements can be seen as symptoms of an underlying problem that is best described as an operations/maintenance gap. The notion of a gap between production and maintenance is not unique to the mining industry, but potentially exists in any organisation that has one group responsible for operations and a separate group tasked with maintaining their equipment. In the manufacturing sector, for example, operations managers also rely heavily on the maintenance staff to keep their equipment operating in order to meet production targets. In the mining industry, the problem is far more acute due to the

demanding operational environment under which the equipment must operate. Clearly, the overall performance of the mine depends on both operations and maintenance. When targets are not met, the potential for the two departments to assign blame to each other is high. It is the underlying need to assign blame for poor performance that creates the potential for conflict between the two departments.

The degree of cooperation and the quality of the interactions between operations and maintenance will determine how well these two groups work together. For example, one area where this interaction would be very important, yet appears to be almost non-existent, is in the equipment selection process. Although upper management normally makes the final decision on which equipment to purchase, many people are involved in the decision process. In most cases, operations are involved since they represent the people that will actually operate the equipment. The maintenance department, however, is rarely involved in the decision-making process despite being a primary stakeholder in terms of what equipment is actually procured. Only through an understanding of the full life cycle costs, including maintenance costs, can the mine hope to make an informed decision. The decision-makers at the mine should not rely solely on the cost estimates provided by the original equipment manufacturer (OEM). Rather, they should involve their own maintenance personnel to at least confirm these estimates. More importantly, however, the maintenance department should be asked to conduct their own analysis into the maintainability of the equipment under consideration. They are the only group capable of accurately assessing the impact of the new equipment with respect to maintenance costs. Making a major equipment procurement decision without consulting the maintenance department will result in decisions that do not

accurately take into account the full life cycle cost implications of the purchase. Furthermore, if left out of the decision, the maintenance department could be in a position to criticise the selection putting them at odds with the operations department.

### *1.2. The Impact of the Information Revolution*

Social scientists generally agree that the key to any successful relationship is clear and open communications. In the mining industry, a more detailed examination of the operations/maintenance gap (presented in Chapter 2) reveals a requirement for accurate information and a need to communicate it more effectively. A mine's information requirements should be based on timely, well defined, recognised and verifiable objectives that can be measured accurately. When the information is not accurate or is late, then the potential for further conflict exists. Furthermore, having confidence in the analysis of properly collected data not only leads to better decisions, but can also promote a shared understanding across departmental boundaries.

Few would argue that the information revolution that has occurred in the latter part of the 20$^{th}$ century has had a tremendous impact on the way the industrialised world conducts business. The combination of powerful software and improving communications technology has lead to an era of incredible technological advancement. The mining industry's participation in this revolution has resulted in many benefits in specific areas such as computer-aided mine design, mine planning software, and condition-based monitoring (CBM). In Chapter 4, a detailed review of the application of this emerging technology to both production planning and maintenance management is presented. Although technology

has proven merits for each organisation when viewed in isolation, it does little to bring these two functional areas together because it is applied in a piecemeal fashion along departmental lines. Rather than breaking down boundaries, technology is reinforcing them. For example, the latest mine production planning software continues to neglect maintenance and maintenance departments' focus on achieving maintenance efficiencies, sometimes at the expense of overall mine effectiveness.

Another potential problem in this area is the practice of applying the latest technology to an existing process without first working out the flaws within the process itself. Software vendors, anxious to promote their successful products used in other industries (e.g., manufacturing), convince mine personnel that, through minor modification, their software can be directly applied to mining practices. In some cases, this has proven successful. In general, however, if the mining process itself is poorly defined it is doubtful that the application of the software will meet the poorly stated or misunderstood requirements. This is particularly true for systems used across functional boundaries where user requirements from different departments may vary. Production planning software, for example, should include the maintenance implications of the plans developed as an integral part of the production planning process. Similarly, maintenance-scheduling packages need to include constraints imposed by production requirements. Software tools applied to existing processes that already lack the required integration might prove efficient for the user department, but will be ineffective for the mine overall. Making matters worse, once committed to a particular tool, users will be inclined to want to justify the expense and as a

result will be even less willing to consider integrating their processes if it means giving up or modifying the software.

The underlying contention of this study is that the key to improved performance lies within the relationship between operations and maintenance. It is the integrated output of these two inextricably linked organisations that will ultimately determine a mine's overall performance. Until operations and maintenance departments recognise the importance of cooperation, continued technological enhancements to existing practices will be ineffective and continue to disappoint. Furthermore, these issues go well beyond the integration of existing stand-alone systems. The requirement for change extends to include a clear understanding of the basic business processes in place at the mine followed by a thorough analysis to reveal information shortfalls and duplication. The last step in the analysis is to determine whether existing information systems meet the requirements of the improved processes. Only then can the effectiveness of technological enhancements be accurately evaluated.

### *1.3. Structured Analysis and Design Techniques*

The risks associated with automating existing information flows without first completing a structured analysis are well documented (Sprague and McNurlin, 1986; Gray et al., 1989). Despite this, the mining industry appears to be falling into the same trap. Production planners, enamoured by the bells and whistles associated with a particular software vendor's product, readily adapt their planning methodology to accommodate the software's input requirements. Owing perhaps to a sense of fear associated with losing the

competitive advantage if they do not modernise, production planners have become anxious to implement the most recent advances regardless of whether or not they actually need it. Maintenance managers have also been buying software, hoping to capitalise on the new technology. Indeed, equipment manufacturers have made on-board data acquisition systems standard equipment on most mobile equipment. The mines do not necessarily require this functionality but assume that since everybody else is getting the capability, then it must be worthwhile. Knowing what to do with the data once it is collected is quite a different matter. Maintenance managers find themselves in a situation that is characterised by the phrase: "Data rich, but information poor".

Information technology specialists, driven primarily by defence contract requirements in the United States, have turned to structured analysis (SA) to avoid this pitfall. Tom DeMarco (1979) was the first to publish a textbook on the subject - *Structured Analysis and System Specification.* Since then, the technique has become very popular to the point where the U.S. Department of Defence decided to create a government standard that could be used for defence contracts. This standard is called the Integration Definition Language 0 (IDEF0, pronounced IDEF zero), (FIPS PUB, 1993).

Chapter 5 describes IDEF0 as a meaningful modelling technique that goes beyond the specification of data requirements and information flows for software programs to include applicability to business process re-engineering. Perhaps the greatest strength of the IDEF0 approach lies in the simplicity of the models themselves. Combinations of boxes (representing activities) and arrows (representing data flows) are presented in a hierarchical

fashion to effectively decompose the most complex process into its simplest components. Based on these models, the effectiveness of changes to the existing processes can be evaluated.

### *1.4. Research Objectives*

This research presents an analysis methodology based on the IDEF0 modelling technique. Rather than using the technique to create an information technology solution, however, it will be applied in a mining context to help derive an understanding of the shared informational requirements of the mine management team. In addition to determining a mine's basic information requirements with respect to operations and maintenance, the methodology will be applied to improve overall mine effectiveness through better communication and coordination between operations and maintenance.

### *1.5. Scope*

The thesis objectives will be achieved using the case study approach. Two concerns when conducting case research are related to objectivity and the ability to generalise the findings. As the researcher becomes directly involved in the processes under study he may lose objectivity. Also, since the case study approach results in the research focusing on a particular mine, the general applicability of approach may become difficult to justify. An alternative approach would be to conduct a survey study. This would improve general applicability of the findings but make it impossible to assess the detailed impacts of actually applying the technique. For this reason, it was decided that the advantages associated with

actually applying the methodology far out-weighed the risks associated with objectivity and general applicability.

### *1.6. Outline*

After a detailed discussion of the operations and maintenance relationship described in Chapter 2, Chapter 3 examines the cost implications of current equipment trends that may potentially increase the operations/maintenance gap. A thorough literature review of current and emerging practices in the operations planning and maintenance management processes is presented in Chapter 4. The structured analysis methodology is covered in Chapter 5. Using Syncrude Canada Ltd. (SCL) as an example, this chapter highlights the effectiveness of this graphical approach to easily represent complex systems. The approach is then applied in a maintenance context to the heavy truck maintenance business unit (HTMBU) at SCL in Chapter 6. Chapter 7 outlines the structured analysis of the production planning process employed at SCL. This analysis is used to demonstrate the importance of integration of the operations and maintenance functions. The findings of the case study are generalised in Chapter 8 to show the broad applicability of the methodology in a mining context. Conclusions are presented in Chapter 9 along with suggestions for future research.

# CHAPTER 2

# 2. Operations and Maintenance Relationships in Mining

## 2.1. Introduction

If a key to future improvements in mining profitability lies in the effectiveness of the interaction between the operations and maintenance departments, then an understanding of the nature of their relationship is essential. In this chapter, we will examine the overall framework of that relationship.

As a backdrop to this discussion, the time management matrix will first be presented (Covey, 1989). This matrix provides an interesting categorisation of the way people spend their time. This will provide insight into the importance of the maintenance function as well as why production mangers may favour putting off preventive maintenance tasks to meet urgent production targets. Through an understanding of these two perspectives, the subsequent discussion on current practices for both sides of the mining equation will become more meaningful. In particular, the key performance indicator linking the two departments, that is the availability of mine mobile equipment, will be discussed.

## 2.2. The Time Management Matrix

In his book, *The Seven Habits of Highly Effective People*, Covey presents the time management matrix as adapted in Figure 2.1 (Covey, 1989). This matrix was developed to illustrate the difference between urgency and importance. This distinction may seem subtle

at first, but provides fundamental insight into the key issues that affect the character of the relationship between the operations and maintenance departments at a mine. Covey argues that urgency and importance are the two primary factors that drive people's choices concerning how they spend their time. He contends that, typically, one of the two factors is paramount. The author further suggests that depending on whether individuals (and organisations for that matter) operate from a paradigm of urgency or importance will have a profound impact on their effectiveness. As will be described below, this characterisation is particularly valid in the mining industry where the requirement to meet daily production targets force managers to operate under what Covey would call "the urgency addiction."

| | **Urgent** | **Not Urgent** |
|---|---|---|
| **Important** | **I**<br>• Crisis<br>• Failure maintenance<br>• Deadlines<br>• Pressing problems<br>• Meetings | **II**<br>• Planning and preparation<br>• Preventive maintenance<br>• Relationship building<br>• Professional development |
| **Not Important** | **III**<br>• Interruptions, some phone calls<br>• Some reports<br>• Some meetings<br>• Many popular activities | **IV**<br>• Irrelevant mail<br>• Excessive maintenance<br>• Gossip<br>• Trivia, busywork |

**Figure 2.1: The Time Management Matrix (adapted from Covey, 1989)**

The four quadrants in the matrix are used to categorise the way we spend our time based on whether an activity is urgent, important, both or neither. For example, a union strike that effectively shuts down a mine would be both urgent and important making the strike negotiations a quadrant I activity. Similarly, repairing a broken-down shovel that is key to meeting the daily production target would also be a quadrant 1 activity. Maintenance resources may well be diverted from routine tasks in order to address this urgent and important requirement.

Quadrant II, on the other hand, is reserved for activities that are important but not urgent. Preventive maintenance, for example, is a quadrant II activity. It is important in order to keep a piece of equipment operating at peak performance levels, but it is not urgent since we can put it off for another day or so if we have some more urgent failure repair to complete. This may well be an appropriate prioritisation of maintenance effort. However, if a mine neglects preventive maintenance, they will eventually have nothing but critical failure maintenance with which to contend. For example, recall from Chapter 1 that the Coopers and Lybrand survey cited chronic equipment failure as one of the reasons for production managers' dissatisfaction with their maintenance programs (Campbell, 1997).

Activities that fall under quadrants III and IV share the fact that they are not important. A ringing telephone is urgent since if you do not answer, you may miss an important call. Unfortunately, we cannot determine whether the call is important or not until we answer. Even then, we may be duped into believing the subject matter of the call is important even if it is not. For example, a request for maintenance from a haul truck operator

would generally be considered urgent since the truck and driver are unable to produce. If it turns out, however, that the nature of the request was frivolous then this urgent activity would also be not important (quadrant III). Again, returning to the Coopers and Lybrand survey we find evidence of quadrant III activity in the comments from the dissatisfied production managers. Conflict between production and maintenance as noted in the survey, is a quadrant III activity. Time spent arguing over this seemingly important issue is really wasted. The important matter is not to assign blame (even though this may seem urgent); rather, it is to discover the root of the problem so that the conflict can be successfully resolved.

Quadrant IV involves activities that are neither important nor urgent. It is the quadrant of waste and procrastination. Excessive preventive maintenance, like that reported in the Coopers and Lybrand survey, would qualify as a quadrant IV activity. Excessive preventive maintenance takes resources away from other important tasks and also introduces the possibility of maintenance induced failures. There is nothing more frustrating to an equipment operator than having to turn in an operational piece of equipment for servicing, only to get it back in worse shape than when it went for service.

The matrix highlights two important factors that are relevant to the study of the relationship between the operations and maintenance departments at a mine. First, it helps explain the way in which importance and urgency affect the decisions people make about the way they spend their time. For example, rather than wasting time trying to assign blame for equipment problems (quadrant III), the time would be better spent trying to uncover the root

of the problem and develop a plan to improve the situation (quadrant II). Second, an understanding of the relationship between importance and urgency can be used to determine the degree to which importance can suffer due to urgency. Crisis management should be the exception and not the rule. Failure maintenance should not consume the maintenance department who would be much more effective if their efforts focused on avoiding the breakdowns in the first place.

### *2.3. Conflicts between Operations and Maintenance*

To illustrate how differences between operation and maintenance can be created, consider an open pit mine that has made a policy decision to operate in what the mine planners consider to be a slightly under trucked mode. This is consistent with industry practice based on a desire to have high equipment utilisation and low production costs (Blackwell, 1998). Production targets are set based primarily on economic factors with due consideration to how well the mine performed last year. For this scenario, assume that the equipment profile has remained constant, but that targets have been set a little higher than last year in an effort to improve cost performance.

Knowing that they are slightly under trucked, the planning staff will demand high levels of truck availability that will be required to meet the production targets that have been increased from last year. Since the planning staff generally work for the operations manager, it is unlikely that they have consulted with maintenance on their ability to meet the availability levels. The planners understand that they will be pushing the equipment a little

harder to meet the increased production targets, but assume maintenance will do its part to meet the mines overall objective to improve cost performance.

If the production targets are met, the cost performance of the mine may improve and there will be very little conflict between operations and maintenance. However, if the production targets are not met and the mine manager, in an honest effort to find solutions, asks his two department heads why, then the stage is set for the creation of an operations/maintenance gap. The operations manager will be inclined to blame maintenance for excessive downtime and too many equipment breakdowns. The maintenance manager, on the other hand, is likely to suggest poor operator practice and low levels of equipment utilisation as underlying causes. In both cases, unless there is absolute trust in the mine's data collection and analysis methods, the numbers used to make the arguments will be disputed.

The above hypothetical scenario is not uncommon. Even though the true underlying cause may well be that the production targets were not realistic in the first place, the strained working relationship between operations and maintenance has resulted in two departments focusing on blame rather than finding a solution. They are far less interested in understanding each others problems than they are in defending their own departments actions. The resulting decision-making climate within the two departments becomes divisive as choices are based on departmental rather than mine-wide objectives. For example, in an effort to document a lack of cooperation, maintenance may increase the frequency of preventive maintenance requests knowing full well that operations will refuse to release the

equipment due to production requirements. Operations may become less inclined to provide the full details of how a breakdown occurred since downtime due to failure is assigned as a maintenance responsibility. Under these circumstances, the working relationship between the two departments is likely to deteriorate over time making matters much worse. Determining the extent of this deterioration is a difficult problem that will depend on how the mine measures performance.

### *2.4. Key Performance Indicators in Operations and Maintenance*

A rather simple characterisation of the relationship between operations and maintenance could be based upon the assertion that operations use the equipment and maintenance keeps the equipment operating. Under this model, the key performance indicator linking the two departments would be equipment availability. Clearly, chronic equipment failures, as reported in the Coopers and Lybrand survey, will result in low availability. This will inevitably have an impact on production creating an urgent situation that could potentially lead to conflicts between operations and maintenance. However, is this purely a maintenance responsibility?

From a more global perspective, what the mine requires from both departments is productivity. The productivity of mobile mining equipment including drills, trucks, shovels and load-haul-dump (LHD) vehicles is a complex function of several factors. The machine's inherent design, operator skill, operating environment and servicing requirements are all critical factors in determining how productive a particular machine will be. Furthermore, as pointed out by Kohler and Sottile (1993), mobile mining equipment is generally operated

under severe conditions that often stress a machine's electrical, hydraulic and mechanical components to the limit of their design capabilities. It should not be surprising therefore, that maintaining high levels of productivity for this equipment poses a significant challenge to equipment manufacturers, operations managers and maintenance managers. Figure 2.2 describes the factors that influence equipment productivity with particular emphasis on availability.

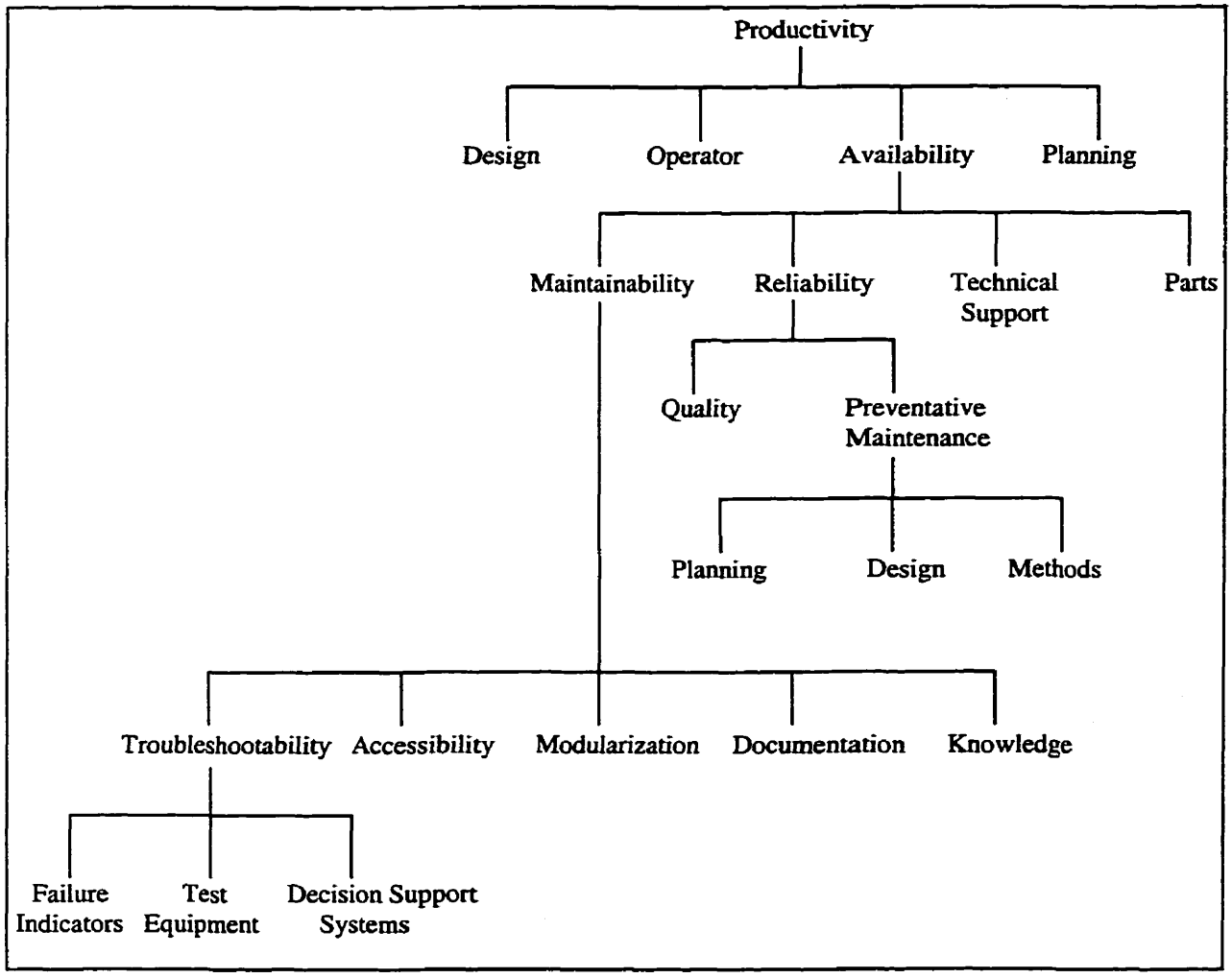


**Figure 2.2: Factors Influencing Equipment Productivity (Nillson and Ouellette, 1992)**

Although design is shown in Figure 2.2 as a distinct factor influencing productivity, it is important to note that the design of the equipment has a pervasive influence across the

other three primary factors. For example, the ergonomic characteristics of the operator interface will play a major role in determining how effectively the equipment can be operated. The basic reliability and maintainability characteristics are also a function of design. The accessibility of frequently changed filters, for example, will have a significant impact on availability. If the equipment designer made it easy for these filters to be changed then there is clearly a direct benefit resulting from less time required to change the filters. Perhaps more important, however, is the indirect benefit associated with the fact that the operator will not view changing the filter as an onerous task. If the filter is difficult to change, operators will tend to avoid this critical task which could eventually lead to more serious breakdowns. Even planning is affected by the equipment design since the design will dictate the maximum productive capacity of the machine.

From a mine's perspective, however, once a particular piece of equipment is purchased, the design is relatively fixed. Although minor modifications are possible over the life cycle of an asset, these will not have a significant impact on the overall characteristics of the equipment. Consequently, once a particular machine is put into service, its inherent availability characteristics are already determined. It is up to the mine to operate and maintain the equipment in a manner that will allow them to achieve maximum performance from the equipment.

Blanks (1992) defines availability as the probability that an item, under the combined influence of its reliability, maintainability and maintenance support, will be able to fulfil its required function over a stated period of time or at a given point in time. He further defines

reliability as the ability of an item to perform a required function under stated conditions for a stated period of time. Similarly, maintainability describes the ability, under stated conditions of use, to be retained in, or restored to, a state in which it can perform its intended function, when maintenance is performed under stated conditions and using prescribed procedures and resources. Quantitatively, reliability and maintainability, like availability, are both probabilities. From a practical standpoint, however, most mines simply measure availability as the ratio of uptime to total time. An appropriate definition for achieved availability is the fraction of scheduled time that an item of plant is able to produce its end product at or above a minimum acceptable level. In most mines, this measure is used as a key performance indicator for the maintenance department.

### *2.4.1. The Availability/Utilisation Conflict*

The definition for achieved availability highlights the point that to be available, an item has to be able to produce and does not necessarily have to be producing. In other words, the fact that a piece of mobile mining equipment is available for use does not necessarily mean that it is producing. For example, an available piece of equipment will sit idle if there is no operator available to run it. Utilisation is another key performance measure that is used to measure the fraction of available time that an asset is actually performing its intended function. In Figure 2.2 both the operator and planning functions would have a significant impact on how well the available production time would be utilised.

Utilisation and availability are easily measured and it is convenient to use them as performance measures for operations and maintenance respectively. Unfortunately, however,

these numbers do not give a complete picture. Looking again at the definition of reliability, note that for the definition to apply, the item must be operated under stated conditions. As described above, mining conditions generally stress equipment to its design capability. One could argue that the operators of this equipment, operating over long shifts in the same working environment, are also stressed to their design capability. Furthermore, the operator is under pressure to push himself and his machine to attain the aggressive production targets. In summary, a common scenario is to have stressed operators pushing stressed equipment in a hostile environment. Equipment failure is inevitable. Before characterising these failures as chronic and assigning the blame to maintenance, a production manager might want to consider the following questions:

(a) Are the production targets achievable?

(b) Are there sufficient quantities of equipment to meet the production targets?

(c) Is the equipment being operated outside of its design capacity?

(d) Are operators following accepted procedures?

(e) Are operators performing the routine service responsibilities assigned to them?

(f) Was the equipment released to maintenance for servicing when required?

Each of these questions highlights possible causes for chronic equipment failure. It is important to realise that keeping the equipment operating in a cost-effective manner is a combined operations and maintenance responsibility. It can not be over-emphasised that

failure to appreciate this shared responsibility will set the stage for what was described in Section 2.3 as the operations/maintenance gap.

### *2.4.2. Maintenance Costs*

The Coopers and Lybrand survey reported that one of the complaints operations managers had about maintenance was excessive maintenance cost. Oliverson (1997) argues that 60% of all maintenance costs are preventable. He provides the following three categories of preventable costs:

(a) Design, procurement and installation defects.

(b) Improper operation.

(c) Mistakes and defects introduced during maintenance and repairs.

If we classify preventable maintenance costs as excessive, then clearly of the three categories described above, only the third is attributable to maintenance. The first category is primarily the responsibility of the OEM, but highlights the importance of selecting the correct equipment for the job. Improper operation is an operations responsibility but category 3 is the sole responsibility of maintenance.

From a business perspective, the maintenance department is a cost centre. Maintenance does not directly generate revenue for the mine but does consume a considerable proportion of the mine's resources. In terms of costs, recent estimates suggest that maintenance costs represent from 40 to 50 percent of a mine's overall cost (Doucet, 1997). This proportion may well have increased over the years, but before labelling these

costs as excessive, one needs to examine the context in which the increases have occurred. In particular, the trends towards increasing levels of mechanisation, automation and higher capacity equipment have tended to increase maintenance costs. The total cost impact of these trends is examined in Chapter 3.

### *2.5. Summary*

In this chapter, we have explored the relationship between operations and maintenance in a mining context. Using the Time Management Matrix to explain the impact that aggressive production targets can have on the working environment, we focused on availability and utilisation of mine mobile equipment as the key factors linking the two departments. When equipment operators run adequate quantities of equipment that have been well maintained and production targets are met, operations and maintenance generally have no reason to disagree. Unfortunately, however, the nature of the mining process and the demands it places on people and equipment makes the above characterisation the exception rather than the rule.

Current equipment trends may potentially increase the tension that already exists between the two departments. In particular, the trend towards increasing levels of mechanisation and automation and the impact of higher capacity equipment on the operations/maintenance gap will be discussed in Chapter 3.

# CHAPTER 3

# 3. Cost Implications of Current Equipment Trends in Mining

## 3.1. Introduction

Over the past twenty years, the most pervasive trends in mining have been towards increased levels of mechanisation, automation and higher capacity equipment. Driven primarily by the need to decrease production costs, but also by a desire to remove people from the harsh mining environment, the mining industry has created better and larger machines to perform the work. These efforts are consistent with Richardson's suggestion that in order to reduce the capital intensity of the mining business continued investment in new technologies capable of greater capital recovery was required (Richardson, 1993). Higher capacity equipment can achieve this through economies of scale. In addition, automation can result in significant savings due to a reduction in the required manpower.

Recent advances towards remote operation and automation for underground mining include:

(a) Automatic loading of LHDs (Laperrière and Miller, 1999).

(b) Infrared telecontrol for mining machinery (Kononov and Willis, 1999).

(c) Automation and remote control of production drill rigs (Hartwig and Mueller, 1999; Hall et al., 1999a; Ackerman and Flynn, 1999a).

(d) Remote operation of scooptrams (Baiden, 1999; Ackerman and Flynn, 1999b).

Despite the apparent emphasis on automation for underground applications, Morrison (1999) suggests that mine automation as it is currently conceived will have little impact on the profitability of most mining operations. This view is supported by the fact that the social and political conditions of developing countries make the implementation of employment limiting technology undesirable. As a result, Morrison (1999) believes that automated or teleremote equipment operation for underground mining will only be viable in large bulk operations in well-developed economies. He suggests the real potential for these technologies lies not underground but on surface. Automated trucks using GPS and computer controlled guidance systems are more easily implemented in open pits than in underground mines. The limitations of truck size in open pit mines are machine components such as tire or transmission design. As these technological issues are resolved, Morrison suggests that open pit trucks will become even larger than they are today.

### *3.1.1. Economies of Scale*

Beyond the efforts towards full automation, both underground and open pit mines, in cooperation with equipment manufacturers, are attempting to achieve economies of scale by increasing the capacity of their mining equipment. Sullivan (1990) suggests that economies of scale associated with larger shovel/truck operations would result in a lower cost per ton of material produced. He lists some of the reasons for these lower costs as follows:

(a) The overall labour force to support larger machines is smaller.

(b) Overall establishment costs will be less, although the mine infrastructure will have to cater to the larger units.

(c) Production and maintenance efficiencies will increase.

(d) Shovel and/or truck energy consumption cost per ton will decrease as capacity increases.

(e) Maintenance costs per ton decrease as capacity increases.

At first reading, these cost reduction advantages appear obvious. Fewer machines will definitely result in fewer operators, and less energy being required to move the same amount of material. As a result, the mine should be able to reduce the size of the workforce and will have fewer pieces of equipment in their inventory resulting in lower infrastructure costs. However, larger capacity equipment with increasing levels of complexity may result in increased maintenance costs. This is due to two factors. First, increasing levels of complexity result in lower reliability. Consequently, failures are likely to become more frequent, at least initially, as machine complexity increases. Second, and perhaps more important, is the fact that there will be potential for an increase in costs associated with lost production due to breakdowns.

Consider haul trucks as an example. The trend in heavy haulage capacity for open pit mines is presented in Figure 3.1. It shows that not only is open pit haul truck capacity increasing, but that it is doing so at an accelerating rate. From this figure, we see that the haul capacity of the largest trucks operating in 1960, when compared with haul capacity in 1980, increased by 70%. The corresponding increase in the last twenty years, which has

culminated with the arrival of the Caterpillar's 360-ton haul truck (Cat 797), is 112%. In fact, over the last thirty years haul capacity has tripled.

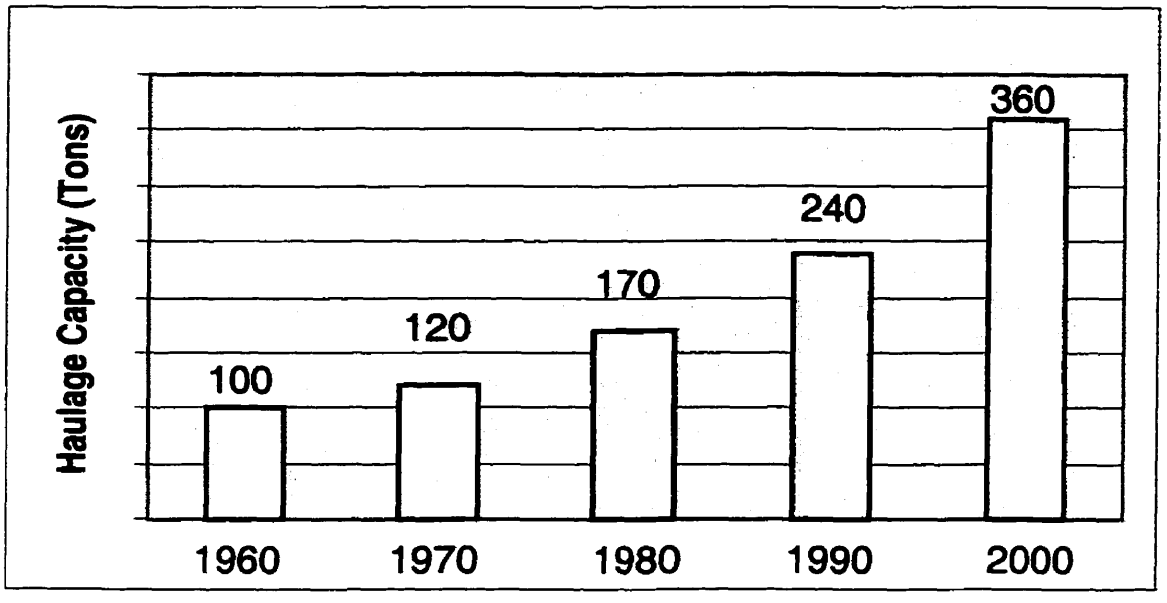


**Figure 3.1: Trends in Haul Capacity for Open Pit Mines**

Currently, several mines are considering the replacement of truck fleets based on trucks with 240-ton capacity to fleets consisting of trucks with haul capacities as high as 360 tons. Operationally, a fleet of thirty 240-ton trucks has the same capacity as a fleet of twenty 360-ton trucks (7200 tons). However, if three of the larger trucks are down for maintenance, the associated decrease in haul capacity for the mine is 360 tons more than would be the case if three of the 240-ton haul trucks were undergoing maintenance. In terms of haul capacity, this difference represents 1.5 additional 240-ton trucks being down for maintenance. For most mines operating 240-ton haul trucks, having 4 or 5 trucks down for maintenance at the same time would result in either lost production, or expensive contract haulage to pick up the slack. The obvious question, that has not received much attention, is whether the production

cost savings justify the increased maintenance costs associated with lost production resulting from unscheduled downtime.

There are also some significant limitations in underground mining that place an upper limit on the cost savings that can be achieved through increasing the capacity of the equipment. The cost of access development (larger drifts) and the cost of ventilation increase dramatically as the size of equipment increases. As underground mines become increasingly deeper, these problems become acute due to the requirement to maintain rock mass stability for the larger equipment and the difficulty associated with disposing of the development waste.

The main problem is to determine that level of technology that maximises profitability. Morrison (1999) points out that this problem is most difficult for large, deep base metal ore-bodies where the tendency is to try to use economies of scale to effectively compete with large open pit operations. However, any advanced technology that can be used effectively underground to reduce costs can generally also be applied in open pits to even greater effect. The remainder of this chapter will focus, therefore, on open pit mining with emphasis on increasing the capacity of haul trucks in an attempt to achieve economies of scale. Any difficulties uncovered for open pit mining will be magnified for underground operations for the reasons outlined above.

At first glance, the only increased cost associated with the purchase of 360-ton trucks to replace 240-ton trucks would appear to be the capital cost. In conducting the analysis to

determine if larger trucks are profitable, the operation cost savings are generally considered to be sufficient to justify the increased capital cost, assuming a relatively long amortisation period. What this analysis should also include, however, is the impact on maintenance costs. In particular, the costs associated with lost production for unscheduled downtime should be factored into the analysis.

### *3.2. Introduction - Haulage Capacity Example*

The Iron Ore Company of Canada (IOCC) has followed the trend for haul truck capacity as depicted in Figure 3.1. Currently, they face the decision of whether or not to increase capacity to either 320-ton haul trucks currently offered with the Komatsu 930E or the soon-to-be-available, 360-ton capacity Caterpillar 797 (Cat 797). Several mines have already committed themselves or are actively pursing these same choices. Recent projections suggest that by the year 2005, approximately 500 of these 300+ ton haul trucks will be in operation throughout the world (Fair et al., 1999).

Current estimates of IOCC's maintenance costs suggest that they represent approximately 40% of the total cost of production (McHattie and Pearcy, 1998). Excluding processing, the $200 million in annual maintenance spending represents 50% of the total cost of mining. Comparing this figure to IOCC's 1989 estimate which was 52%, it would appear that this percentage has remained relatively constant over approximately a nine year period (Freud, 1989). Table 3.1 presents IOCC's mobile equipment costs for 1989. Based on these figures, one could argue that the increase in the capacity of IOCC's haul trucks has not resulted in an increase in maintenance costs. This logic, however, is faulty for two reasons.

First, the fact that IOCC recognised that maintenance costs represented half of the total cost of mining in 1989 has resulted in significant efforts to reduce those costs on an absolute basis. Using techniques such as reliability centred maintenance (described in Chapter 4) and developing effective maintenance management information systems has resulted in significant savings for the IOCC maintenance program. McHattie and Pearcy (1998) describe the work of IOCC's maintenance strategy task force that is aimed at lowering maintenance costs.

| Equipment Type | | Maintenance Cost | | Total Cost |
|---|---|---|---|---|
| | QTY | Millions of $ (per annum) | Percent of Total Maintenance | Millions of $ (per annum) |
| Drills | (10) | 2.9 | 16% | 7.3 |
| Shovels | (10) | 6.5 | 36% | 10.5 |
| Trucks | (30) | 8.7 | 48% | 17.5 |
| TOTALS | | 18.2 | 100% | 35.3 |

**Table 3.1: Mobile Equipment Costs IOCC (Freud, 1989)**

The second reason that maintenance cost figures should not be taken at face value is that the costs associated with lost production due to unscheduled downtime are either hidden or attributed to operations. In most mines, when breakdowns occur, the dispatch system will balance the truck assignments to minimise the impact on production. The mine is basically forced to adjust and tolerate the unexpected decrease in haul capacity resulting in less production. However, the decrease is not usually accounted for as a specific cost. When lost capacity becomes significant, some mines are fortunate enough to have access to contract

haulage trucks. The mine simply has to contract-out for sufficient haul capacity to help meet production targets. The high cost of contract haulage shows up as an operations expense, not as a maintenance cost due to unscheduled downtime. When contract haulage is not available, production is lost and the mine will fall behind its production targets with potentially higher penalties associated with not meeting customer demands.

The fact that the percentage of maintenance cost to total mining cost has remained constant over this period of increasing haul truck capacity at IOCC indicates that, without major improvements to the maintenance program, the proportion of maintenance costs as part of the total mining cost would have clearly increased. However, it is unlikely that the analysis conducted to determine the production cost savings for higher capacity trucks included examination into the corresponding increases in maintenance costs. Noting that the current choice to increase to 360-ton capacity haul trucks represents an even bigger increase than the decision to go to 240-ton capacity, it is possible that lost production costs may have an even bigger impact.

### *3.2.1 Estimating Downtime Costs*

As described above, larger capacity trucks result in decreased production costs based on fewer hauls and fewer drivers. A naive observer might even suggest that maintenance costs would decrease since there would be fewer trucks in the fleet to maintain. However, this argument neglects the costs of lost production due to breakdown maintenance, which, with larger equipment, can potentially be greater than the savings achieved from a production perspective. This relationship is theoretically depicted in Figure 3.2. If we define downtime

costs due to breakdowns to consist of the repair cost (including parts and labour) plus the cost of the lost production due to the failure, we can plot total downtime cost per truck as the sum of these two component costs. For example, if a truck fleet consisted of 30 low capacity haul trucks, the lost production costs associated with downtime per truck would be much lower than if a fleet of 20 high capacity trucks experienced the same downtime.

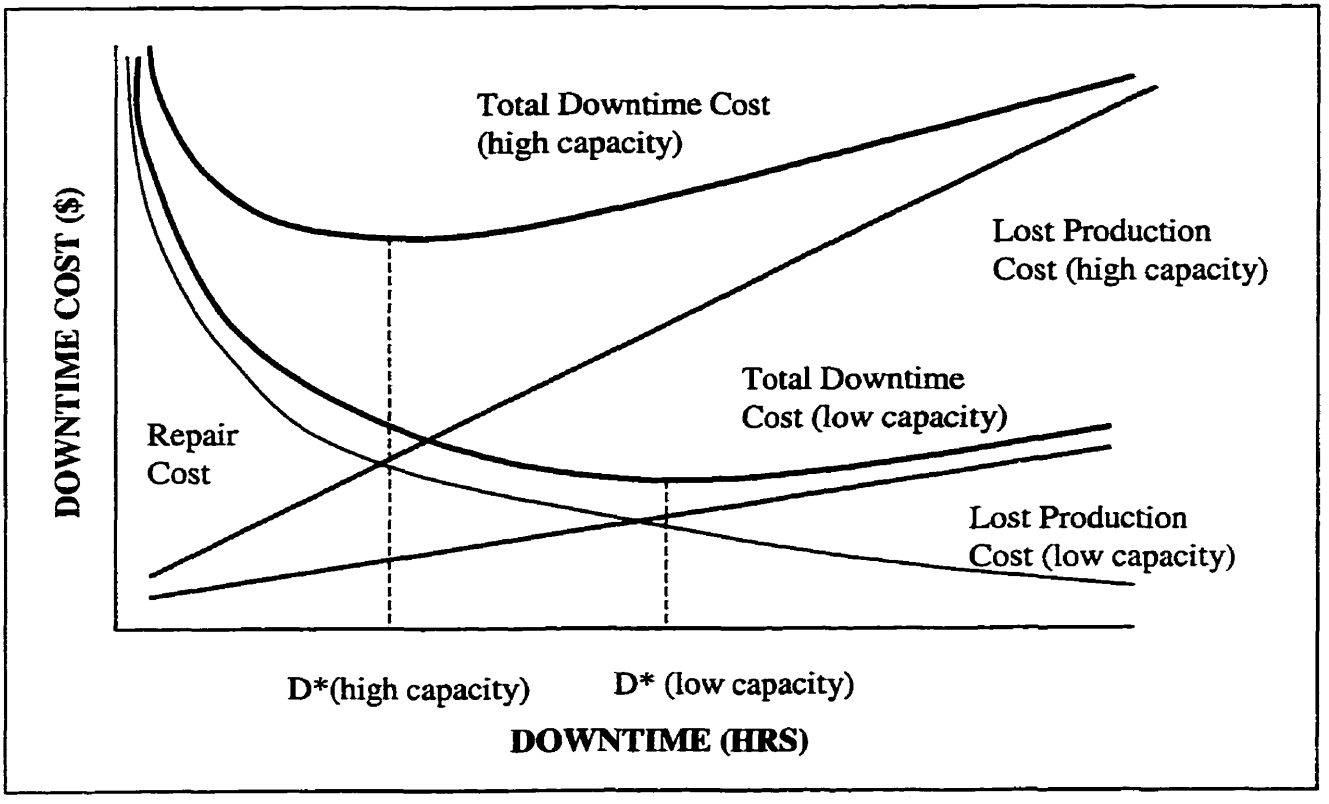


**Figure 3.2: Effects of Larger Capacity Equipment on Downtime Costs**

In Figure 3.2 we see that the total downtime cost per truck for the low capacity fleet is much lower than that associated with the high capacity fleet. Note also, that the minimum downtime cost (D*) for the high capacity fleet occurs much earlier than it does for the low capacity fleet. Hence, for high capacity equipment, downtime is less acceptable due to

higher costs associated with lost production. The fundamental question as to whether production cost savings are greater than maintenance cost increases is generally not considered in the decision to purchase higher capacity equipment.

It should be noted that repair costs in Figure 3.2 are assumed to be the same for both high and low capacity fleets. The overall shape of the repair cost curve reflects the fact that if more downtime can be tolerated (as would be the case for lower capacity fleets) fewer mechanics and fewer inventories for replacement parts are required. However, replacement parts for the larger equipment are becoming capital intensive. For example, the tires on the Komatsu 930E are approximately $35,000 each. Therefore, the actual repair cost curve for low and high capacity equipment would be similar in shape. However, it would probably shift upwards for the high capacity equipment. Another example of increased repair costs would be the requirement to build maintenance bays sufficiently large to accommodate the larger trucks. This change in repair cost has been omitted in Figure 3.2 since the difference in cost is mainly due to a significant increase in lost production associated with the breakdown of larger equipment. Unfortunately, as discussed above, there is little data available with respect to the downtime costs associated with lost production. Therefore, simulation will be used to estimate the scope of the problem.

### *3.3. Description of Simulation Example*

Lost production costs due to unscheduled downtime are difficult to estimate from historical data. As described above, they are either not accounted for at all, or appear as an operations cost associated with contract mining. Consequently, the Rapid Availability

Prototype Operational Readiness (RAPTOR™) simulator was used to estimate the amount of lost haul capacity associated with the decision to increase from 240-ton capacity to 360-ton capacity haul trucks for one year of operations at an open pit mine. A baseline simulation model was developed assuming that haul truck failures followed the exponential distribution with a mean time between failure (MTBF) of 65 hours. The repair time distribution was assumed to be lognormal with a mean of 4 hours and standard deviation of 1 hour.

The baseline model was replicated five times using a fleet of thirty 240-ton haul trucks with each replication simulated for one year of operations. The equivalent haul capacity would be achieved with twenty 360-ton haul trucks. Therefore, five replications of the model were also run for twenty 360-ton haul trucks. Initially, both the reliability and maintenance parameters for the 360-ton trucks were kept the same as for the 240-ton trucks. This is unlikely to be the case, but will serve to provide an optimistic estimate on the impact of lost production due to unscheduled downtime.

In order to accumulate unscheduled downtime in the RAPTOR™ model, it was assumed that regardless of the fleet size, one truck would be continually down for scheduled maintenance. It was also assumed that the mine had sufficient excess haul capacity to tolerate up to 720 tons of unscheduled downtime capacity before production losses would be significant enough to call for contract haulage (assuming it was available). This equates to three 240-ton trucks or two 360-ton trucks. The model kept track of the proportion of time that the mine would be in a "lost production" position. No distinction was made as to how many trucks in excess of the 720-ton threshold were down.

### *3.4. Sensitivity Analysis*

As described above, it is doubtful that the repair characteristics of the 360-ton trucks will be the same as the 240-ton trucks. For example, should the truck require steam cleaning prior to the maintenance being performed, it will obviously take longer to prepare the larger truck. To examine the impact of this difference, the model was replicated an additional five times for the 360-ton trucks assuming that the mean of the repair-time distribution increased by one hour. Again, this is considered an optimistic view and it may turn out that the repair time is significantly longer, especially during the conversion period as the technicians become accustomed to the larger truck.

A fourth set of 5 replications were also conducted to examine the impact of decreasing the MTBF of the higher capacity trucks. In the long run, these trucks will eventually have reliability characteristics very similar to the 240-ton trucks. However, the increase to 360-ton capacity is likely to result in some new reliability problems that will be resolved over time. For example, the tires for the Komatsu 930E are proving problematic as haul distance restrictions are being imposed to minimise crack propagation. This simulation also included the longer mean time to repair and is, therefore, considered closest to the initial characteristics of these trucks during the conversion period.

### *3.5. Results*

The results of the simulation based on 5 runs for each model, simulated for one year of operation, are presented in Table 3.2. In the initial 2 models with failure and repair-time distributions assumed equal, the 240-ton fleet was in a lost production position 6.96% of the time versus 8.88% for the 360-ton fleet. The last two columns of Table 3.2 present the total downtime cost as the sum of the direct cost of being unable to use the truck plus the cost of the material that did not get hauled. Assuming a 240-ton haul truck makes a little over three round trips per hour, the production rate is approximately 800 tons per hour. Depending on the stripping ratio, ore-price and grade, the profit contribution of each ton of ore can be assumed to be in the range of $1 - $5. The production rate for 240-ton trucks is therefore between $800 and $4,000 per hour. Using these same assumptions, the production rates for 360-ton trucks increase to between $1,200 and $6,000 per hour. In order to determine the total downtime cost we must add the cost associated with losing the operation of the truck for the duration of the unscheduled downtime. Returning to the IOCC cost data presented in Table 3.1, we see that in 1989, the mine paid $17.5 million to operate and maintain a fleet of thirty 190-ton haul trucks. This implies that it costs $583,000 per year to operate and maintain a single truck in 1989. Accounting for inflation, assume that the current costs to operate a 240-ton haul truck are closer to $750,000 per year ($86 per hour). Therefore, the total downtime cost associated with unscheduled downtime for a 240-ton haul truck is between $886 and $1,286 per hour. Assuming a 360-ton haul truck costs $100 per hour to operate, the total downtime cost associated with unscheduled downtime is between $1,300 and $6,100.

| Capacity | No. Trucks | MTBF (hours) | Repair Distribution Parameters ($\mu$,$\sigma$) | Lost Production Downtime | Total Downtime Cost ($1 profit/ton) | Total Downtime Cost ($5 profit/ton) |
|---|---|---|---|---|---|---|
| 240-t | 30 | 65 | 4,1 | 6.96% | $0.54 M | $2.5 M |
| 360-t | 20 | 65 | 4,1 | 8.88% | $1.0 M | $4.7 M |
| 360-t | 20 | 65 | 5,1 | 14.7% | $1.7 M | $7.9 M |
| 360-t | 20 | 58.5 | 5,1 | 18.3% | $2.1 M | $9.8 M |

**Table 3.2: Results of RAPTOR™ Simulation**

The simulation model appears to be very sensitive to the value assumed for the mean of the repair-time distribution. Increasing the average repair-time by only one hour increased the lost production proportion to 14.7% for the 360-ton fleet resulting in a 7.74% increase from the baseline model. This represents a potential increase in lost production costs of between $1.16 million and $5.4 million depending on the profit per ton.

A modest 10% decrease in the MTBF of the 360-ton truck from 65 to 58.5 hours resulted in the lost production proportion increasing to 18.3%. It is unlikely that a mine would tolerate this amount of unscheduled downtime and an additional truck purchase might be called for, but this would reduce the production cost savings overall. However, assuming they did continue to accumulate downtime at this rate, the annual downtime costs would be between $2.1 and $9.8 million per year.

Of course, if production feels they have insufficient haulage capacity they can always purchase more trucks. To test how many 360-ton trucks would be required to keep the proportion of lost production time the same as was achieved in the baseline model, additional simulation runs were conducted for a fleet of twenty-one 360-ton haul trucks. Assuming that this additional truck represented haul capacity in excess of the capacity of the baseline mine, it decreased the probability that the mine would cross the threshold beyond which contract haulage would be required. The result of this simulation was that the proportion of time the mine was in a lost-production position returned to the levels associated with the baseline model. Therefore, another way to estimate the cost associated with lost production for this example would be the cost associated with purchasing, operating and maintaining one additional 360-ton truck over one year. Unfortunately, due to a lack of experience with these trucks, operations and maintenance costs are difficult to estimate.

### *3.6. Conclusions and Recommendations*

The argument that higher capacity equipment reduces production costs is sound. This is clearly the case for haul trucks for open pit mines but can be made equally for shovels and to a lesser extent for underground mobile mining equipment. However, larger capacity equipment reduces flexibility making the mine more sensitive to the downtime and utilisation associated with a single piece of equipment. In particular, costs associated with lost production due to unscheduled maintenance may become acute as the capacity of mobile equipment increases. This cost should be considered as part of the decision whether or not to increase capacity.

This brief analysis has served to at least demonstrate the order of magnitude of an increase in downtime costs that can be expected with the larger fleets. In terms of haul capacity, two 360-ton trucks are equivalent to three 240-ton trucks. One might expect to reduce haulage costs, therefore, by one third. However, unless the reliability and maintenance characteristics of the larger trucks are better than those of the existing fleet, unscheduled downtime will result in an increase in lost production. For mines fortunate enough to have access to contract mining on short notice, this loss can be minimised, but expensive contract mining fees will cut into the production cost savings associated with the larger truck. For mines without access to contract mining, the costs due to an increase in lost production can never be recovered.

It is recommended, therefore, that the costs associated with a potential increase in lost production form an integral part of any cost benefit analysis conducted into the decision to purchase larger capacity equipment. These costs may prove difficult to estimate, but can be based on the costs associated with contract mining necessary when production falls below an acceptable level. Alternatively, a cost per ton of lost haulage capacity can be applied in situations where the equipment failure results in actual production being less than expected.

Furthermore, it is recommended that mines be wary of the reliability and maintenance characteristics of higher capacity equipment. Decreased reliability coupled with less flexibility and increased repair time will result in some significant lost production costs. As a minimum, manufacturers should be expected to share the risk associated with these potential circumstances.

### *3.7. Summary*

In this Chapter, the current trend towards increased automation and higher capacity equipment was discussed. Using simulation, it was shown that increased costs associated with lost production due to unscheduled downtime could potentially offset the production savings upon which the decision to make the purchase was based. Although the emphasis was on open pit mines using haulage trucks as an example, the quest for economies of scale is also occurring in underground mining. In the context of the relationship between operations and maintenance, failure to address this issue will likely lead to an increase in tension as the mine loses the flexibility associated with having more numerous, but lower capacity, mobile equipment.

The key to avoiding these increased costs and avoiding the resulting strain between operations and maintenance lies in the ability of equipment suppliers to design and manufacture reliable equipment that is operated and maintained in a manner that will minimise downtime. In Chapter 4, operations planning and maintenance management practices will be discussed in order to assess the state-of-the-art practices in these areas. Emphasis will be placed on the impact that emerging technologies are having on the combined performance of operations and maintenance.

# CHAPTER 4

# 4. Mine Operations Planning & Maintenance Management

## 4.1. Introduction

This chapter provides a detailed examination of the two primary activities that influence a mine's performance and profitability – operations planning and maintenance management. An effective operations plan is key to keeping production costs under control. Similarly, without a correspondingly effective maintenance program, higher than necessary maintenance costs will consume the mine's profits. Only through understanding the current state-of–the-art processes for these two equally important activities can we hope to propose improvements based on better interaction between them.

The operations planning process is generally considered the most important planning activity in the mine and will be discussed here in some detail. Surprisingly, despite the importance of this activity, very little research is available on how to best achieve an effective plan. In contrast to the lack of basic research, there is no shortage of software products that claim to be production planning tools. Considerably more research effort appears to have been expended on the maintenance management process that will be presented next. As each activity is presented, emphasis will be placed on the impact of information technology. What will become apparent is that these two processes are generally viewed as quite distinct. Furthermore, rather than facilitating the integration of these two important processes, it will be shown that information technology is serving to drive them further apart.

### *4.2. The Operations Planning Process*

The operations planning process is generally tied to the *mine business plan*. These long-term plans can be for periods of up to 25 years but normally do not include any significant detail beyond 10 years. The details of how the 10-year business objectives will be achieved are normally specified in a 5-year *mine development plan*. Late in the fiscal year the next year's plan from the 5-year plan is finalised as the *annual mine plan* which includes the budget for the upcoming year. This plan, along with survey information about the ore body being mined, forms the major inputs to the production planning process. These inputs, together with the outputs, resources and constraints that influence the operation planning process, are depicted in Figure 4.1.

The operations plans would normally include daily, weekly and monthly production schedules describing how the production targets, set in the annual mine plan, will be met. The arrow coming into the top of Figure 4.1 represents the controls under which the operations planning process is conducted. The arrow coming in from the bottom represents the physical resources necessary to implement the operations plans. In Figure 4.2 the operations planning process has been expanded to include the four main activities that make up the process.

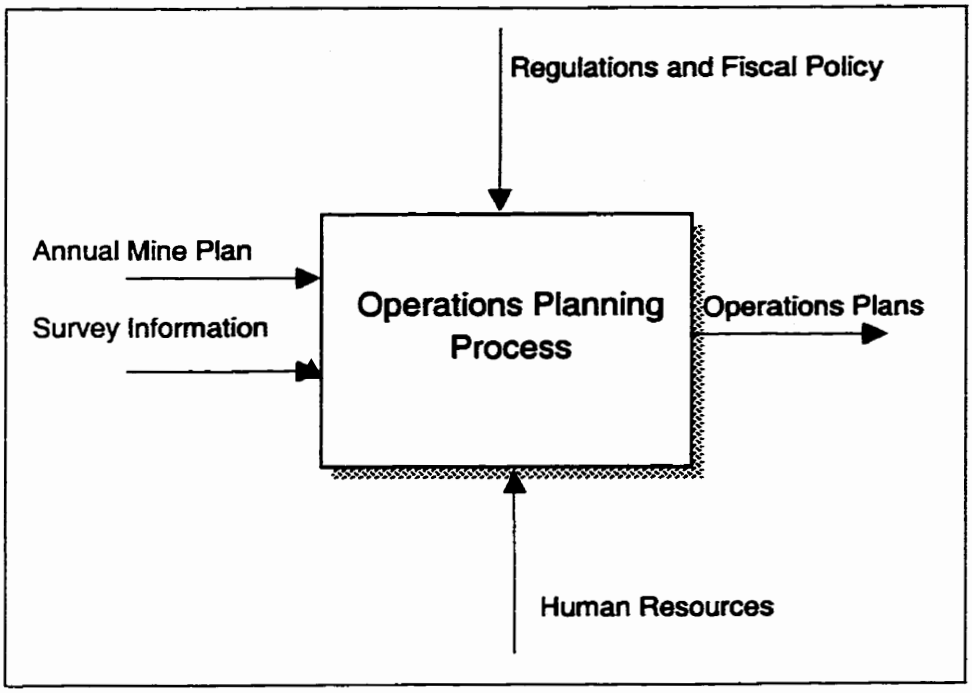


**Figure 4.1: Scope of the Operations Planning Process**

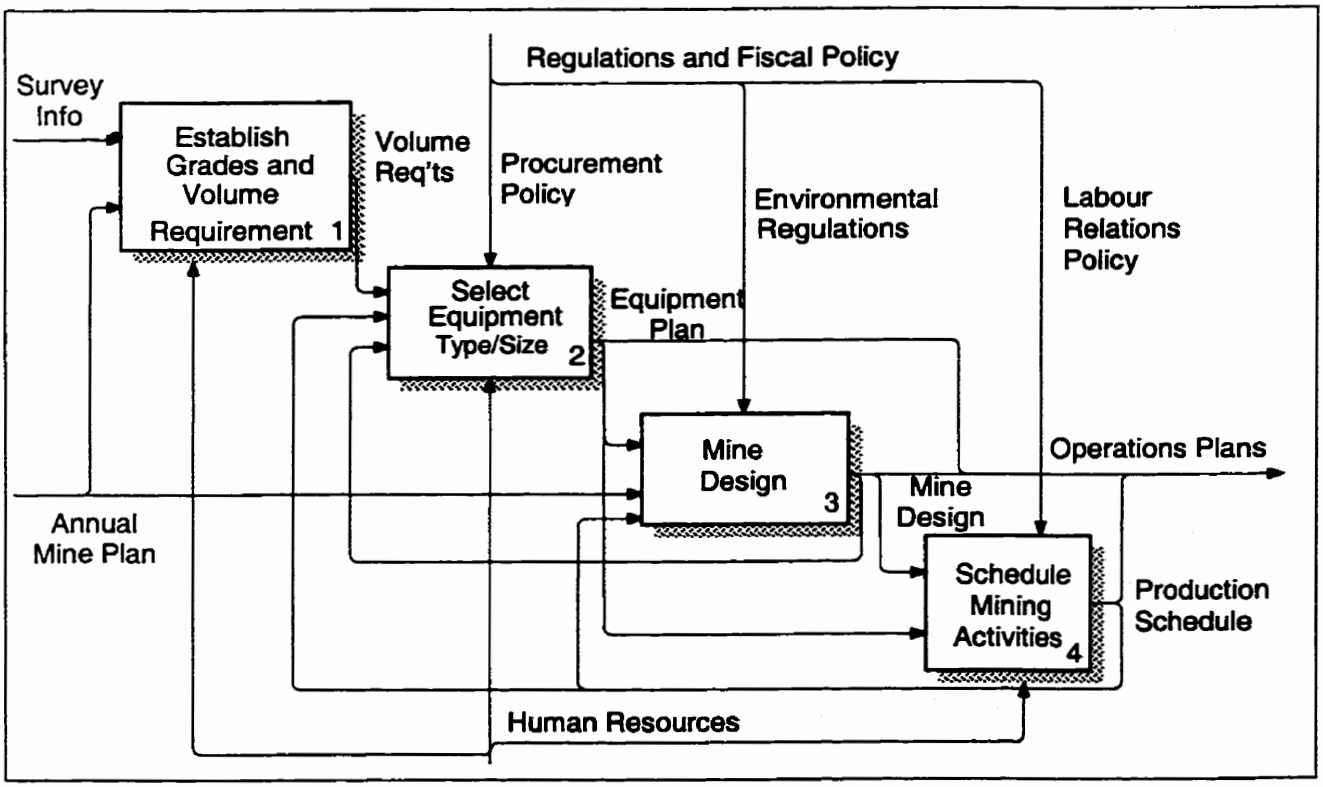


**Figure 4.2: The Operations Planning Process**

Notice that the inputs and outputs of Figure 4.2 match those of Figure 4.1. *Survey information* and the *annual mine plan* are turned into *operations plans*. In Figure 4.2 however, more detail is provided in terms of the processes or activities required making the transformation from inputs into outputs. The general labels on the arrows have also been expanded to provide more detail about the functions of the basic processes. For example, we can see from the diagram that the arrow labelled *production plans* from Figure 4.1 actually consists of three subordinate plans called: *equipment plan*, *mine design* and *production schedule*. The sequence of activities and iterative nature of the process is represented by the data flows including feedback loops between the basic processes. This diagram is sufficiently generic to represent the operations planning process for both open pit and underground mines. Not until we describe the details of how each of these four basic activities are conducted will the differences become apparent. In particular, the mine design task is substantially different between open pit and underground mines.

The first process takes survey information and production targets from the annual mine plan to determine the ore and waste requirements. Based on these requirements, activities 2 and 3 determine what combination of equipment and mine design are best suited to economically achieve the derived mining volume requirements. For an open pit mine using a shovel/truck system, mine planners would determine if their existing equipment would be adequate to meet the volume requirements. If this were not the case, options for increasing fleet sizes or contract mining would be considered. To accurately determine fleet sizes, planners need to make assumptions about equipment availability and utilisation that are sometimes based on manufacturer recommendations (for example, see Caterpillar, 1997).

Despite the fact that the mine's maintenance department may eventually be held accountable for the availability assumptions made during this stage, they are generally not consulted in the decision making process.

In open pit, the mine design process consists primarily of determining the best overall pit layout. This is more challenging for an underground mine, as the equipment will be closely tied to the mining method selected. Selection of mining method is also considerably more complex for underground mining. In either case, however, once the pit layout or mining methods have been selected, the sequence of extraction in terms of a detailed schedule is determined. It is this schedule that becomes the primary implementation document for the mine. Closer inspection of these activities, with emphasis on the technological support available, will be useful in determining their effectiveness.

### *4.2.1. Establishing Grades and Volume Requirements*

This process consists of using the geological and geotechnical information available about the ore body to determine how much ore and waste must be moved to meet the production targets. Several modelling packages are available that assist in creating 3-dimensional block models for ore reserve calculations, blast planning, ore grade predictions and mine design planning. SURPAC 2000™, Vulcan™ and Medsystem™ are examples of the many systems available. The challenge in successfully implementing these systems lies in the mine's ability to arrive at accurate grade reconciliation and to provide dependable production grade forecasting on a daily basis for the mill. Figure 4.3 depicts how this is achieved at the Myra Falls underground copper mine on Vancouver Island.

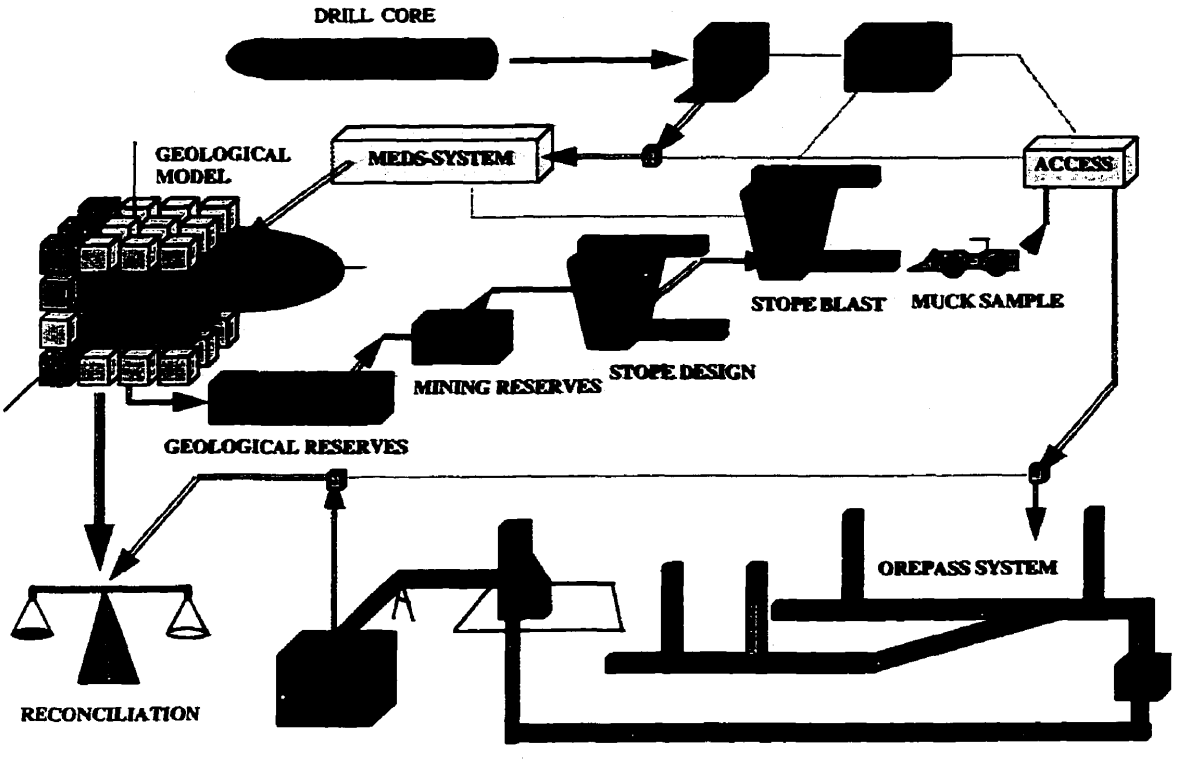


**Figure 4.3: From the Model to the Mill (Bakker & Sawyer, 1999)**

Bakker and Sawer (1999) describe how the Myra Falls Mine achieves the practical link between the mill and the block model through a production-sampling program carried out by load haul dump (LHD) operators at the loading point. Their program provides for continuous sampling of production sources that are typically highly zoned. This allows for orepass blending to produce a constant mill feed grade as well as a physical check on the Medsystem™ model predictions. Failure to conduct a sampling program of this type would result in unexpected grade swings, excess dilution and significant disruption to mining schedules. When evaluating a new orebody, however, long before grade control measures are

considered, the mine must decide what equipment it needs and which mining methods will be employed.

### *4.2.2. Equipment Selection/Mine Design*

The selection of mining equipment and the mine design are obviously closely linked. The primary aim of these two processes is to select that combination of mining method and equipment that will meet the production requirements at minimum cost. This is more straightforward in an open pit design as compared to an underground setting. Indeed, the Lerchs-Grossman algorithm has been implemented in many software packages to help open pit designers to translate the 3D representation of the orebody into economic pit limits upon which they can base the remainder of their equipment selection and mine design (Lerchs and Grossman, 1965). For a description of several other algorithms and the corresponding economic justification for computerised open pit design see Lizotte (1988). Schofield and Denby (1990) also describe an expert system that is used for surface mining method selection and excavation and haulage equipment selection.

The variety of mining methods and complicated geometry generally faced by underground planners make their task considerably more complicated. Oberndorfer (1993) describes underground mining method selection as one of the most demanding and complex tasks in mining engineering. Pareja and Pelley (1996) go so far as to suggest that underground hardrock, metal mining is unique in that the mine design and planning are strongly controlled by the geological and geotechnical features of the orebody and the surrounding rock mass. These authors further point out that, being a capital-intensive

activity, underground mining is very sensitive to financial management. Furthermore, the mine design and planning processes are highly iterative and inter-disciplinary. Initial feasibility of whether to commence mining or not is usually followed with a detailed assessment of the technical/non-technical resources and their influence on the selection of a mining method. As the mine design parameters, such as stope size, stope sequencing, ore value, and mining methods change, based on geotechnical and geomechanics constraints, the specific mining layouts of stopes and drifts must also be regenerated. Each design alternative represents a significant level of effort, as all operational and physical factors must be combined into one integrated mining plan before the ultimate selection of mining method can be made.

The size and specifications of the equipment must also be considered in the design. In fact, as an operating mine ages and newer technology is developed over time, the mine design and planning must also change. The design requires constant updating and modification to ensure optimisation of the development and production processes. Therefore, most mining engineers are continuously assessing the resources to be used in operations, as well as the cost of mining, in an effort to balance the cash flow and maximise profitability (Yazici and Espley, 1999).

In the end, underground mining method decisions are mostly subjective based on personal experiences. Current computer aided design (CAD) and orebody-modelling applications help the design process but do not support the mining engineer for method and equipment decisions. Furthermore, these systems often do not fully integrate costing and

planning/scheduling modules. Sequencing of the production stopes and development drifts are usually determined from geotechnical analyses, which is done separately from geological modelling. Therefore, the mining engineer is faced with subjective decisions since the tools have not been available to allow for analytical and diverse decisions. In addition to the 3D modelling software and some very task-specific products (for example, SURPAC's Ring design), there is very little software available to help select the most economical underground mining method.

Knowledge-based systems (also called expert systems) have been proposed by researchers to deal with mining method selection (for a detailed review, see Camm and Smith, 1993 and Oberndorfer, 1996). Linear programming optimisation, simulation, and their integration with knowledge-based systems, have also been investigated (Wilke et al., 1996). For example, Yazici and Espley (1999) illustrate how simulation can be used to generate the sequencing and 3D geometry representations of particular mining methods such as *blasthole*, *vertical retreat*, and *mechanised cut-and-fill*. These authors present the implications of simulation models for mining method selection and how they can be used to conduct feasibility studies to aid in the mining method selection process. Each of these techniques shows promise, but, to date, the underground mining method selection process remains a subjective process based primarily on individual expertise.

In both underground and open pit applications one trend is clear. The mine design process, whether assisted by software tools or not, is generally conducted without consideration of the maintenance impact associated with the various options considered.

That is not to say that mine designers/planners do not interact with mine operations and mine maintenance. Blackwell (1993) points out this interaction is generally limited to the next several days or weeks of operation. They effectively "iron out" the details of the overall mine plan as issued by the planning office. As a result, the maintenance effort at the mine is generally reactive rather than proactive.

### *4.2.3. Scheduling Mining Activities*

Once the mining method is selected, the actual scheduling or sequencing of the mining activities is, by comparison, a much simpler task. Several software products exist to take the mine design and produce an optimum sequence based on several factors. For a detailed discussion of these factors and a description of how computerised mine planning was implemented for a medium sized open pit mine, see Blackwell (1993). Recently, software vendors have been offering mine-sequencing modules as part of their 3D modelling packages. Examples include:

(a) SURPAC™ 2000's mine scheduler (soon to be replaced with a new product called ALPS allowing for linear programming optimisation).

(b) CHRONOS™, a new product soon to be released by MAPTEK™ that will accompany their VULCAN™ 3D mine design software. This will also feature a linear programming optimiser for mine sequencing.

(c) Go Scheduler by GemCom™.

All of these products are applicable for open pit mines. They offer an effective way to convert the overall mine plan into effective short-term mining sequences that can be easily updated as factors change. For underground mine design, however, the large number of

variables and exhaustive set of constraints involved are generally beyond the capabilities of these software packages.

Again, despite the effort required to purchase and implement one of the software tools described above, these tools do not take into account any maintenance considerations. The only link between maintenance and the mine sequencing software is indirect. In particular, the software typically requires estimates for mining costs that include maintenance. This information is generally input into the models based on historical costing records with no regard to possible maintenance alternatives. This helps to explain the historical perception on the part of mine planners that maintenance is a cost centre - a necessary evil that detracts from profitability.

### *4.3. Emerging Technologies – Mine Planning and Operations*

Beyond the software planning tools discussed above, several emerging technologies are approaching the point of readiness for operational integration into the mining industry. In particular, advanced information system applications, improving communications technology, and automation offer much promise in improving mining efficiency.

Unfortunately, the full impact of these technologies is difficult to assess. The product vendors quickly point out the strategic advantages of their systems without fully explaining how these advantages will be achieved. As highlighted by Desserault et al. (1999), technology providers do not necessarily have the expertise or resources to properly transfer technology from the development stage to the operational stage. Mining companies are

similarly inexperienced at justifying and implementing these new technologies. In order to gain a better insight into this situation and the impact it is having on the relationship between operations and maintenance, these technologies and their implications will be briefly described.

### *4.3.1. Advanced Mining Management Information Systems*

The first computer-based mine management system for haulage optimisation was introduced by Modular Mining in the late 1970's (Zoschke, 1997). The initial function of their product, DISPATCH, was as the name implies, to simply dispatch haul trucks in such a way that production was maximised. These meagre beginnings sparked the development of computer-assisted systems to the point where, in 1985, the Bucyrus-Erie Company proposed a fully integrated, computer-assisted Distributed Mine Management System (DMMS) (Laprarie, 1985). This system was intended to link special purpose computer-based monitoring equipment on drills, trucks and shovels or draglines with a mine management information system. In many respects, this effort could be considered the first step in the effort to create a computer-assisted total mine management system. The emphasis for this system, however, was for production planning with very little attention paid to the information requirements for maintenance management. Although this project never attained all of the functionality originally envisioned, it clearly demonstrated the potential to take advantage of information technology for mine management.

A more recent attempt to develop a real-time monitoring and information system called the Total Mining System (TMS$^{TM}$) was undertaken by AQUILA Mining Systems Ltd.

in 1994. This project had a lofty 5-year goal to allow for the autonomous operation and/or real-time supervisory control of mobile and stationary equipment in open pit mines. Rather than basing their system on a sound understanding of a mine's information requirement however, the initial TMS™ effort was focused on applying the new technology to existing processes without much regard to what was actually required. As a result, even though TMS™ proposed some interesting uses of new technology, there was no guarantee that these systems would actually meet the mine management's requirements. Furthermore, just like the Bucyrus-Erie effort in 1985, the integration of maintenance information as part of TMS™ appears to be almost an after-thought. Recent efforts at AQUILA have focused on the integration of stand-alone systems that have been developed and are currently in service but not networked together (Murphy and Peck, 1997). To achieve this, AQUILA has formed a strategic alliance with Caterpillar and Mincom. Their combined effort to create a fully integrated total mining system will be discussed later in this chapter.

Modular's DISPATCH system has also continued to evolve. Based on experience with over 80 installations worldwide (Zoschke, 1997), two major revisions were undertaken. Most recently, a packet-switched radio communications package and global positioning system (GPS) technology have been included to allow for real-time updates on equipment locations and the ability to plot equipment movement over a specified period. Furthermore, Modular has attempted to provide computer interfaces to on-board condition monitoring systems to allow for real-time transmission of this information over the DISPATCH network. Although not specifically designed for this purpose, the ability to use this "operation's

system" for the transmission of maintenance information represents one of the first attempts to integrate operations and maintenance management systems.

### *4.3.2. On-board monitoring systems*

One of the enabling technologies for the total mining system as envisioned by the Caterpillar alliance is on-board monitoring systems. These systems are useful for both production monitoring and equipment condition monitoring. It is interesting to note that even though these systems are currently sold as standard equipment with most mobile mining equipment, the technology was generally not specified as a requirement from the mine. As a result, most mines are struggling to determine how to best use the large volumes of data generated by these systems. In many cases, the data is simply being archived without being analysed (Murphy and Peck, 1997).

Figure 4.4 provides a schematic representation of an embedded production monitor/controller (Daneshmend and Roman, 1997). The production planning and control system provides directions through the operator interface that, in turn, gives commands to the machine components. Through the same interface, sensors attached to the machine components provide feedback on machine status and performance to the production planning and control system.

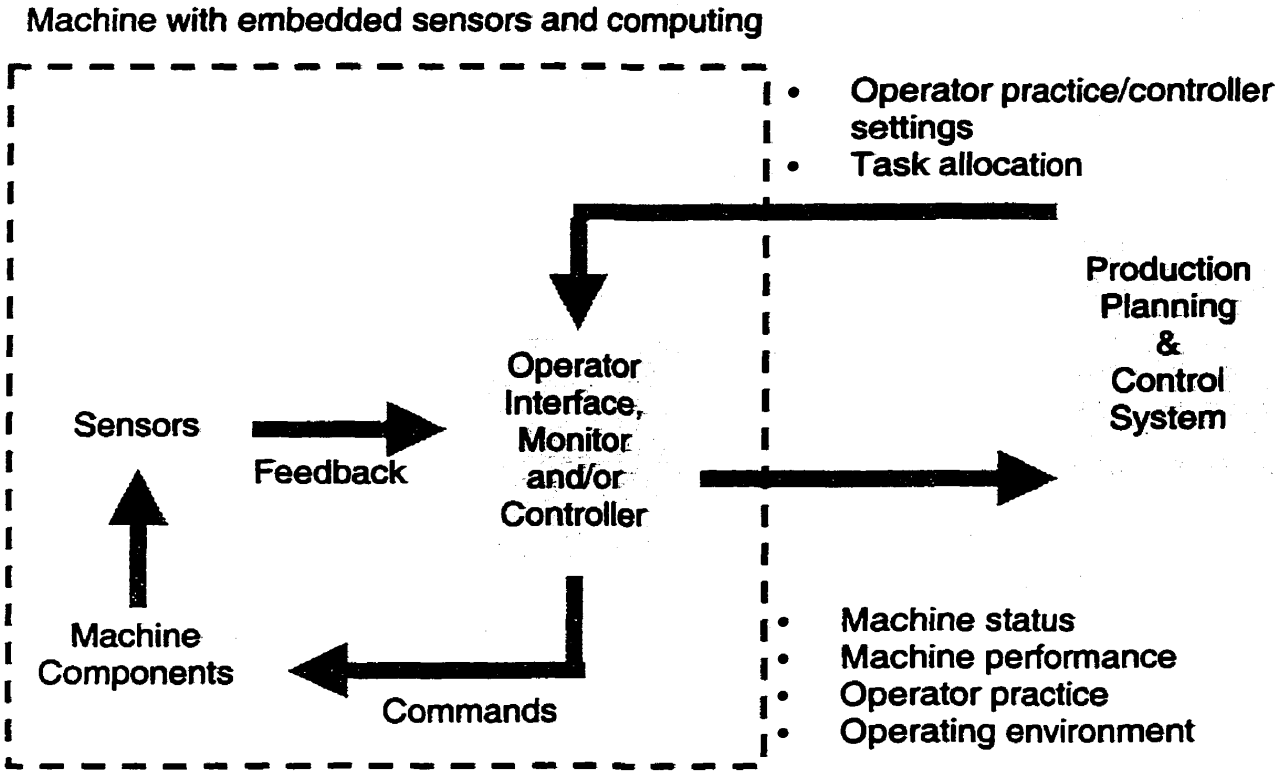


**Figure 4.4: Embedded Production Monitor/Controller (Daneshmend and Roman, 1997)**

Lipsett (1999) describes how one open pit mine is adjusting to the proper use of performance monitoring sensors. He describes the installation of displacement and pressure transducers to measure the motion and forces of the shovel attachment on a production shovel used to collect data while the shovel is operating. The collected data is then used to validate an analytical model of shovel performance and to monitor machine cycle times. An analytical model of one shovel type has been validated with field data. Based on these results, Lipsett suggests further work on operator assistance systems to give machine performance and health feedback to the operator. Work is ongoing to compare different shovel types, and to consider how on-board systems for remote machine monitoring,

diagnostics, and operator assistance can be integrated into a framework for mine-wide visualisation of mobile equipment performance and reliability.

Lipsett discusses several examples of sensors that are either available or being developed to give direct feedback to shovel operators while digging. These include:

(a) Motion Tracking (measuring bucket angle of attack and comparing each pass against "best practice").

(b) Real-time Payload Monitoring (reporting bucket fill to the operator before the bucket has broken away from the bank to dump).

(c) Co-ordinated Motion Control (CMC) which simplifies joystick manipulation when executing shovel motions.

(d) Ore grade sensing at the face with a multi-spectral camera (so that ore blending can begin as trucks are filled).

(e) On-board diagnostic systems (for example, an on-line, image-based system that checks for a missing shovel tooth).

Of course, as the information available about the operation of a particular piece of equipment becomes increasingly detailed, the need for operator judgement diminishes. The ultimate result of this trend is the automation of operator functions.

### *4.3.3. Mining Automation*

In an attempt to remove operators from unsafe work environments and decrease labour costs, some mines are turning to automation. For example, the use of tele-operated systems allowed the operator of an LHD to dismount before entering a stope. Recent

advances in underground communications infrastructure now offer reliable voice, video and data communications between both stationary and mobile machines all the way to the surface (Vagenas et al., 1999). Figure 4.5 provides a schematic diagram for a tele-operated LHD using a video control system.

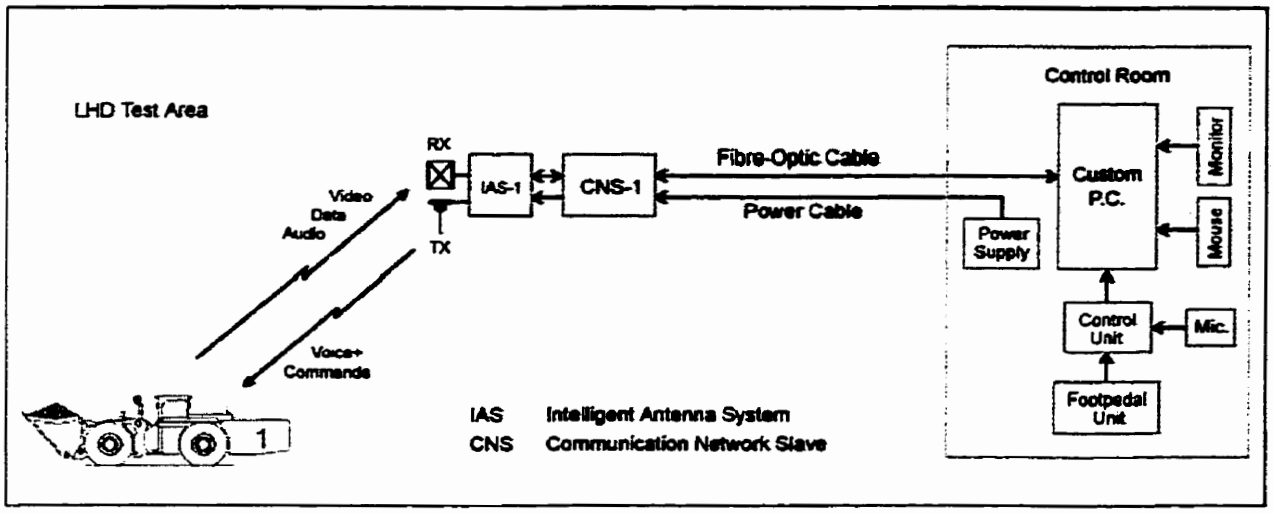


**Figure 4.5: Schematic diagram for a tele-operated video control system LHD (Hart, 1999)**

The tele-operation and eventual extension to full automation of mining equipment offer the possibility to operate underground mobile machines from surface. Vagenas et al. highlight some advantages associated with automated mining:

(a) Machine design will not be constrained by the need to accommodate onboard operators.

(b) Excavation sizes, layouts and profiles will be more adaptable to ground conditions and local geology.

(c) Access tunnels will likely be smaller with reduced development costs and increased rates.

(d) Productivity will be enhanced by more prolonged operation of machinery.

These potential advantages along with the corresponding improvement in safety and decreased costs have fuelled a considerable research effort aimed ultimately at creating a mine that can be operated in a fully automated manner. One area closely associated with the automation effort that has received limited attention is an appropriate maintenance strategy for automated equipment. Consider, for example, that in order to achieve the anticipated economies associated with automation, the equipment will have to operate for extended periods without operator attention. In reliability terms, automated equipment will have longer mission lengths. Furthermore, the automation equipment and its supporting communication technology add complexity to the overall mining system. In tele-robotic applications, for example, Dasys et al. (1994) point out that the operator is replaced by:

(a) a camera system,

(b) a control system,

(c) a guidance system,

(d) an on-board monitoring system,

(e) an obstacle detection system,

(f) a personnel detection system,

(g) a traffic control system,

(h) a communication system, and

(i) a control room.

Increased complexity reduces reliability. Consequently, the automated mine will rely on more complex equipment that will be expected to perform longer missions in a

presumably more harsh environment (assuming some human safeguards have been removed) while relying on more complex infrastructure. Without a major improvement in the reliability of these systems, the maintenance requirements for the automated mine will be problematic at best. Failures that were minor in nature and easily identified and rectified by the operator could now become major problems. A flat tire, for example, may result in significantly more downtime, as the failure will be more difficult to detect. Once detected, it will have to be repaired, which implies that the equipment is either recovered or that a field maintenance team will be required to perform a task that was previously handled effectively by the operator.

Kallio et al. (1998) recently highlighted the importance of high reliability for automated systems. These authors stress that the best way to achieve the necessary degree of reliability is to apply a design for automation concept throughout the product development process. Using this approach, the entire machine is built with computer control in mind with emphasis on the integration of all subsystems. Currently, the majority of automation packages are developed as add-ons and integration efforts are limited to making the equipment function as opposed to designing for high reliability.

In summary, it should be recognised that the learning curve toward full automation is very steep. Several key steps have been taken in the right direction. However, the lack of an appropriate maintenance strategy to effectively meet the high reliability requirements of autonomous mining equipment is a major deficiency. This is far more critical for underground as opposed to surface mining where technicians can still presumably reach the

equipment. Rather than racing ahead with the operational technology in isolation, technology developers need to focus some attention on the maintenance requirements of these systems if they hope to ever reach their objectives.

### *4.3.4. Evaluation of Emerging Technology*

With so many technological advances, mining managers may feel somewhat overwhelmed by the wide variety of alternatives. Further complicating the situation, is the fact that it is extremely difficult to objectively evaluate the worth of these systems. In extreme cases, mines may feel forced to adopt new technology for fear of losing a competitive advantage to mines that appear to be using the technology effectively. As a result, some systems are purchased without a full understanding of their capabilities or overall value.

In addition, as pointed out by Dessurault et al. (1999), technology providers do not necessarily have the expertise or resources to properly transfer technology from the development stage to the operational stage. Similarly, mining companies are also inexperienced at justifying and implementing these new technologies. The strategic nature of these systems make traditional capital budgeting evaluation techniques such as net present value (NPV), and payback period inappropriate. Many of the advantages of these new technologies, such as improved flexibility, manpower efficiency, engineering quality, and planning optimisation, however, are qualitative in nature (Dessurault et al.). As a result, the business case for implementation is difficult to quantify when using traditional financial justification techniques.

In summary, the mine operations planning process has undergone a long period of evolution. Most recently, emerging information technology is being applied in several ways in an attempt to improve individual processes. As a result, several stand-alone systems have been implemented in a segmented way throughout many mines. These systems have met with varying degrees of success, but none of these "operations systems" appear to take maintenance considerations into account. Similarly, research and development efforts aimed at eventually creating autonomous mining equipment will make the maintenance of this equipment even more crucial. Despite this, the focus remains on implementing the technology with little attention being paid to how the increased reliability requirements will be achieved.

### *4.4. Maintenance Management*

The primary objective of maintenance is the repair and upkeep of production equipment to keep it in a safe, effective, as designed, operating condition so that production targets can be met on time and at or below cost (Tomlingson, 1993). In his book, *Effective Maintenance*, Tomlingson further suggests that effective maintenance is the key to profitability. Conceptually, it is easy to agree with this statement. Any dollar saved on maintenance costs represents a corresponding increase in profit. However, without an understanding of the magnitude of these costs, it is difficult to assess the potential savings.

The Iron Ore Company of Canada (IOCC) is a large-scale open pit mine near Labrador City with an annual budget of approximately $500 million. Maintenance costs are

estimated to be $200 million per year (Doucet, 1997) representing 40% of the total costs at IOCC. If we restrict the costs to the mining part of the IOCC operation (and exclude processing), the maintenance proportion of total costs increases to in excess of 50%. The annual amount spent on maintenance at IOCC represents approximately 5% of the estimated replacement value of the mine's capital assets. The current world class benchmark for this performance indicator is 2.5% (McHattie and Pearcy, 1998). One could argue therefore, that there is room for a 50% reduction in maintenance spending at IOCC. This would result in increased profits of approximately $100 million per year representing an order of magnitude increase in profits that are currently estimated at $10 million annually. As was briefly described in Chapter 2, IOCC has been very proactive in reducing maintenance costs since 1989. Consequently, mines that have paid less attention to the maintenance side of the mining equation would presumably have even greater potential savings.

Looking beyond the IOCC example, Campbell (1997) studied the ratio of direct maintenance costs to total value-added costs for five industries. His data, presented in Table 4.1, shows that mining pays the highest proportion of maintenance costs compared to any other industry listed. Clearly then, the opportunity for savings in maintenance costs is industry wide.

| Sector | Percentage |
|---|---|
| Mining | 20 to 50 |
| Primary metal | 15 to 25 |
| Manufacturing | 5 to 15 |
| Processing | 3 to 15 |
| Fabrication and assembly | 3 to 5 |

**Table 4.1: Ratio of Maintenance Costs to Total Value Added Costs (Campbell, 1997)**

In order to understand where these savings might come from, this section will focus on maintenance management. In particular, the impact of some recent and some not so recent concepts and technologies will be examined. To provide some context for the discussion, this section begins with a description of maintenance strategy. Figure 4.6 presents a hierarchical representation of maintenance policies that can be applied to a particular piece of mining equipment.

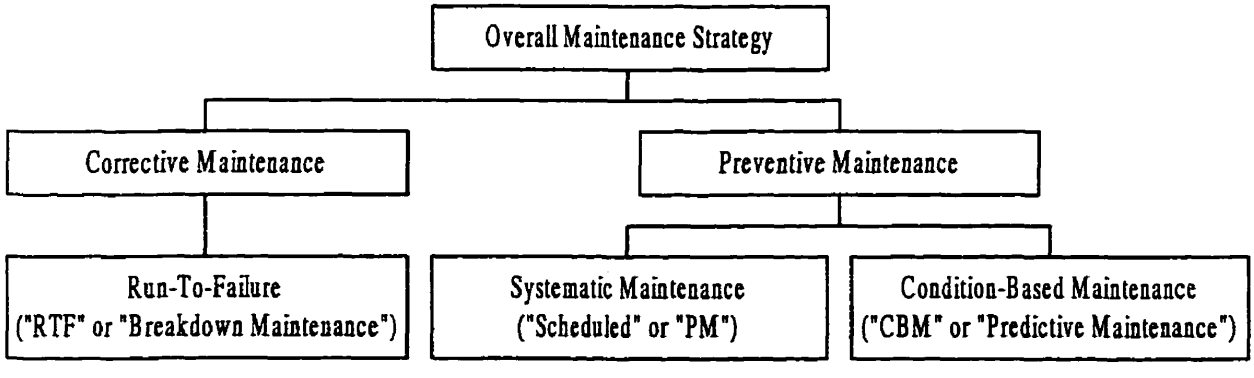


**Figure 4.6: Possible Maintenance Policies**

In deciding how to best maintain their equipment, maintenance managers will generally come up with a maintenance strategy consisting of a combination of the possible policies depicted in Figure 4.6. For non-essential systems (subsystems or components) that can fail without significant safety or cost implications, a run-to failure (RTF) policy may well be an appropriate means to minimise maintenance costs. However, the unpredictable nature of an RTF policy can make scheduling difficult. Furthermore, given the high utilisation requirements in most mines, breakdowns often result in lost production, the cost of which can go well beyond the direct maintenance costs associated with the breakdown.

In order to avoid costly corrective maintenance, mines have adopted preventive maintenance policies, the aim being to reduce the number of breakdowns for essential equipment. Figure 4.6 shows that preventive maintenance can be either systematic or condition-based.

### *4.4.1. Preventive Maintenance*

The term "preventive maintenance" (PM) made its way into the mining industry during the 1950s and 1960s. Albert (1996) suggests that along with the term, came what he calls a "fear factor" resulting from the perception that if a mine does not have a PM program in place, then they are not doing maintenance right. He further points out that initial estimates and the plethora of preventive maintenance articles written during this time all but promised that a formalised PM system could be designed to schedule maintenance on a programmed basis with the "guarantee" that breakdowns would be a thing of the past. These high expectations led to considerable investment and reorganisation efforts as mines

attempted to capitalise on this new concept. Of course, the promise of no breakdowns has yet to be achieved. However, most would agree that PM (also called scheduled or planned maintenance) has made a significant contribution in terms of avoided breakdowns.

The key question of whether the level of PM performed at a particular mine is appropriate or not remains. From an operations perspective, downtime means the equipment is not available for production regardless of whether the downtime was planned (PM) or due to an equipment failure. Consequently, operations will be inclined to view all downtime, scheduled or corrective, critically. However, both Albert (1996) and Mitchell (1998) seem to agree that too much maintenance is being done due to poor scheduling. Mitchell suggests that components are being replaced on schedule despite being in excellent condition with substantial life remaining. Johnston (1998) reports on maintenance departments measuring the number of PM procedures created and the number of procedures performed as key indicators of their effectiveness. He states that these organisations and the enterprise they support will become more efficient as the ratio of PM to corrective maintenance (CM) increases. The fallacy of this approach is obvious since the ultimate efficiency would be attained by stopping all productive work and devoting 100% of all resources to PM all of the time. Furthermore, all corrective maintenance is not urgent. If a piece of production equipment has failed, but was not being utilised during the unscheduled downtime, it makes no sense to expend extra effort (for example, in overtime) repairing the asset. Maximising equipment availability may seem like an appropriate objective for the maintenance department; however, meeting the uptime requirements at minimum cost would generally

save the mine money. What is required is an appropriate balance between PM and CM that maximises the equipment's contribution to the mine's bottom-line.

To achieve this balance, operations managers need to realise that PM is a reasonable way to avoid costly corrective maintenance. Similarly, maintenance managers must recognise that PM is a means to an end and not an end unto itself. Indeed, one could argue that unnecessary PM is negligent since it creates the opportunity for maintenance induced failures. Failures occurring in equipment that was operating perfectly prior to the PM procedure frustrate operations, embarrass maintenance and cost the mine money. Before implementing a PM program for a particular piece of equipment, maintenance managers should ask themselves the following questions:

(a) What are the desired functions and associated performance standards of the asset in its present operating context?

(b) How does the asset fail to fulfil its functions?

(c) What causes each functional failure?

(d) What are the effects of each failure?

(e) Are the effects of each failure significant enough to invest in avoiding them?

(f) If the failures are worth avoiding, is it possible to prevent them?

(g) If failure is significant but cannot be avoided, what else can be done?

One methodology that has been used to effectively address these questions is reliability centred maintenance (RCM). For a detailed description see Moubry (1992).

Although RCM is well established, particularly in the military, it has only recently been introduced into the mining industry.

### *4.4.2. Reliability Centred Maintenance*

The RCM methodology was developed by the US commercial airline industry in cooperation with the US federal government, aircraft manufacturers, and air carriers. It provides guidelines on how to best monitor equipment and their failures to derive scheduled maintenance tasks (including frequency) to best prevent unit malfunction (Jones, 1995). A simplified look at the RCM methodology is presented in Figure 4.7 (Jardine, 1999).

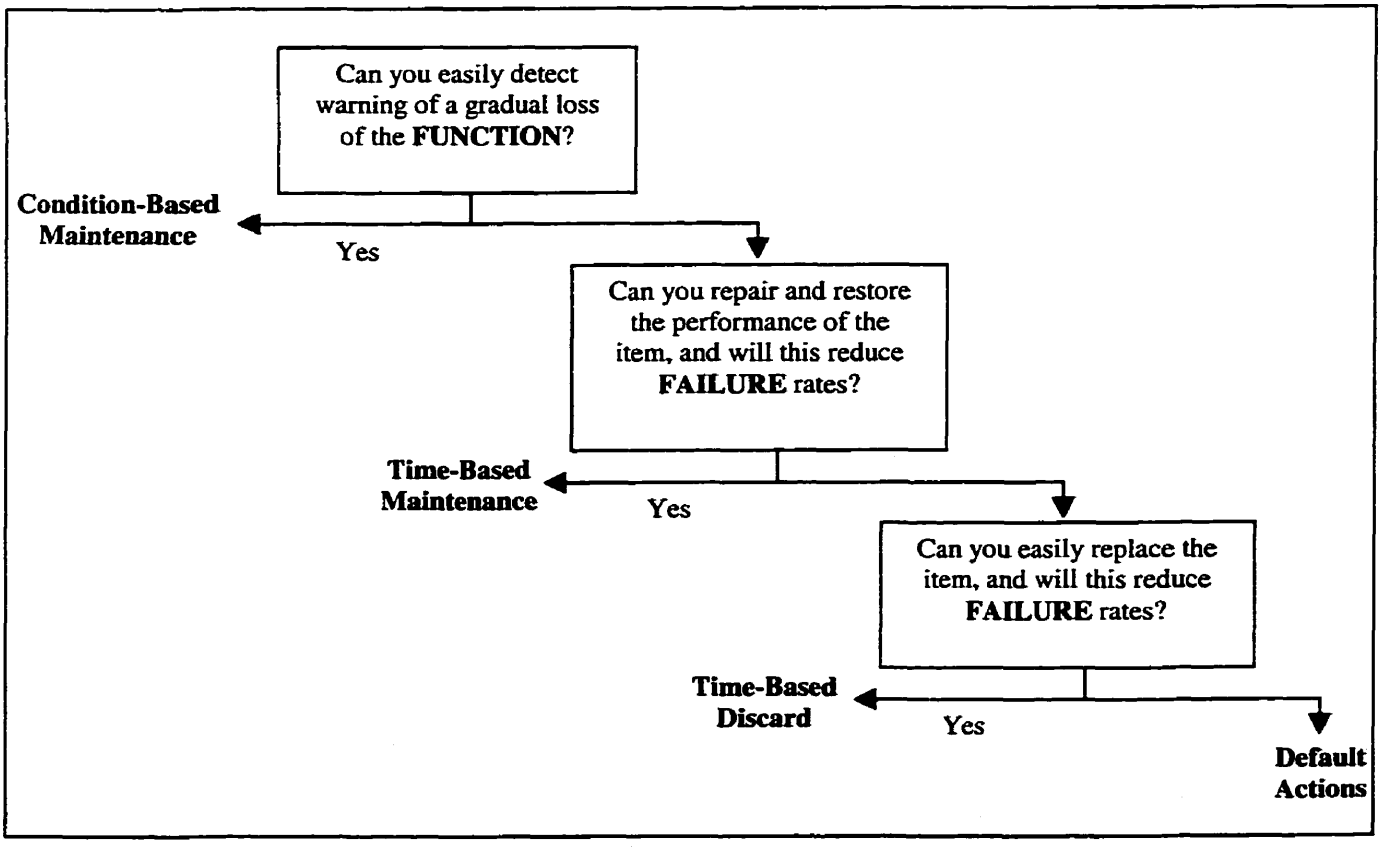


**Figure 4.7: Simplified RCM Logic (Jardine, 1999)**

Based on the success of the methodology for the airline industry, RCM was also adopted by the U.S. Department of Defence and the commercial nuclear power industry. There are many other industries that have either implemented RCM or are actively studying its philosophy to decide how it will fit into their environments, industrial systems' designs and cultures (Jones, 1995).

Although the initial RCM methodology focused on failure data, Ludwig and Nelson (1995) proposed a modification to the process logic to allow for the use of in-service maintenance data. Their approach, based on experience with conducting RCM for the Canadian Air Force, includes rationalising scheduled maintenance requirements for the maintenance of significant items. The use of maintenance data for in-service equipment was further studied by Spezzaferro (1996). In this case, the author discusses the application of logistic regression to maintenance data to establish maintenance inspection intervals.

Despite the fact that there has been significant interest in the reliability of mining equipment (Dhillon, 1984; Dhillon and Anude, 1992), few researchers appear to have paid any attention to RCM. In contrast, a large proportion of the published work is related to the reliability of mine transport equipment with focus on reliability analysis (estimation and prediction), safety, and condition monitoring. However, according to Paraszczak and Perreault (1994), despite the importance of reliability analysis very few in-depth analyses have been undertaken in the mining industry. Paraszczak (1999) suggests that a lack of uniform terminology and a misunderstanding of reliability terms are further complicating the application of reliability methods in the mining industry. One Canadian exception to this

trend however, appears to be IOCC where a rigorous RCM process was implemented in 1995 (Doucet, 1997).

### *4.4.3. Predictive Maintenance*

In a perfect world, maintenance staff would know exactly when a particular system critical component was going to fail. Although this degree of knowledge is a long way off, there are techniques available to make reasonable predictions about the relative likelihood of failure over time. Based on these predictions, maintenance activity can be scheduled to avoid costly failures. In order to make these predictions, the maintenance staff must in some way measure the condition of the equipment. A schematic representation of the condition-based maintenance process is depicted in Figure 4.8.

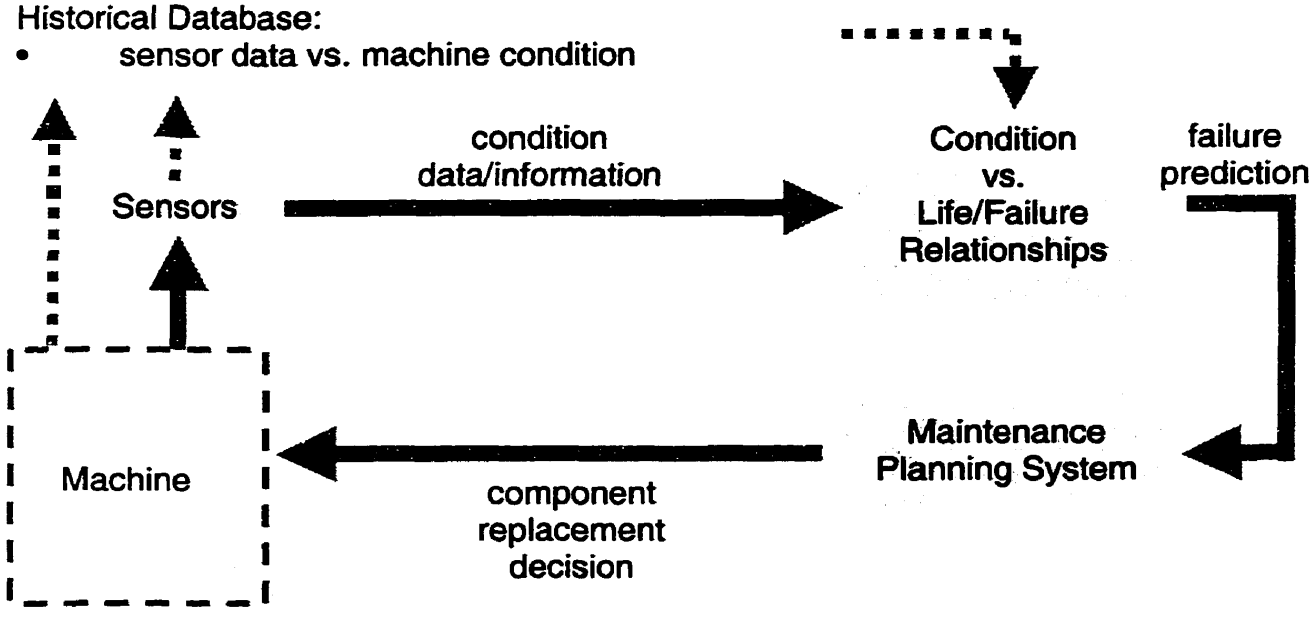


**Figure 4.8: Conventional Condition-Based Maintenance (Daneshmend and Roman, 1997)**

In the conventional model of condition-based maintenance periodic inspections are performed using sensors to determine, for example, the amount of metal (usually iron, chrome or copper) in the lubrication oil or the degree of vibration. These measurements are then compared to historical data in order to diagnose the current condition (health) of the equipment that can then be used to predict the risk of failure prior to the next inspection. Should this exceed some threshold value, the maintenance planning system would schedule a component replacement. Otherwise, the machine is left operational until the next inspection.

Jardine (1999) describes how proportional hazards modelling (PHM) can be used as a basis to model the condition-based maintenance decision as a semi-Markov decision process using objectives such as minimising total cost or maximising availability. The advantage of this approach is that it combines the traditional age based component of the PHM with the condition-based information to predict an overall risk of failure. Makis and Jardine (1992) describe how this combined PHM information can be further combined with economic considerations (like the cost of a failure replacement versus a preventive replacement) to identify optimal replacement decisions.

Recent advances in sensor technology have effectively reduced the need to conduct inspections in order to measure the condition of the equipment. More and more mining equipment comes (or will soon come) with devices similar to flight data recorders (black boxes) used on aeroplanes. In addition to the performance monitoring sensors described in section 4.4.2 above, systems such as VIMS (Vital Information Management System) from Caterpillar (Caterpillar, 1997) or CECAM (Computerised Equipment Control And

Monitoring) from Tamrock (Kallio et al., 1998) are also capable of collecting condition monitoring information. Typically, the information is downloaded periodically and analysed to determine the condition of the equipment. The next logical step would be to have the analysis conducted as part of the on-board system. By effectively automating the analysis function, inspection requirements could be drastically reduced. This would require that the diagnostic models and life/failure models used to transform sensor readings into failure predictions be embedded into the on-board system. A schematic representation of this process is depicted in Figure 4.9.

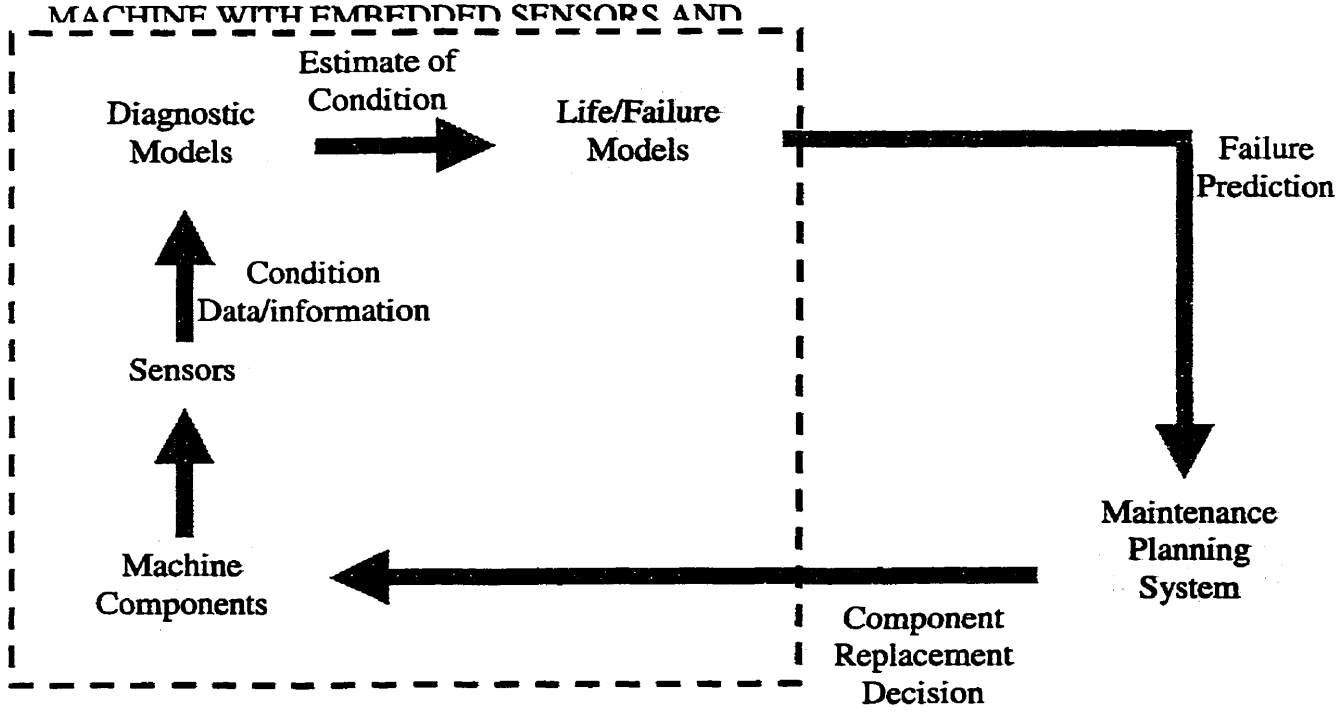


**Figure 4.9: Embedded Model-Based CBM (Daneshmend and Roman, 1997)**

The primary advantage of the embedded model is that the measurements and computations are done automatically, on-board the machine. As a result, the failure

prediction information is the only thing required to be transmitted to the maintenance planning system. If the sensors are continuously monitoring the machine's health, alarms can be triggered whenever any of the key parameters start to indicate impending failures.

### *4.4.4. Maintenance Management Information Systems*

All of the predictive maintenance and the component replacement systems described above require timely and accurate information in order to be effective. The effectiveness of any maintenance and reliability analysis depends to a large extent on the collection and of accurate field data. Achieving the benefits of reliability assessment techniques, such as RCM, requires a culture of diligent data collection, data maintenance and processing over an extended period of time to generate reliable historical information. This information then allows for the critical evaluation of equipment reliability, maintenance practices and management, mine logistics and maintenance support.

Perhaps IOCC has achieved the most significant advances in this area with respect to maintenance information. They have successfully integrated three main computer systems at the mine: the Mine Dispatch System, the Maintenance Management System and the Novel Local Area Network (LAN). In an effort to implement a Maintenance Integration Plan, these three systems were forced to be compatible allowing for data interchange-ability between systems. A maintenance expert system that was planned to reside on the LAN creating a strategic link between these systems providing for the automatic issue of work orders based on the condition of all mine equipment proved too difficult to implement (Goddard, 1996). In contrast to the TMS$^{TM}$ effort that has been driven primarily from a

production perspective, the IOCC effort has been maintenance driven with future plans to integrate production planning. These plans call for a total integration plan that includes the interconnection of quality control and production with the maintenance systems.

### *4.4.5. Equipment (Asset) Management*

One way to improve the understanding of the role maintenance plays in the mine is to adopt an equipment management model based on the value added by a piece of production equipment rather than simply trying to minimise maintenance costs. Mitchell (1998) suggests that traditional measures of maintenance effectiveness are primarily subjective and intangible. He characterises these measures with four questions:

(a) Does equipment operate when needed (availability)?

(b) Are production interruptions and catastrophic failures few and far between (reliability)?

(c) Are problems corrected promptly (maintainability)?

(d) Is operations/production happy?

When asked in this manner, these measures are indeed subjective. Furthermore, if a mine does not have a comprehensive data collection and analysis capability, they will be unable to calculate the appropriate measures such as mean time between failures (MTBF) and mean time to repair (MTTR). However, availability as presented in Chapter 2 is relatively easy to measure and relatively more objective compared to any qualitative responses that one might receive from the other questions posed by Mitchell (1998). However, does meeting availability targets demonstrate the profit impact of a failure that does not occur?

Mitchell (1998) proposes an economic value added (EVA) model that shifts the focus from minimising costs to gaining maximum value and profitability over the lifetime of an asset. Simply stated, EVA is the after tax operating profit less the cost of capital. Consequently, a positive EVA indicates value added above the cost of capital. Mitchell makes a convincing argument for the adoption of such a model. The advantages of shifting from a cost centred model to a profit centred model are based primarily on mindset. On one hand, as Mitchell points out, a cost centre contains no systematic incentive to optimise. Consider a maintenance department that finishes its year under budget. The likely reward based on a "spend it or lose it" mentality would be a decrease for next year's budget. A similar systemic disincentive occurs when there is pressure to reduce costs. The cost centre mentality causes everyone to become task protective rather than results oriented. Conversely, a profit centre mentality promotes initiative, ingenuity and a feeling of ownership. The successful application of this mindset will result in investments and added costs being evaluated based on results and returns.

Unfortunately, the EVA model may prove difficult to implement in a mining context for several reasons. First, there is a major requirement for accurate, traceable information. MTBF for each individual piece of equipment as well as all components and the exact reason and cost of failure is imperative. Generally, this level of detailed information is not maintained on an ongoing basis. Depending on mine data collection practices and internal communication means, records are sometimes quite precise, but usually information stored is non-uniform and inconsistent. As a result, in many cases information/data recorded is such a

rough approximation of reality that it becomes almost meaningless. Some of the most common problems encountered include:

(a) Missing or imprecise data on the time failures actually occur.

(b) Failure to record the start of active maintenance actions. Without this information tracking down delays becomes almost impossible.

(c) Failure to accurately record the termination of downtime. For example, logistic delays associated with waiting for a piece of repaired equipment to be returned to service is generally counted as downtime.

(d) Confusion and lack of standardisation of reliability and maintainability measures. For a summary of these issues see Paraszczak (1999).

(e) Confusion over what constitutes preventive maintenance. For example, if corrective actions (such as replacing a poorly operating component) are scheduled in advance they should not count as corrective maintenance.

(f) Unknown or unclear logistical delays. Waiting for parts or an available technician are both valid reasons for a delay. However, if the reasons for the delays are not recorded and tracked, it is impossible to determine where the bottlenecks are occurring in the maintenance facility.

A second reason why the EVA model would be difficult to implement in a mining context is that it requires activity based costing as the underlying financial accounting mechanism for the organisation. Most mines have not adopted this accounting method. Third, the EVA model requires a very broad approach to equipment management that goes across traditional departmental lines. A realignment of a mine's accounting procedures

based on asset management would be a significant departure from current practise that may prove difficult to implement. However, as the trend towards larger equipment and automation continues, asset management employing an EVA model as proposed by Mitchell, will become increasingly attractive. As Steenstrup (1999) points out, however, asset management only addresses one corner of the mining enterprise and will not reap the dividends that are possible if the business works as a whole. This gives rise to an even more sophisticated model which includes information gathering and sharing across the entire mining enterprise.

### *4.5. The Road to an Enterprise Wide Mining Information System*

In sections 4.3 and 4.4, several information technology applications were described for operations and maintenance respectively. In both cases, attempts were made to expand the scope of the information system to include integration across functional boundaries. Although neither of the systems described above was particularly successful at achieving this, the quest for enterprise wide solutions continues.

The lack of success for information technology (IT) projects was studied in detail by the Standish Group (1995). They conducted a survey of management information system (MIS) professionals in many industry sectors. The total sample size was 365 respondents representing 8,380 IT projects. The survey was followed up with focus group workshops and interviews. The authors defined projects to be a success only if they achieved all of the desired capability on time and on budget. Based on this definition, only 16.2% of the projects were successful. Conversely, project failure was deemed to have occurred only if,

for some reason, the project was cancelled. Despite this harsh definition for failure, 31.1% of the projects fell into this category. The remaining 52.7% of the projects fell between these two extremes, having not met the criteria set out for project success but eventually reaching completion with at least some of the promised functionality being implemented.

Returning to the mining industry, it is clear that both business information systems and technical mine planning packages have been in use for a number of years to enable efficient operation of the mining enterprise. Typically, however, these information systems have not been integrated together. As a result, many of the recent software efforts have been driven by the need to connect various mining activities together so that data can be exchanged and decisions made based on information derived from data across functional boundaries. Steenstrup (1999) suggests that this has led to a number of separate non-integrated specialist software solutions or "islands of information" that complicate the information flow and cause, in extreme cases, manual transfer of data. This approach leads to a loss of information and a proliferation of spreadsheets and other applications that need re-writing as new data is acquired and as the data/information systems grow. As a result, these applications are hard to maintain and update and in the long run are very expensive.

In order to avoid this expense, Steenstrup (1999) proposes an enterprise wide mining solution that provides the following linked functions:

(a) Production and logistics management to efficiently acquire the materials for mine expansion and the logistics for shipping predicted production volumes.

(b) Asset and maintenance management to ensure the highest availability of equipment at the lowest expenditure. Predictive maintenance based on immediate response to out of limit conditions and alarms. Also co-ordinating scheduled downtime to avoid critical production times where possible.

(c) Management of consumables including analysis and deployment of replenishment services (e.g. fuel).

(d) Deposit modelling, planning and forecasting to manage the exploitation of the ore deposit.

(e) Seamless connection to customers and vendors so that parts and materials can be ordered and tracked more directly, and shipping of product can be transmitted to customers and/or smelters to give the same integration of planned volumes.

(f) Mining activities seen as part of the complete business process so that the financial repercussions (Pros and Cons of decisions) can be examined.

(g) Use of "control room" concept to run the enterprise. Based on improvements or problems in recorded profitability, adjustments to procedures can be made.

(h) Productivity control and communication will support senior and middle management in keeping the whole company informed of current progress and position.

To ensure that strategic decisions can be made based on the information being gathered Steenstrup further proposes a number of critical elements that are derived from this Enterprise model. These include:

(a) Historical data on all activities and events occurring during the operation of the mine. These provide the basis for forecasts as well as analysis of causes of any improvements or degradation of operations. For example, has production decreased because of machine failures due to parts, or staff training, or other factors?

(b) Models and plans that parallel the actual mining operation.

(c) A Basis of all reconciliation and comparison between planned and actual events/activities.

(d) A basis for all costing, budgeting and forecasting.

(e) A visual and spatial stage on which all mining activities are visualised and interrogated.

Mottola and Patton (1999) point out that numerous implementations of enterprise wide systems have precipitated the re-engineering of certain business processes with a mixture of success and failure. In the latter case, the authors suggest that the fault does not lie within the software systems, but rather with the notion that a fairly standard technology can be force fitted to a variety of complex business environments. Specifically, software vendors achieving success for the manufacturing or financial industries wrongly believe they can implement these same systems at a mine. Returning to the Standish Group survey, the

top six opinions about why projects were ultimately cancelled are listed in Table 4.2 (Standish Group, 1995).

| Project impairment factor | | % of responses |
|---|---|---|
| 1 | Incomplete requirements | 14.1% |
| 2 | Lack of user involvement | 12.3% |
| 3 | Lack of resources | 10.6% |
| 4 | Unrealistic Expectations | 9.9% |
| 5 | Lack of executive support | 9.3% |
| 6 | Changing requirements and specifications | 8.7% |

**Table 4.2: Top six reasons for IT Project Failure (Standish Group, 1995)**

If we combine impairment factors 1 and 6 in Table 4.2, we see that incomplete or changing requirements account for almost 22% of the failures. This would seem consistent with Mottola and Patton's (1999) opinion that applications that meet the requirements of one industry may fall well short of the requirements in a different industry. Without a thorough understanding of what the actual user requirements are any effort to create an enterprise wide solution will be problematic at best. In particular, the impressive list of linked functions and critical elements presented by Steenstrup are only worthwhile if they meet an actual information requirement.

This has not deterred the software vendors who have continued on the quest to create an "enterprise wide" mining information system. Several such products were showcased during the Tradex portion of the CIM AGM held in Calgary in May of 1999. The most comprehensive of these appears to be based on the Minestar product soon to be offered by Caterpillar. Through a strategic partnership with AQUILA Mining, Mincom and Trimble Navigation, Caterpillar hopes to offer a fully integrated mining information system early in the year 2001. Although this alliance shows much promise, there is very little official literature available on Minestar. A generic, logical system view of how this might be achieved was presented by Steenstrup (1999) and has been reproduced in Figure 4.10.

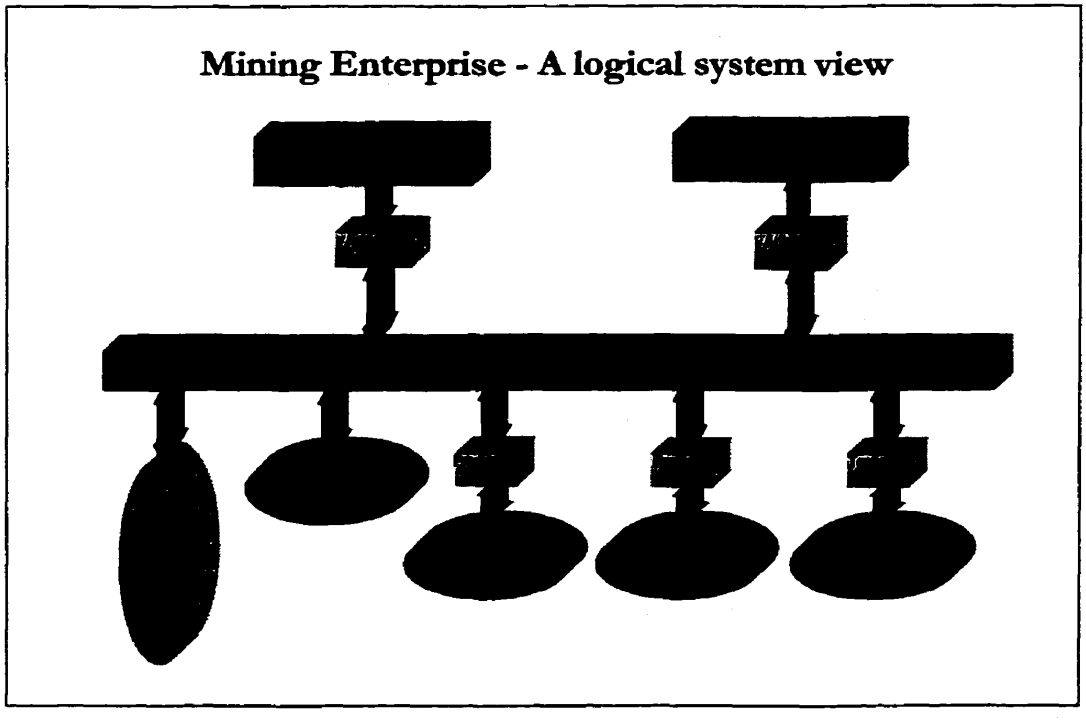


**Figure 4.10: Mining Enterprise Information System (© Mincom 1999 - reproduced with permission)**

The key technological challenges to achieving the model depicted in Figure 4.10 are based on successfully creating the five "adaptors" that will allow for the seamless integration of existing systems through the enterprise component connector. For mines already committed to systems in functional areas (e.g., a specific dispatch system), the adaptors would have to be custom built.

Beyond these technical challenges however, remains the fundamental question of user requirements. Do most mines have a fundamental need for an enterprise wide solution? What are the detailed information requirements across the functional business boundaries that make this necessary? The fact that manufacturing has successfully implemented similar solutions does not automatically mean they are required in the mining industry. In his book titled, *The CIM Debacle*, Singh suggests that computer integrated manufacturing technology has not fully matched its potential (Singh, 1997). He describes several new systems modelling and engineering tools capable of supporting the integration and interoperability of software applications for CIM.

In order to illustrate the need for these systems in a mining context, Steenstrup (1999) presented a data flow model of the enterprise solution as reproduced in Figure 4.11. This diagram shows how the asset management focus on equipment is tied in to the company's overall mission. The key enabling technologies, including real time geological, dispatch and condition monitoring information are also represented in the diagram. This combination of technologies, if done correctly, could result in a significant step towards a totally integrated information structure for mining. However, unless the implementation of this concept

includes a detailed analysis of the mines basic information requirements the risk of failure will remain high.

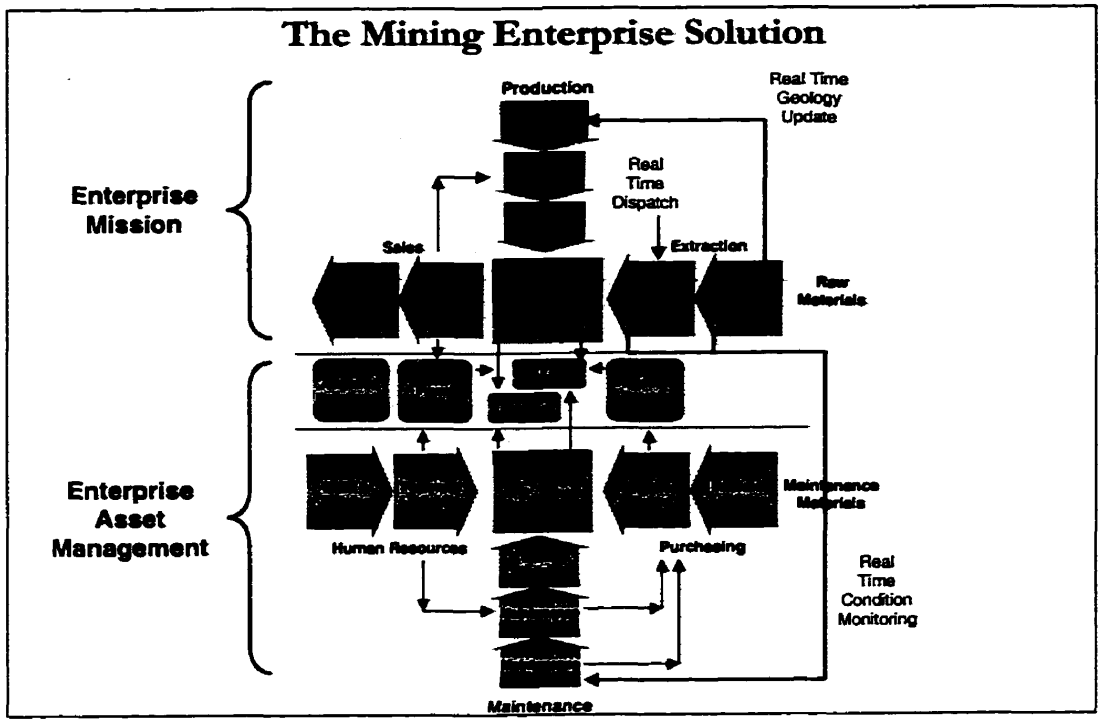


**Figure 4.11: The Mining Enterprise Solution (© Mincom - reproduced with permission)**

### *4.6. Summary*

In this Chapter, both the operations planning process and maintenance management have been discussed. In both functional areas there has been increasing emphasis on applying emerging technology in an attempt to improve these processes. In particular, mines have recognised the need for timely and accurate information to improve the decision making process. This has resulted in a significant amount of investment being made into improving the information systems in use at mines.

The information systems described in this chapter have met with varying degrees of success. Each has had a slightly different focus but all appear aimed at taking advantage of new technology to improve operations, maintenance or both. In addition, all appear to have a second thing in common, that is, a proposed technological solution (or at least a conceptual design) that attempts to optimise "something" (operations or maintenance). The solution is generally based on the effective application of new technology to existing mine practices. In none of the examples does there appear to have been a requirements analysis conducted to determine if the proposed solution meets the needs of the intended users. Not surprisingly then, the users are often disappointed with the results and the proposed systems are dropped or not used. Furthermore, systems that do eventually get implemented are generally specific to either operations or maintenance, as attempts at integration across these boundaries prove too difficult to achieve. As a result, the lack of information flow between these two groups is reinforced as these systems further isolate the adopting department.

At the same time, efforts to increase the level of automation and the trend towards higher capacity equipment continue. Automation adds complexity to the equipment and, as a result, will decrease reliability. In addition, larger capacity equipment decreases maintenance flexibility, as lost production costs become much more sensitive to unscheduled downtime. The combined impact of these two factors will increase the criticality of the maintenance function.

Furthermore, since maintenance is one of the largest overall mining cost components, any maintenance cost decreases directly translate into increased profitability and corporate

competitiveness (Goddard, 1996). This means moving away from the crisis oriented approach that has been the characteristic of mine maintenance (Brown, 1984). It also means becoming proactive rather than reactive, and finding ways to maximise the maintenance contribution to the mines overall success. To achieve this, an integrated mine management system that transcends departmental boundaries should be implemented. In addition to dealing with routine management issues (policy, planning, organising and scheduling), such a system must collect relevant information, not just for reporting purposes, but also enable the continuous evaluation and improvement of the maintenance function and the reliability and performance of the production equipment. The first step in achieving an integrated maintenance system is to determine, in detail, the specific information requirements necessary to achieve these aims. An accepted methodology for determining user requirements is called *structured analysis*. This approach will be presented in Chapter 5.

# CHAPTER 5

# 5. The Structured Analysis Methodology

## 5.1. Introduction

Several contemporary analysis methodologies capable of analysing the information flow in organisations exist. Data flow techniques tend to be preferred by information system analysts while those interested in business process re-engineering tend to favour object-oriented and workflow techniques. The structured analysis (SA) methodology chosen for this research is a generic modelling technique that is suitable for any modelling application and as a result is simpler and more flexible compared to the other possible methods.

The SA technique was developed in late 1960s, during the structured programming revolution. The focus at that time was aimed at improving computer programming methods, but some researchers were concerned with the more difficult problems of building large-scale systems made up of people and machines as well as software. As large-scale system developers faced issues related to things like the command and control of nuclear weapon systems, the need for a more disciplined process became apparent. The process of system development was therefore organised into a sequence of phases such as:

(a) Analysis – Determine what the system will do.

(b) Design – Define subsystems and their interfaces.

(c) Implementation – Create the subsystems independently.

(d) Integration – Combine the subsystems into a single unit.

(e) Testing – Verify that the system works.

(f) Installation – Make the system operational.

(g) Operation – Use the system.

This traditional process allowed for feedback between phases and repetition of the complete sequence because the system never perfectly met the perceived needs of its users, and because the users' needs changed.

Over time, several problems were identified with the traditional approach to systems development. For example, Marca and McGowan (1993) reported that a high percentage of the errors in a system were made during the analysis or design with relatively fewer errors occurring during implementation and testing. The fact that the cost in both time and money necessary to identify and correct errors increased as the development progressed highlighted the importance of getting the first steps of the process correct. For instance, these authors suggest that an uncorrected analysis error could cost twice as much to correct during design, ten times as much to correct during testing and one hundred times as much to correct during system operation and maintenance. In terms of schedule, errors made during analysis or design took around twice as long to find and around five times as long to correct as errors made in subsequent phases. Furthermore, the users often found analysis and design errors after implementation resulting in much dissatisfaction. As an analogy, consider an automobile manufacturer forced to conduct a major recall as a result of a safety problem uncovered through a series of automobile accidents. The direct costs of the recall are significant, however, these pale in comparison to the indirect costs associated with the loss of

goodwill likely to occur as customers, who in addition to being inconvenienced, will be wondering what other design flaws may be left undiscovered.

In addition to the impact of analysis and design errors outlined above, Marca and McGowan list several other problems with the traditional approach to system development. These include:

(a) Lack of a uniform approach.

(b) Users' involvement in the process was not controlled.

(c) Checking for consistency was lacking or sporadic.

(d) Lack of integration between subsequent development tasks.

(e) Difficulty in measuring the process quantitatively or qualitatively.

(f) Poorly stated or misunderstood requirements.

(g) Incomplete functional specifications or inconsistencies between the specification and design resulting in errors very early in the design process.

At the same time as these problems were being uncovered, the complexity of the systems being designed was increasing dramatically. Designers soon realised that improved analysis methods were the key to creating cost-effective, maintainable and reliable systems. SA grew out of the belief that better methods, tailored specifically for use very early in the process were required to address the problems of large-scale system development as outlined above.

At the heart of SA is a formal graphical language. The old adage "a picture is worth a thousand words" describes the value of representing system designs in a precise graphical way that is easily understood. SA is by no means unique, as there are many different types of graphical modelling techniques that people use in an effort to communicate concepts, ideas and processes that are essentially pictures used to document the modeller's vision. Flow charts, for example, have proven very useful in helping computer programmers design their software. Although flow charts as applied to computer programming have a fairly rigid set of well-defined symbols and rules, many models are created without any formal syntax as the modeller uses some combination of boxes, circles and arrows to try to represent the system under study. Sometimes these "free-hand" models come with definitions explaining what each of the symbols actually means, but more frequently they do not. Conceptual models prepared in this way are usually such broad abstractions that the modeller probably isn't even sure exactly what the model means. As a result, without a fairly detailed description, it is difficult for anyone but the modeller to understand in detail, what the model represents. SA started out as a formal graphic language used to describe the workings of systems in general, but with increased use its procedures for describing systems were expanded and refined. The greatest strength of the technique lies in how its simple modelling constructs (boxes and arrows) can be used to accurately describe complex systems.

Before describing the details of SA, it is worth highlighting a few principles from general systems theory that help explain why it is an appropriate analysis methodology for mining processes (Weinberg, 1976). In particular, there are a few general principles that are

common to all systems that provide insight into the applicability of SA. These principles include:

(a) *The more specialised a system is, the less able it is to adapt to different circumstances.* Many mining systems are extremely specialised. As a result, user requirements for systems such as the control of in-process inventory will also be specialised. The more specialised the user's requirements are, the less likely it is that an off-the-shelf commercial solution or software package can be used.

(b) *The larger a system is, the more of its resources must be devoted to everyday upkeep.* Most mining operations would be considered large. They generally include significant bureaucracies dedicated to addressing the day to day needs of the business. Surprisingly, however, despite the large volume of policy documentation there is very little documentation relating to several of the basic business activities performed as part of the actual mining processes. SA is basically a documentation process that can be used to accurately describe these processes leading to an improved understanding.

(c) *Systems are always part of larger systems, and they can always be partitioned into smaller systems.* This principle provides the justification for the hierarchical decomposition of systems that is fundamental to SA. It enables the analysis to be conducted at any level of the system and gives analysts the ability to move from the general to the specific within an

understandable framework. Without this ability, it would be very difficult to model the size and complexity of most mining systems.

(d) *Systems are dynamic.* In most instances, systems grow, but they can also get smaller and even cease to exist. This is certainly true of mining systems. The relevance of this principle to SA is that during the conduct of a particular analysis, the system under study may change and the modelling approach must be capable of making changes along with it. SA models provide a mechanism that can be used not only to document changes but to also evaluate their impact.

The SA methodology, which will be described in this chapter, is well suited to take these general system principles into account. The complexity involved with describing mining systems is caused by the fact that the systems are hard to enumerate and cannot be simplified through generalising assumptions without the risk of invalidating the model. SA was specifically developed to completely describe such complex systems using a straightforward graphical approach.

### *5.2. Structured Analysis Defined*

A SA model is a system description that has a single subject, a purpose and a viewpoint. The model organises its description into a hierarchy of interconnected diagrams. The top of this tree structure is the most general description of the system and the bottom of the model comprises the most detailed description.

### 5.2.1. Styles of SA

Ross (1993) highlights the fact that there are two distinct styles associated with SA. *Activity models* stress what actually happens in the system while *data flow models* stress the "things" of a system. Both styles use the same box and arrow syntax as described below, but provide for different emphasis. The activity-based diagrams are better suited to describing business processes. The government standard, IDEF0, was created to specify the methodology for activity based diagrams (FIPS PUBS, 1993). Data flow diagrams allow for a few additional constructs such as a data store that are more suitable for software development. It is also possible to use both styles of diagram in the same model. Activity diagrams used to describe the upper levels of a process can be decomposed into data flow diagrams when it becomes necessary to describe entities that are not part of the activity modelling tool kit. This is the approach that is applied in this research. Data flow diagrams can be identified by rounded corners on the boxes as compared to the square corners used on the boxes in activity based diagrams.

## 5.3. Model Syntax and Usage

Marca and McGowan (1993) provide a comprehensive description of the SA process using activity models in accordance with the IDEF0 standard. The original textbook on data flow models was written by DeMarco (1979), but Senn (1984) and Yourdan (1989) also provide excellent descriptions. The basic construct for both styles of SA model is the SA box that is depicted in Figure 5.1.

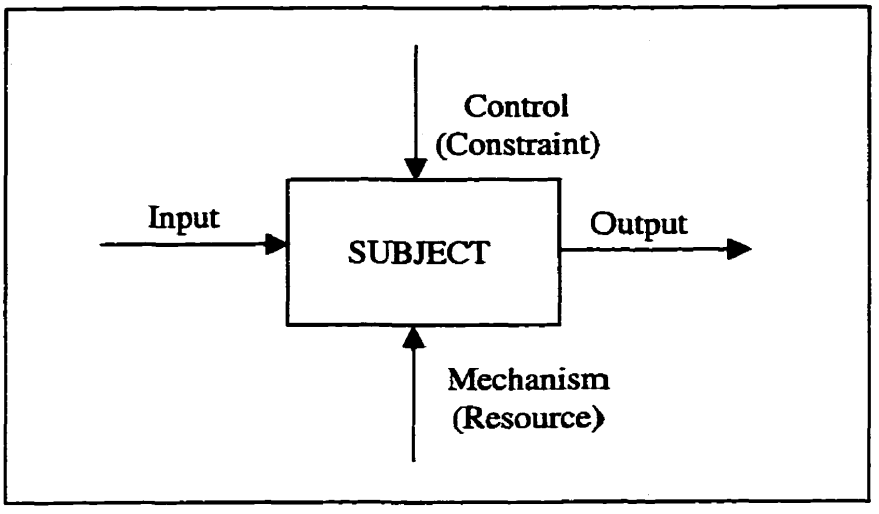


**Figure 5.1: The SA Box**

The subject (activity) of the SA box transforms inputs into outputs through the use of mechanisms (also called resources) provided under the controls (also called constraints) as specified on the diagram. Outputs from one box may be inputs, controls or mechanisms for other boxes. Inputs always approach a box from the left while outputs always exit from the right. Similarly, controls always enter from the top and mechanisms from the bottom. The boxes are named and the arrows are labelled using natural language. Arrows may branch and join, and any box can be decomposed, as a whole, into its constituent parts on a detail diagram. Inputs, controls and outputs describe the interfaces between the boxes, and mechanisms can allow for constrained allocation between several activities when appropriate. Box and diagram boundaries must match and the resulting hierarchic, interconnected collection of diagrams is called a model. The top-down structure of the hierarchy is organised through the use of node numbers. Structured decomposition first breaks the one-box boundary (called a context diagram) into a single diagram having from two to six boxes, then breaks one or more of these boxes into another diagram with two to six

boxes each and so on. The title for each diagram is taken verbatim from the box it decomposes. The result of this process is a model whose top diagram describes a system in general "black box" terms and whose bottom diagrams can describe very detailed aspects of the operation or system. A sample context diagram, using data for Syncrude Canada Ltd. (SCL) is presented in Figure 5.2.

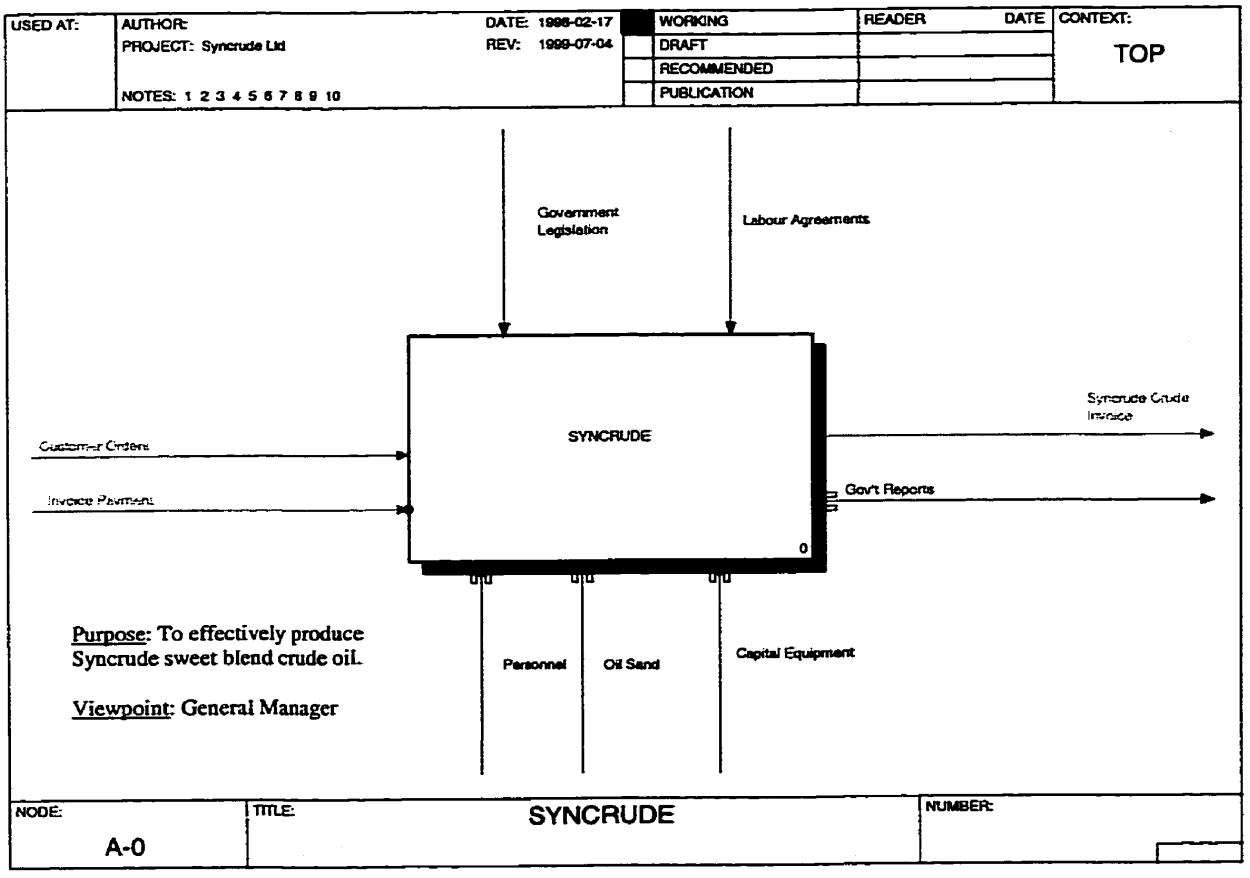


**Figure 5.2: Sample Context Diagram**

This diagram shows that Syncrude uses *personnel, capital equipment* and *oil sand* (resources) to convert *Customer Orders* and *Invoice Payments* (inputs) into *Syncrude Crude Invoices* (representing the amount of actual crude oil shipped) and *Government Reports* (outputs). This process is subject to controls imposed *by Government Legislation* and *Labour Agreements*. The context diagram is also important because it depicts the scope of the SA model. This is achieved in two ways. First, the inputs, outputs, resources and constraints completely define what is included in the model. Anything not included is outside the scope of the study. For example, Figure 5.2 does not include any input or outputs related to community involvement. Being one of the two major employers in the Fort McMurray area, SCL is closely tied to the community. Based on the context diagram depicted in Figure 5.2 however, community involvement is clearly not part of this particular model. Second, the context diagram is accompanied by a purpose statement and includes a description of which viewpoint the model represents. The purpose statement provides insight into the motivation for the activity being modelled. On the other hand, the viewpoint describes the perspective from which the models are created. The operations manager at a mine, for example, would have a different perspective than that of the maintenance manager. As will be seen in the case study presented in Chapters 6 and 7, the selection of the appropriate viewpoint is a critical step in assuring the value of the model created.

The context diagram, along with all of the decomposition diagrams are each integral parts of an entire model. The various other fields shown in Figure 5.2, such as the *used at* field are part of the IDEF0 standard and serve to aid in the control of model construction. For example, each diagram in a particular model can be uniquely identified by what is called a

node number. The node number for the context diagram has the form: model name or abbreviation, slash, the capital letter A (for activity diagram), a hyphen, and zero. The node number for the sample context diagram presented in Figure 5.2 is Syncrude/A-0. The node number for the diagram that decomposes the boundary is the same node number without the hyphen (i.e., Syncrude/A0). This is called the level zero diagram which is presented in Figure 5.3. Taking the node number of the parent diagram and appending to it the number of the box that is being decomposed forms all other node numbers. The diagram representing the decomposition of activity 2 (Bitumen Processing) in Figure 5.3 would therefore have node number Syncrude/A2.

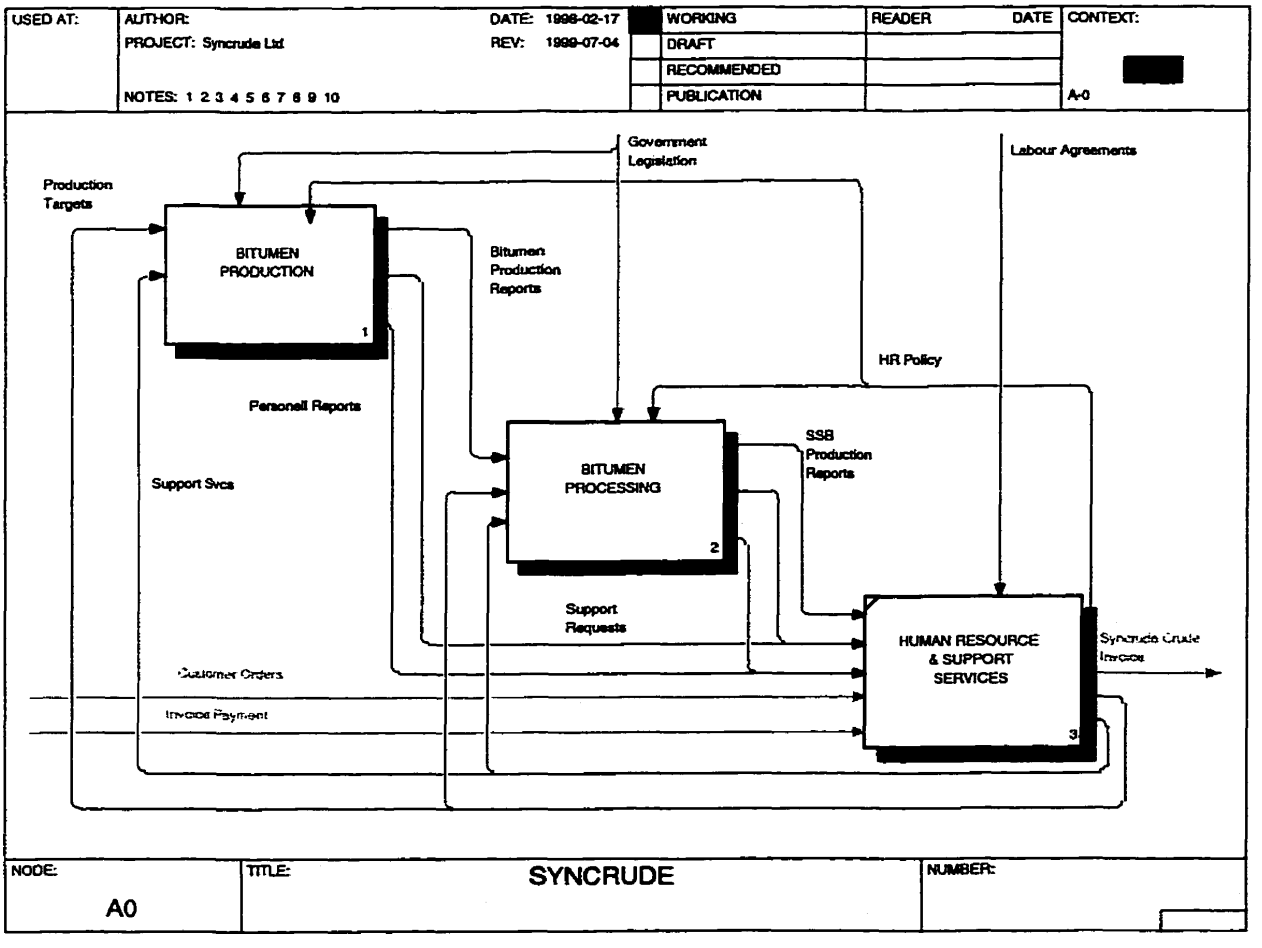


**Figure 5.3: Sample Level 0 Diagram**

The style of the diagram in Figure 5.3 should look familiar. The same SA conventions were used in Chapter 4, Figures 4.1 and 4.2, which were the context and level 0 diagrams, respectively, for the production planning process. Even without the detailed description of the SA model syntax, it is relatively simple to interpret the meaning of the diagrams. The structural decomposition is intuitive, and the node numbering scheme allows modellers to easily keep track of which level of the system is being modelled.

In Figure 5.3, the A0 diagram, also called the level 0 diagram, describes the three fundamental processes for the model. Note that the arrows in the diagram for node Syncrude/A-0 (Figure 5.2) are almost all reproduced in the diagram for node Syncrude/A0 (Figure 5.3). There are two exceptions in the context diagram for the Syncrude model. The output from node Syncrude/A-0, labelled *Gov't Reports,* is not an output from node Syncrude/A0. Similarly, although *Capital Equipment* is shown as a resource in the context diagram, it does not appear in the level 0 diagram. In general, all decomposition diagrams have the same external arrows as the parent diagram. Exceptions occurs when an arrow in the parent does not show up until much deeper in the model or for some reason, the analyst chooses not to decompose a particular arrow any further. When this occurs, it is indicated in the parent diagram by placing brackets (called a tunnel) around the arrow that does not appear at the next level of the diagram. Small lines at a 45° angle in the top left-hand corner of an activity box indicate that there are no further decompositions of that activity in the model. Arrow splitting (or decomposition) is also demonstrated in the level 0 diagram. The single arrow labelled *Government Legislation* is split to act as a control for both ***Bitumen***

*Production* and *Bitumen Processing*. If there were specific types of legislation applicable to each, new labels could be placed on the two new arrow segments.

Bitumen is the raw material (commonly referred to as tar sand) that Syncrude converts into crude oil. From the Figure 5.3 (Syncrude/A0) we see that the conversion is completed in two steps, *Bitumen Production* and *Bitumen Processing*. Note that the activity names, although still very general at this level in the model, use verbs as names describing the activities. To find more detail about how these activities are actually performed we must proceed to the next level of the diagram. Figure 5.4 (node Syncrude/A1) shows the decomposition for the activity called *Bitumen Production*.

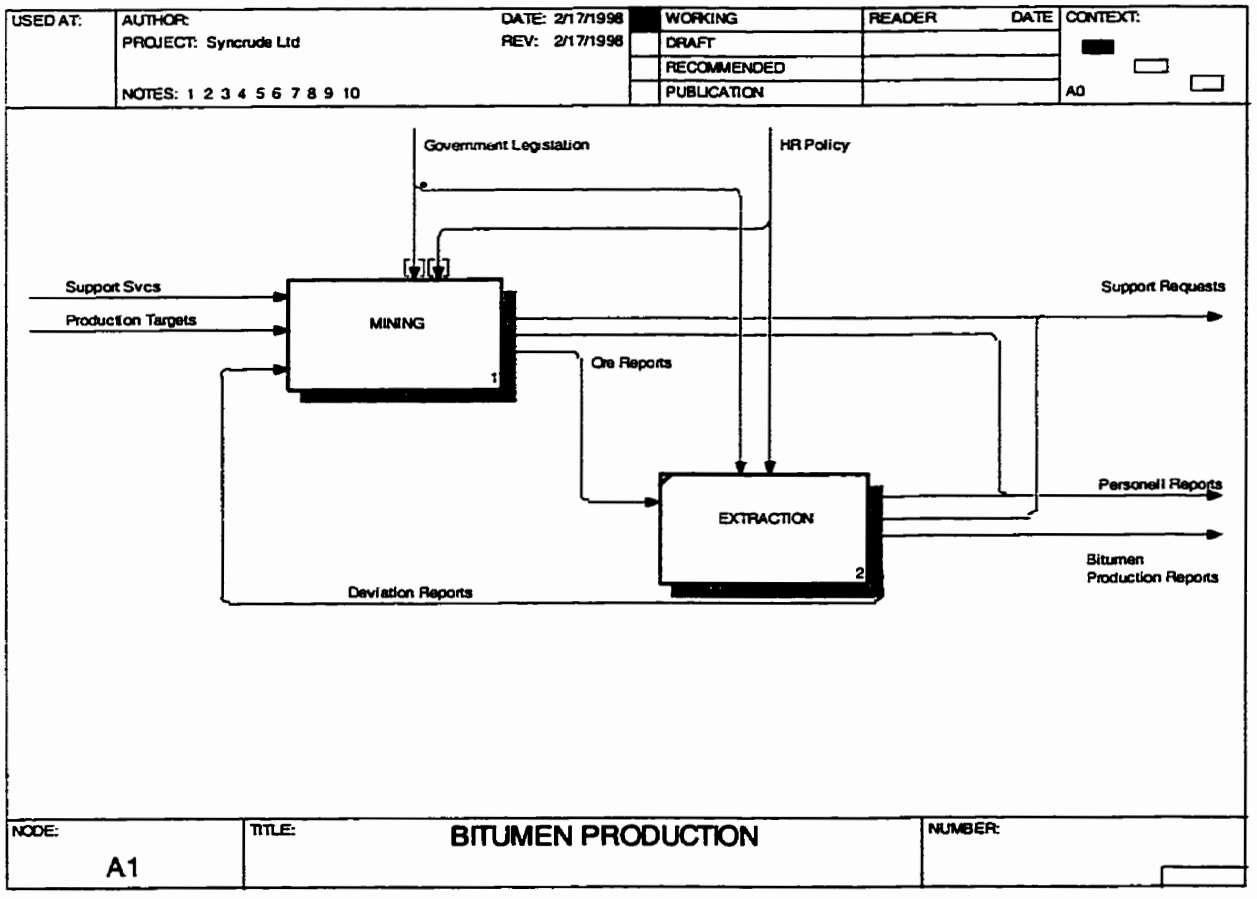


**Figure 5.4: Bitumen Production, Syncrude/A1**

From the diagram, we see that ***Bitumen Production*** is completed in two steps. The emphasis of this research is on the mining process that has been decomposed in Figure 5.5 (Mining, Syncrude/A11). At this level, the arrow labels are becoming more detailed and we can start to see some of the interfaces between mine operations and maintenance. Recall however, that the viewpoint for this model is from the General Manager's perspective. This viewpoint would be significantly different from that of the production planners responsible for coming up with plans to meet the production targets. In Chapter 7, several viewpoints from which to examine the interaction between operations and maintenance are examined.

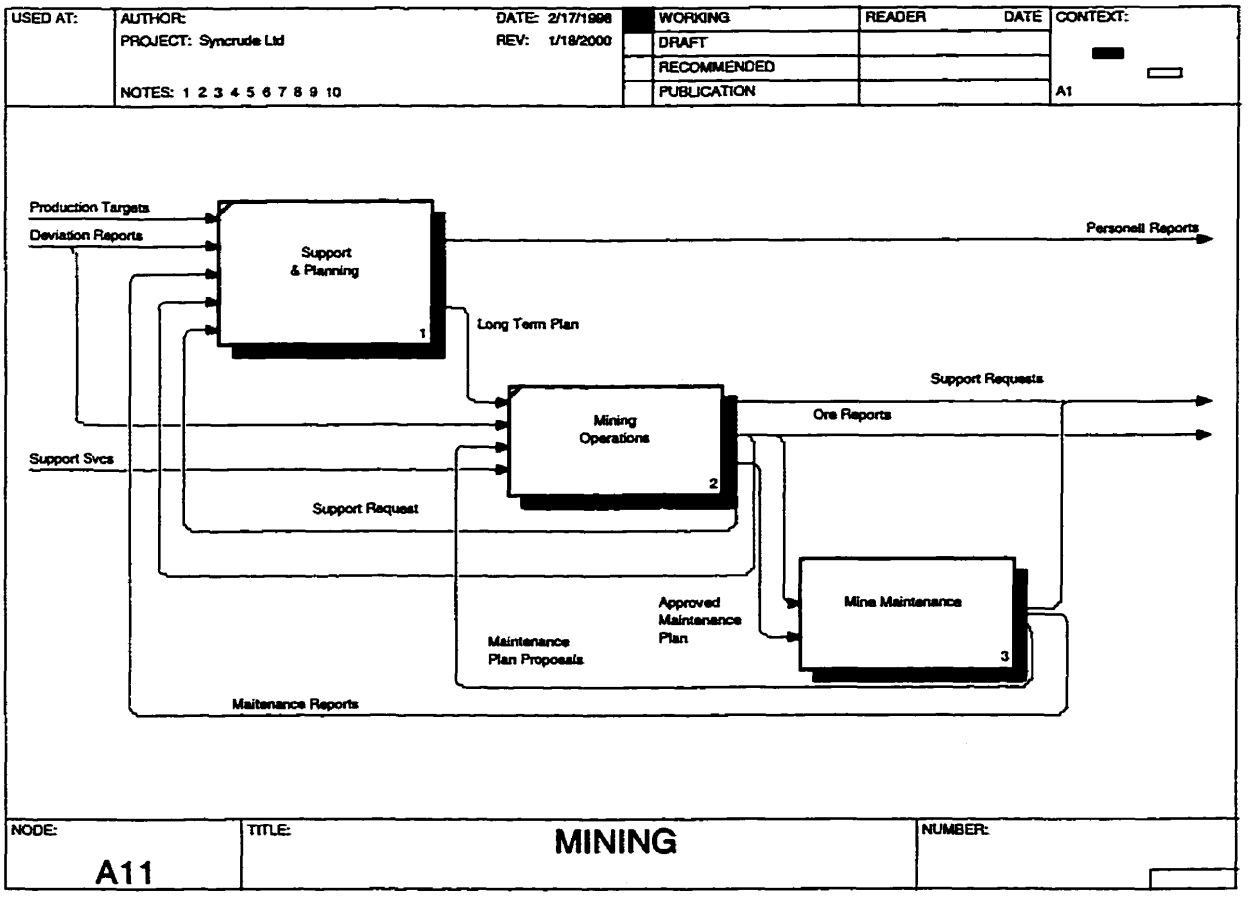


**Figure 5.5: Mining, Syncrude/A11**

The mining process at SCL is based on open pit methods employing both dragline/bucketwheel excavation and, more recently, shovel/truck operations. Current plans include phasing out the dragline systems in favour of purchasing additional shovels and trucks to increase flexibility. A major expansion called the Aurora project is planned to start production in the year 2001.

## *5.4. The Modelling Process*

The SA process guides the analyst through the steps of obtaining knowledge about a domain, documenting the acquired knowledge by making a model, and validating a model through iterative review. As the analysis progresses, it is important to keep the intended use of the model in mind. In some cases, the aim of the study may be to simply document and understand an existing system. More often than not, however, the SA is conducted to try and improve an existing system. The nature of the improvements sought will have a significant impact on each of these steps of the process that are briefly described below.

### *5.4.1. Knowledge Acquisition*

The primary method for gathering the necessary information about a system during the conduct of a SA is the interview. Interviewing techniques have received a lot of attention as a result of the emphasis that expert systems development places on the knowledge acquisition process. Domain experts are often the best source of information because they

are most familiar with the system nuances and undocumented aspects of the system under study. In addition to conducting interviews, analysts should gather information by:

(a) Reading documents.

(b) Observing existing operations.

(c) Surveying with a questionnaire.

(d) Using their own knowledge.

(e) Developing new descriptions when necessary.

Rather than simply taking notes based on these information sources, the key to effective model development is to begin the diagrams as soon as possible. The SA models can then be used to determine what information must be determined at the next interview. Thus, by following the hierarchy of a model, a series of interviews can be conducted that address increasingly specific details about the domain.

### *5.4.2. Documenting Acquired Knowledge*

Starting a SA model means creating A0 and A-0 diagrams appropriate for further review. These two diagrams completely describe a system under study at a very high level of detail. This is an iterative process that includes defining the purpose and viewpoint of the model. It may be necessary to create models from several different viewpoints to determine which viewpoint is the most appropriate to meet the intended use of the model.

Determining the most appropriate natural language to describe the activities and data flows in the A0 diagram is also an important step. The names of processes and labels for

arrows must strike an appropriate balance between being descriptive enough to provide meaning while being sufficiently general such that the number of processes does not exceed six and the number of arrows does not over clutter the diagrams. Generating lists of all of the activities performed by the system along with lists of all of the data used to perform these activities is helpful in determining appropriate categories that can be used to generalise activity names and bundle data flows. When actually drawing the A0 diagram, boxes should be placed according to their dominance (e.g., perceived importance or required sequence). The most dominant box is usually put in the upper left-hand corner and the least dominant box in the lower right-hand corner. This results in a layout in which the more dominant boxes constrain the less dominant boxes in the diagram, creating a "staircase" pattern. The arrows linking the boxes are then added starting with external data flows followed by internal arrows between the boxes in the A0 diagram. The final step in starting the model involves summarising the A0 diagram with an A-0 diagram, which contains major system inputs, outputs, and controls, as well as the stated purpose and viewpoint of the model. Repeating the above process for those activities that the analyst feels require further explanation based on the intended use of the model completes decompositions of the activities in the A0 diagram.

### *5.4.3. Model Validation*

Unless a model is validated, any results based on its intended use can be easily disputed. Validation can only come from those experts that were interviewed to create the models. To facilitate this, it is important to explain the modelling technique to all of those who will eventually be asked to "sign-off" on the model. This should be done as an integral

part of the interviewing process as the diagrams are used for a basis of discussion. Disagreements between experts are inevitable, but fortunately, the precise nature of the diagrams can be used to improve the quality of the discussion between them, hopefully leading to a consensus. One way to overcome roadblocks is to accept the opinion of the expert who most closely reflects the "agreed to" viewpoint of the model.

For large projects, a technical review committee can be established to act as the final authority on the approval of diagrams and models. Models that are deemed to have reached the required degree of detail to meet with its intended use are either presented or distributed to the members of the committee for their approval. If deemed useable by the committee, the model is published for use. Otherwise, comments are sent to the authors indicating areas that need additional work.

### *5.5. Automated Support*

The number of changes and iterative nature of the SA process make paper-based model development a very inefficient option. Development of the first automated SA tool called AUTOIDEF0 was funded by the U.S. Air Force in the late 1970s. Since that time, improvements in computer technology, specifically in the area of computer graphics, has resulted in several improvements to AUTOIDEF0. More recently, Computer Aided Software Engineering (CASE) tools have been commercialised to the point where a competitive market for tools that not only generate the diagrams but can also effectively aid in controlling their development now exist.

The tool selected for this project is called BPwin™, or business processes for Windows. Although created and distributed by LogicWorks, Inc., the rights to the software transferred to Platinum Technologies during the course of the project. The selection of this product was based on the recommendation of project officers in National Defence Headquarters who had adopted the tool for similar work. Since SCL was already using ERwin™, a complimentary product to BPwin™, this selection was readily accepted for use by SCL. The Windows-based software is easy to use and automatically provides for all of the model control procedures specified in the IDEF0 standard. It also has excellent report generation capabilities that aid in the preparation of reports.

### *5.6. Summary*

To start a model, a SA analyst prepares, gathers information, decomposes the subject, and summarises the decomposition. Purpose, viewpoint and intended use are determined during preparation models. Through the iterative nature of the process, these may well change as the analyst gathers information and begins to create diagrams. Decompositions are based on data lists and activity lists that must first be represented in the A0 diagram. The A-0 diagram is then created as a summary of the A0 diagram. Following strict model syntax conventions, decomposing the appropriate activities in the A0 diagram creates increasing levels of detail. Throughout this process, domain experts are consulted and in the case of large projects, technical review committees may be created to conduct reviews and finally validate the model making it ready for use.

Once validated, models can be used in a variety of ways, from acting as standard operating procedures for training, to becoming the basis for an analysis of the effectiveness of an existing system. It is this latter use that provides the motivation for using SA to document and analyse the mining processes presented in Chapters 6 and 7. Initial models created for "as-is" systems are created and validated. Alternative designs are examined through the use of "to-be" models that are created as a means of documenting changes for discussion. Once agreed to, the to-be models are used as a basis to determine how the transition from as-is to to-be can best be achieved.

# CHAPTER 6

# 6. A Structured Analysis of Heavy Truck Maintenance at SCL

## 6.1. Case Study Part I - Introduction

SCL was selected as the mine for the case study. This large-scale surface mine produces approximately 235,000 barrels of Syncrude Sweet Blend (crude oil) per day. Three factors at SCL that make SA an important activity at the time of the study were:

(a) As new competitors move into the oil sands business, there is a significant risk of loss of personnel and increased competition. This makes it critical to document existing practices in a structured, straightforward manner and improve profitability.

(b) For many years, the dragline/bucketwheel was the primary mining method, with shovel/truck acting in an auxiliary capacity. However, by 2006, all dragline production will be phased-out. As a result, the mine needs an effective way to measure and improve the performance of the shovel/truck operations.

(c) The Aurora Project needed an effective organisation analysis method to ensure smooth integration with the base mine. In addition to guiding the design of the new system, to-be SA models can be used for capacity planning, budgeting, and resource allocation.

It is worth pointing out that SCL is not new to *business process reengineering* concepts. Indeed, the recent adoption of team-based business units was a very progressive

step aimed at improving effectiveness. Although many at the mine believe this has been achieved, there is no organisational benchmark against which these improvements can be measured. SA of current practices can provide this benchmark for future developments. Indeed, strategy development and implementation are themselves processes that can be analysed and designed. The more efficiently any company can adapt its strategy to capitalise on new opportunities and counter new competitive threats, the greater its chance of sustaining a long-term competitive advantage.

The case study was conducted in two phases. In this chapter, the results of the first phase that used SA to analyse the effectiveness of the heavy truck maintenance business unit (HTMBU) are presented. The second phase of the study, presented in Chapter 7, applied this same approach to analyse the interaction between operations and shovel/truck maintenance.

### *6.2. Description of the HTMBU*

The HTMBU consists of 6 maintenance teams and a group of 6 team leaders that share responsibility for the maintenance of all heavy haul trucks at SCL. During the course of this study, SCL was planning a transition from 240-ton (all capacities quoted in short tons) capacity haul trucks to 320-ton (Komatsu 930E) and 360-ton (Caterpillar 797) capacity haul trucks. At the start of the study, SCL had a mixed haul fleet consisting of the following trucks:

(a) Eight leased Komatsu 930E (320-ton capacity)

(b) Twenty-one Caterpillar 793 (240-ton capacity)

(c) Five Titan trucks (170-ton capacity)

By the end of the study period, the truck fleet had changed considerably to include:

(a) Eight leased Komatsu 930E (320-ton capacity)

(b) Twenty-one Caterpillar 793 (240-ton capacity)

(c) Nine leased Caterpillar 793 (240-ton capacity)

(d) Three Titan trucks (170-ton capacity)

Plans for the near future will see the replacement of the entire 240-ton fleet with the Caterpillar 797, 360-ton haul truck and/or additional Komatsu 930E 320-ton haul trucks.

Two maintenance managers, who report directly to the mine general manager, manage the Mine Maintenance Division including the HTMBU. They are actively involved in periodic team and leadership meetings but generally allow the business unit (BU) to operate in an autonomous fashion.

### *6.3. Case Study Scope*

The as-is models were developed through observation, interviews with technicians, team leaders and support staff, and a review of relevant documentation. The context diagram is reproduced in Figure 6.1. The scope of the study is clearly represented by the diagram. In particular, it includes a detailed examination of how the maintenance teams convert the listed inputs into outputs subject to the constraints imposed by *Company Policy*.

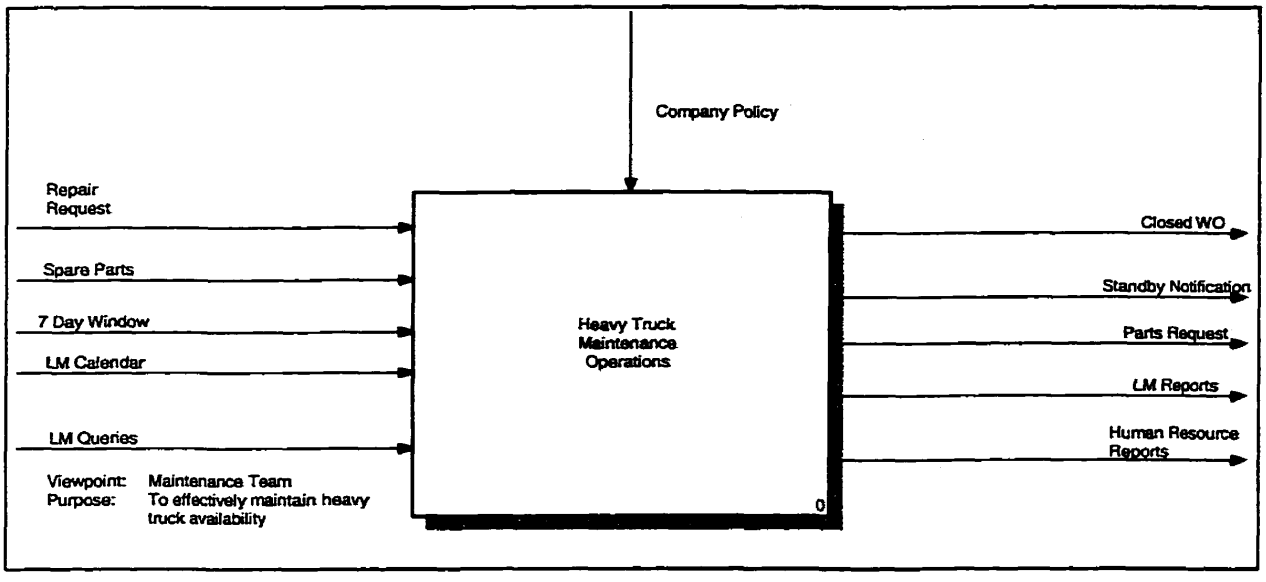


**Figure 6.1: Context Diagram (MT-1)**

The full set of data flow diagrams for this model, including definitions for each of the data flows, can be found in diagrams MT-1 to MT-14 in Appendix A. Each diagram is followed with a report that briefly defines each of the activities and data flows in the diagram. For Figure 6.1 (MT-1) the definitions are:

(a) **Activities:**

***Heavy Truck Maintenance Operations*** – all efforts undertaken by the maintenance teams of the HTBMU to effectively maintain heavy truck availability.

(b) **Inputs:**

***Repair Request*** - any request arriving at the HTMBU for failure maintenance.

***Spare Parts*** – represented by a packing slip that arrives from the warehouse or directly from vendors.

***7-day window*** - represents all scheduled work for one week scheduled by day.

***Loss management (LM) Calendar*** – specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

***LM Queries*** - represents any requests for information on loss management issues.

(c) **Outputs:**

***Closed work order (WO)*** - represents the WO form that is fully completed from the mechanics perspective.

***Standby Notification*** - when maintenance activity is completed, operations is notified by entering the standby code through the WENCO dispatch system.

***Parts Request*** - several types of parts requests exist and are either sent to the warehouse for inventory items or directly to vendors if necessary.

***LM Reports*** - represents all reports generated in accordance with (IAW) the LM program.

***Human Resource Reports*** - all reports submitted IAW human resource policy.

(d) **Constraints:**

***Company Policy*** - all company policies that the HTMBU is required to follow.

Note that the context diagram in Figure 6.1 does not show any resource data flows coming into the bottom of the diagram. The key resources include the maintenance personnel and their equipment along with the business unit's operating budget. It became clear during the analysis that changes to these resources levels were beyond the scope of this study so it was decided not to include resources in any of the models. It should be pointed out that this did not mean recommendations in these areas were not welcome, only that this level of change was beyond the decision making authority of the members of the HTMBU.

### *6.4. Selecting the appropriate viewpoint*

The team leaders' viewpoint was the initial one selected for analysis. This seemed appropriate since this group appeared most interested in the work and as a result were easily available for interviews. The set of diagrams created from this viewpoint, representing the as-is model, was presented to the team leaders and representatives from the maintenance teams for validation. During this presentation, it became quite clear that the team leader viewpoint was significantly different from that of the maintenance teams. This is not surprising, since both groups within the HTMBU have quite different roles and responsibilities.

In terms of the processes representing the primary work of the HTMBU, a maintenance team perspective was far more illustrative. It was decided therefore, to redo the

analysis from the maintenance team viewpoint. The majority of the recommendations made in this part of the case study are based on the model prepared from the maintenance team viewpoint. Before discussing this particular analysis however, it is interesting, to contrast these two viewpoints and compare what a team leader views as the primary functions of the BU versus the view from a technician's perspective. The complete as-is model from the team leader viewpoint is presented in Appendix B.

### *6.4.1. The Team Leader's Viewpoint*

The context diagram from the team leader's perspective has been reproduced as Figure 6.2 (TL-1). The difference in viewpoint is immediately apparent since the inputs and outputs differ from those associated with the model developed from the maintenance team's perspective (Figure 6.1). The team leaders view their inputs as *Task Force/Focus Group (TF/FG) Requests, Incoming reports, Requests for Information (RFI)* and *Failure Reports.* The inputs at this level of the model are very general in nature. They represent the broad categories of responsibility within which the team leaders function. The outputs at this level of the model are correspondingly general; in particular, the *Plans & Reports* data flow represents several different data flows that have been fit into this category. In order to determine the primary activities that transform these inputs into outputs, we must refer to the level–0 diagram.

Before describing the level–0 diagram, it is worth noting that resources were included as part of the team leader model. A major part of the team leader's job is resource allocation. Consequently, when viewing the BU from this perspective, it was necessary to account for

resources. In contrast, although the resources available to the maintenance teams may change over time, they are generally not responsible for their allocation. It is true that the teams have a certain degree of autonomy in scheduling jobs, but on any particular day, the resources available to them are fixed.

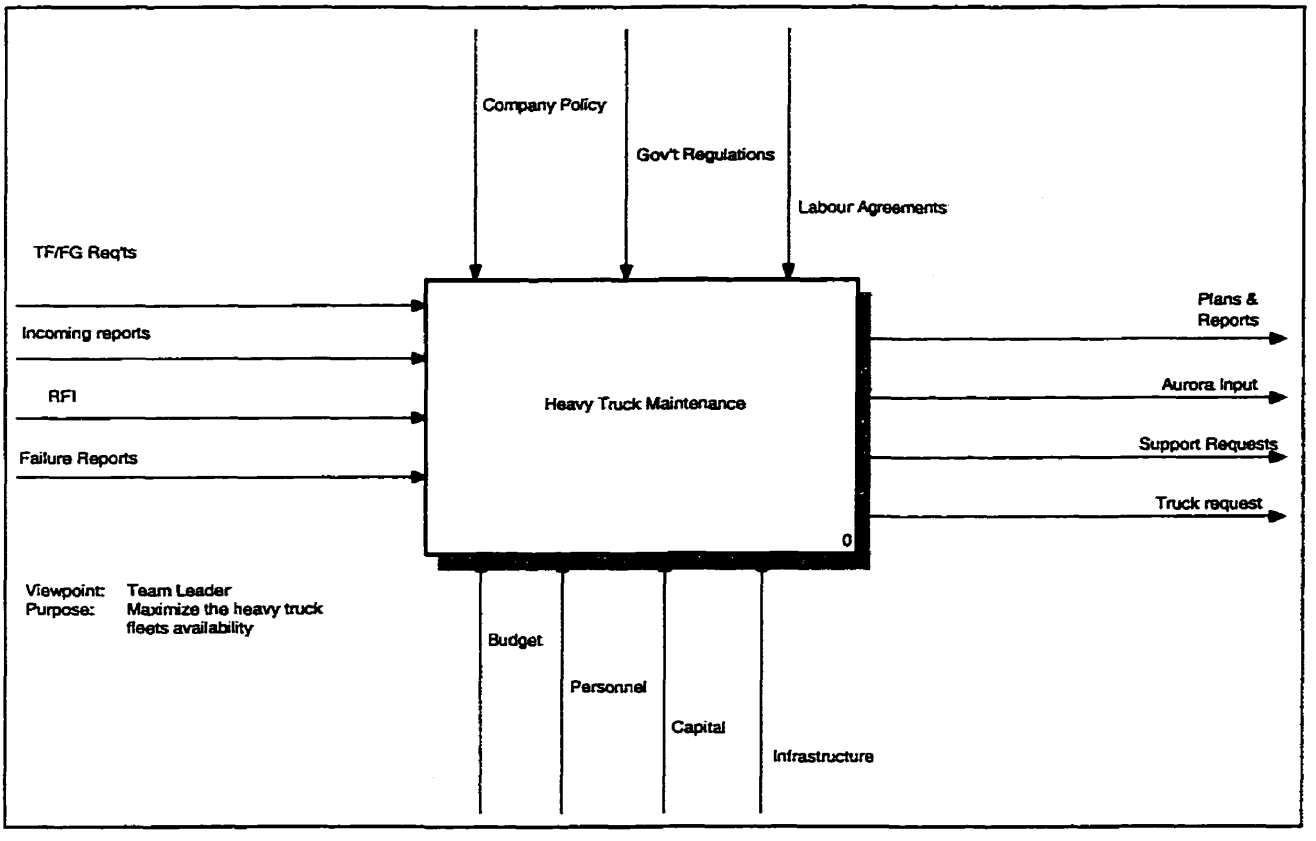


**Figure 6.2: Context Diagram – Team Leader's Perspective (TL-1)**

An analysis of the level–0 diagram (TL-2) revealed that the team leader's roles and responsibilities can be grouped into four primary activities as presented in Figure 6.3. *Loss management* (LM) is a very structured process that is implemented in a standardised way across all of SCL. It is a management control system that aims at creating a safe work environment where losses due to damage are minimised. Since a large part of the team leader's responsibility is to ensure this type of work environment exists, it should not be

surprising that much emphasis is placed on this activity. Readers interested in a more detailed understanding of the LM process are referred to diagrams TL-3 to TL-7 in Appendix B.

Like *LM*, both *business plans and finance* (diagrams TL-8 and TL-9) and *human resource management* (TL-11) represent management activities for which the team leaders are responsible. Although the initial modelling efforts placed some emphasis on these activities, it later became clear that the primary work of the BU as a whole was activity 3 – *maintenance operations* (TL-10). As mentioned above, during a validation presentation one of the senior mechanics pointed out that the maintenance teams had very little interest in the bulk of the activities presented but were rather concerned with fixing trucks! Indeed, he pointed out that all of the emphasis on LM was viewed by many of the mechanics as an annoyance that essentially kept the maintenance teams from performing their primary function. Based on this revelation, it was decided to restart the analysis from the viewpoint of the maintenance teams. This new focus ensured that the results would reflect the reality faced by the technicians as opposed to the perceived reality from the team leader or management perspective.

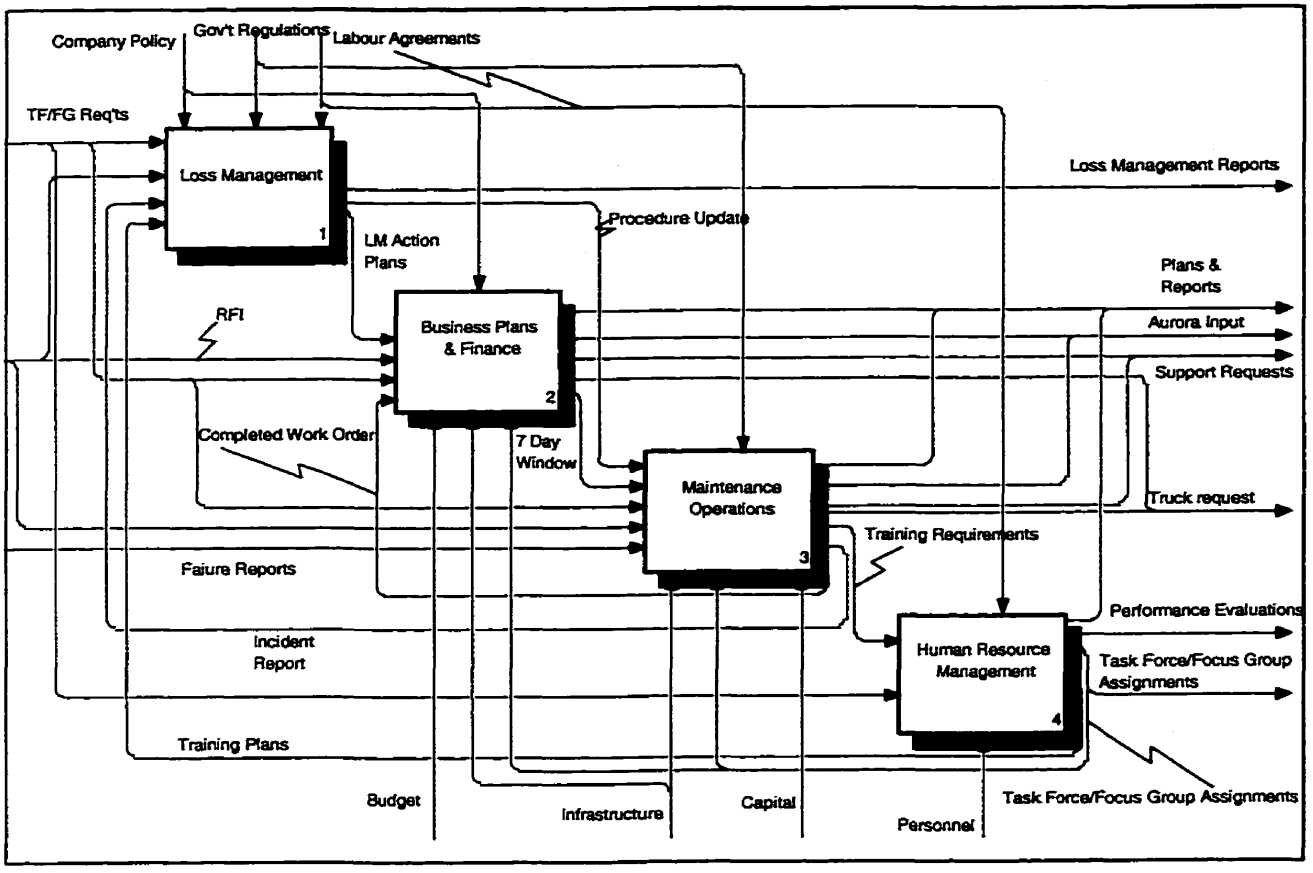


**Figure 6.3: Level-0 Diagram from Team Leader's Perspective (TL-2)**

### *6.4.2. The Maintenance Team Viewpoint*

The diagrams associated with the maintenance team model are presented in diagrams MT-1 through MT-14 (Appendix A). The context diagram (MT-1, reproduced above as Figure 6.1) shows that from the maintenance team viewpoint, there are five broad categories of inputs that are converted into five categories of outputs. The same inputs and outputs are present in the level-0 diagram (MT-2) that has been reproduced as Figure 6.4.

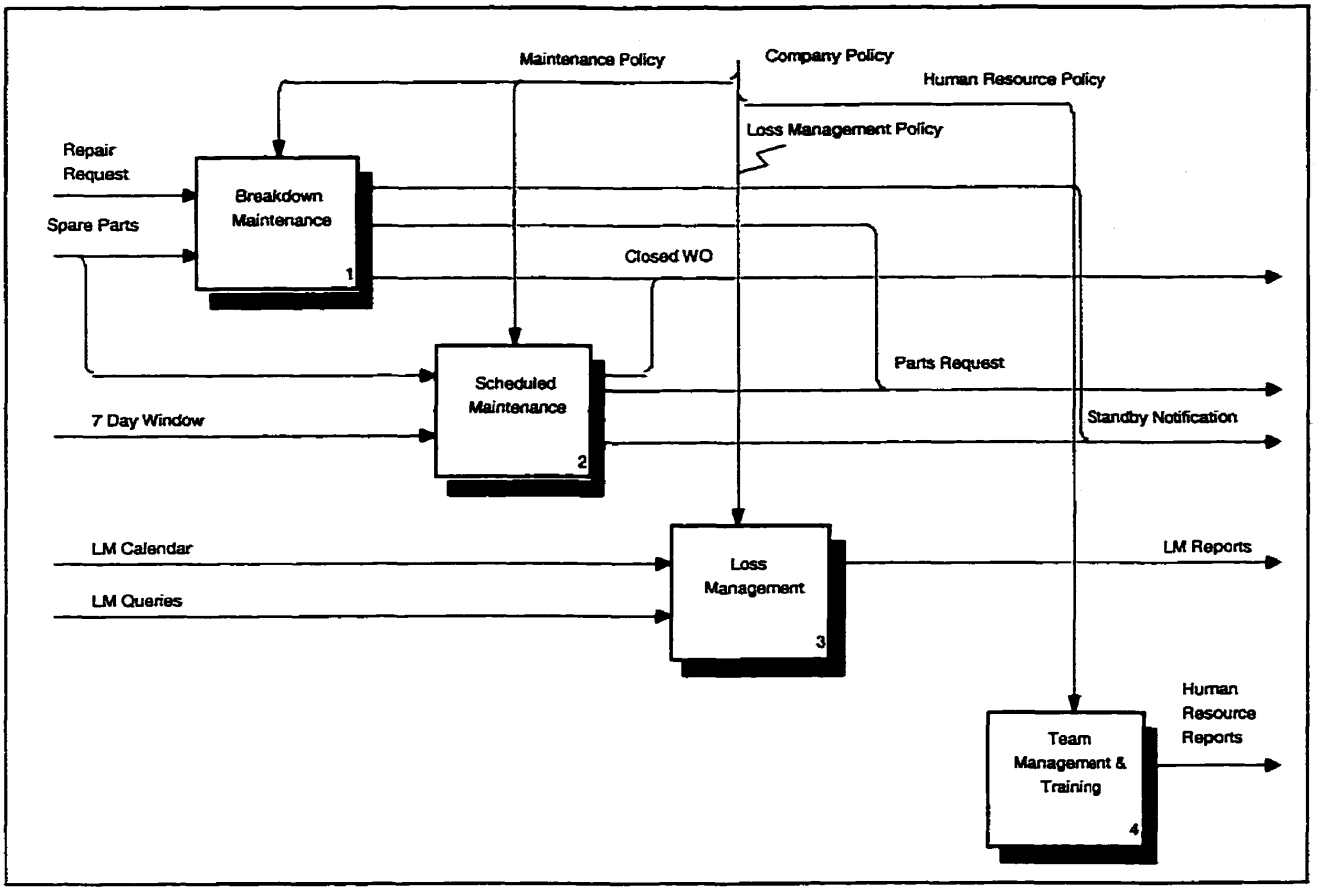


**Figure 6.4: Level-0 Diagram from Maintenance Team Viewpoint**

From Figure 6.4 we can see how this viewpoint is better aligned with the primary work of the BU. For example, *breakdown maintenance* and *scheduled maintenance* are the first two activities in the model representing the primary function of the HTMBU. *LM* is relegated to activity 3 (versus activity 1 from the team leader viewpoint) and the last activity is *team management & training*. As explained above, resources are not included in this model since they are generally fixed with respect to the day-to-day operations of the maintenance teams. Similarly, although the policy constraints are included in the context and level-0 diagrams, from the maintenance team perspective, these too are fixed representing the basic rules that must be adhered to while performing their duties. Consequently, the

emphasis in the analysis was placed on the inputs, activities and outputs that comprise the work of the maintenance teams.

Note also, that from this perspective the inputs and outputs in the level-0 diagram are much more specific than those associated with the team leader viewpoint. The inputs, outputs and constraints are the same as those listed for the context diagram (Figure 6.1). However, the general constraint from Figure 6.1 – *company policy* has been expanded to include *maintenance, human resource and LM policy.*

### *6.5 Analysis and Results*

The analysis focused on those areas over which the HTMBU had the greatest degree of influence. In particular, *breakdown maintenance* (activity 1 from Figure 6.4 as further described in diagrams MT-3 to MT-5) and *scheduled maintenance* (activity 2 from Figure 6.4 and further described in diagram MT-7) were analysed in depth. *LM* (activity 4 in Figure 6.4 and further described in diagrams MT- 8 to MT-13) and *team management and training* (activity 4 from Figure 6.4 and further described in diagram MT-14) were analysed to a lesser degree.

The analysis of the as-is models revealed four significant opportunities for improvement. The opportunities, along with the resulting changes, are described below, as is an assessment of the resulting improvement. Before describing the improvement opportunities however, it is worth noting that the overall assessment of the HTMBU suggests that it is an excellent, innovative organisation with an effective mix of highly talented and

dedicated individuals. Throughout the analysis, it was quite clear that the people in this business unit take pride in their work and are committed to continuous improvement. The frank and open dialogue achieved at all levels of the organisation is testament to an excellent work environment.

### *6.5.1. Opportunity 1 – Breakdown Maintenance Data Collection*

While conducting interviews with field mechanics, it became apparent that no detailed data was being collected for breakdown maintenance. The model presented in diagram MT-4 represents the way the process is supposed to work. Upon breakdown, the operator of the truck inputs failure code 50 (breakdown) into the WENCO system. WENCO is the truck dispatch system used at SCL. In addition to truck operation optimisation, it provides a user interface and communications link to all mobile equipment (WENCO, 1999). This failure code is represented in the diagram as a *repair request*. However, rather than updating the status upon the arrival of the technician, as indicated in diagram MT-4 with an *arrival notification*, the breakdown status is not changed until the vehicle is ready to be returned to service. This is achieved by entering code 99 into the WENCO system that is represented in the diagram as a *standby notification*. As a result, no data is currently being collected for field mechanic response time, time required to diagnose breakdowns, and time spent in active repair or administrative delays. The various categories of downtime that were not being accounted for are presented in Figure 6.5.

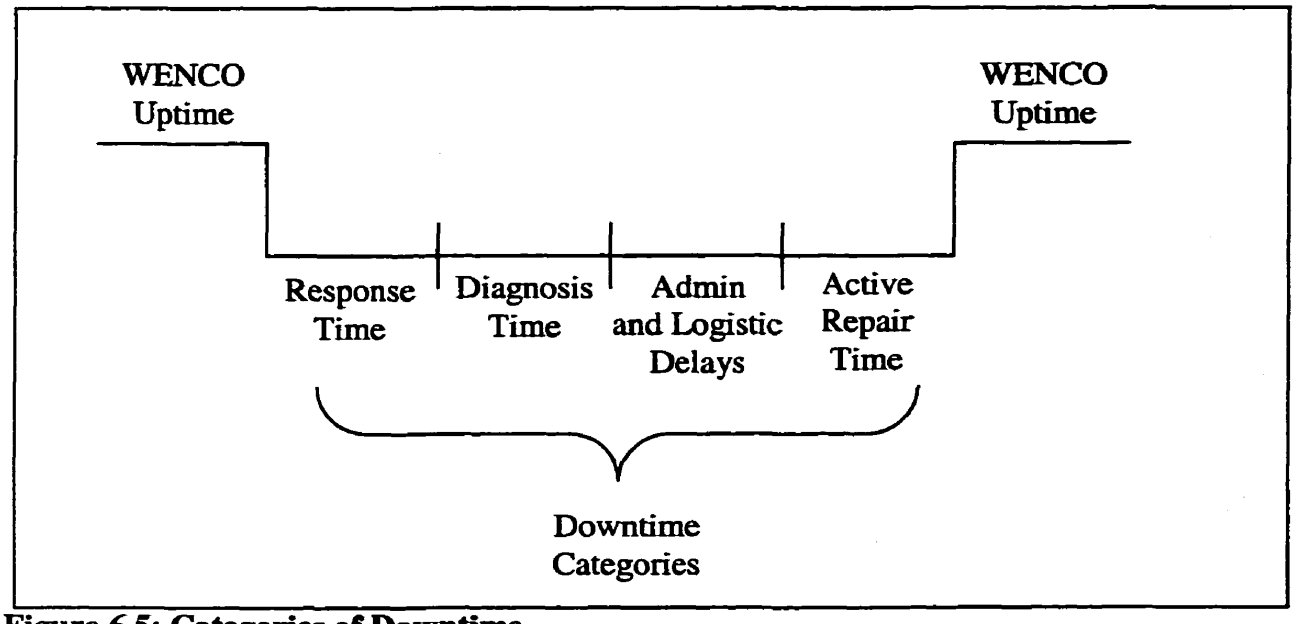


**Figure 6.5: Categories of Downtime**

Although WENCO codes exist for these activities (with the exception of administrative delays), they were not being utilised. Reasons for this appear to be twofold. First, the field technicians did not perceive any value in having to climb into the cab of the truck to enter the codes, as they derive no direct benefit from doing so. To the contrary, they viewed this as a waste of time. This is understandable since, from the technician's perspective, his primary role is to return the truck to service as soon as possible. Similarly, the truck operator and the truck dispatcher's only concern, once a breakdown has occurred, is how long it will take to return the truck to service. This lack of data collection was considered a serious problem since breakdown maintenance is perhaps the most critical aspect of the HTMBU's responsibility. Without this data, it is difficult to measure, track and improve the performance of breakdown maintenance.

In addition to any detailed data associated with breakdown maintenance, there was an apparent lack of easy-to-access information on fleet and unit performance. In particular, the HTMBU relied on monthly reports from operations in order to track fleet availability and received no information on fleet utilisation. This information shortfall was compounded by the fact that the HTBMU had no way to track the availability of individual trucks. As a result, it was very difficult to perform trend analysis on fleets of trucks or to try to determine, for example, which trucks in a particular fleet were causing the most maintenance problems. Again, this was viewed as a serious information shortfall. For example, suppose a particular truck was experiencing the same breakdown periodically over a period of time. The only way this trend would be picked up would be if the same technician happened to be on shift when the recurring breakdown occurred. It is more likely, given Syncrude's shift system that different technicians will make the repair on successive breakdowns and the trend would go unnoticed. As a result, the root cause of the recurring breakdown might never be investigated.

In order to explore to-be alternatives to remedy this situation a focus group including team leaders and technicians was convened. Several alternatives were discussed, including the possibility of providing the field technicians with hand-held data devices; however, the implemented improvement turned out to be very simple. The unit breakdown code is now input to the WENCO system by the dispatcher rather than the truck operator. When the mechanic arrives, he radios the truck operator to input a new sub-code for "response time" allowing for an accurate measure of the time required to get the mechanic to the site of the breakdown. This data is now being accurately collected to establish benchmarks and to help measure maintenance effectiveness. In addition, a new capability called "maintenance

monitor" has recently been developed as part of the WENCO system. Once a truck is reported to have failed, this new system keeps track of specifically what occurs during the downtime. This has increased the data entry requirements placed on the mechanics, but through education and by providing appropriate feedback, they have come to value the contribution made by this system. As a result, the HTMBU is now collecting and analysing accurate information with respect to the way that they conduct breakdown maintenance.

The other problems described above with respect to lack of information on fleet and truck availability were beyond the scope of the initial phase of the case study as it crossed the boundary of the HTMBU into operations. The problem was resolved through interaction with operations and will be discussed further in Chapter 7.

### *6.5.2. Opportunity 2 – Breakdown Maintenance Cost Data Collection*

Compounding the data collection problem was the fact that a large proportion of breakdown maintenance work was being charged to a standing work order. On average, approximately 25% of the monthly truck maintenance budget was being charged to standing work orders for field maintenance. As a result, approximately one quarter of the total truck maintenance budget could not be tracked beyond business unit level. This represented most of the costs associated with breakdown maintenance.

The analysis of breakdown maintenance clearly revealed the reasons for this situation. From diagram MT-5, *field repair set-up*, we see the first activity is to *determine WO status*.

The options available to the technician are to charge the repair to the *standing WO*, or create a *new work order requirement*. In the latter case, the technician (or his partner) is required to drive to the shop and generate a work order on IMMPOWER, the maintenance management information system (MMIS). From the field mechanic's perspective, the key is to get the repair done quickly, hence, whenever possible, the tendency is to use the standing work order that avoids the requirement to access the MMIS. However, the net result of this practice is that it renders cost analysis for breakdown maintenance virtually impossible. In summary, the required data was not being collected and there was no way to accurately track the costs associated with breakdown maintenance beyond business unit level.

Again, several alternatives for improvement were discussed with the team leaders and technicians. It was decided that the requirement would best be met through an overhaul of the cost centres and activity codes currently in use. In particular, additional codes were created to enable cost data collection for:

(a) Unscheduled component replacements

(b) Welding

(c) Running maintenance for jobs lasting less than 2 hours

All other work requires individual work orders charged against the specific truck. In effect, the convenience of the standing work order still exists with the running maintenance activity code. However, the 2-hour limit ensures that these tasks are minor in nature. The specific code for welding was created because it was noticed that most breakdown maintenance tasks were also resulting in welding tasks. This separate code will allow this activity to be monitored more closely.

Since the change was implemented, approximately 12% of the monthly truck maintenance budget has been charged to the new activity code for running maintenance. This represents a 50% improvement in terms of the ability to more accurately track costs associated with breakdown maintenance. The 12% figure is still considered to be high, so this situation will continued to be monitored by the HTMBU.

### *6.5.3. Opportunity 3 - Streamlining Loss Management Reporting*

There was a perception from the technician's viewpoint, that too much time was wasted on "loss management". That is not to say that they disagree with the management philosophy to take measures to ensure a safe productive workplace. However, the technicians were clearly frustrated with having to enter reports on the computer system. All of the *LM reports* represented in diagrams MT-8 through MT-13 take time to either prepare or enter into the computer system. From the technician's perspective, the data entry requirement is time away from maintaining trucks with little or no value added. Indeed, interviews confirmed that from the technician's perspective LM had become synonymous with submitting reports and that their perception of the activity was generally limited to the data entry requirement.

This perception was in stark contrast to the view of LM held from the team leader's perspective as discussed earlier. Clearly, the technician's focus is on maintaining trucks. As a result, the management system, that team leaders perceived to be a primary activity, has considerably less significance to the technicians. A discussion of these differences in perspective facilitated an understanding of the underlying issue. Technicians accepted the

importance of the LM activities, but felt the time required to enter the reports on the activities was excessive. Therefore, a survey was prepared in order to estimate the amounts of time technicians were spending on data entry for LM. The LM portion of the SA was used as a basis for determining exactly which activities were considered to be LM.

There was already a project underway at SCL to convert all of the data entry requirements to a single web-based interface. This simplified system was previewed and assessed to be a significant improvement to the existing system. However, the new, single interface would not alleviate technicians from the data entry requirement. The preferred option to improve this situation was based on centralising the data entry requirement with the maintenance clerk. Technicians would still be required to complete the report forms as they conducted the procedures, but would then submit these forms to the clerk for entry into the system.

The survey indicated that technicians were spending 16% of their time on LM activities. It was also concluded that 25% of this total was expended on the data entry requirement. Assigning this activity to the shop clerk has resulted in approximately 4% more time available for the technicians to perform their primary function. Petersen (1999) suggests that active repair time or *tool time*, defined as time spent actually doing, thinking, and mentoring a job at hand, is perhaps the most direct measure of a maintenance trade person's productivity. This 4% represents an increase in manpower available for active repair of approximately two person-years annually.

There is a risk that the reporting efficiency will decrease as a result of having someone other than the technician who completed the procedure input the report. However, a motivated clerk is likely to make fewer data entry errors than a frustrated technician. If the clerk is unclear or if the values entered in the report do not appear to be consistent, it will be brought to the attention of the originating technician. This new approach is expected to improve the quality of the loss management reporting system and increase the time technicians have available for active repair. Furthermore, having worked through this process, the technicians have gained a better appreciation of the purpose and importance of the loss management system.

### *6.5.4. Opportunity 4 - Alignment of Pay and Rewards with Team Performance*

With the re-organisation to team-based business units, SCL made a significant departure from the hierarchical system that had been in place up until that time. Hierarchical systems generally reward individual performance as a natural way to identify and reward good performance. The pay for knowledge and skills (PKS) program that is in place at SCL was well suited to the old management system. However, this system is considered to be somewhat incongruent with the team-based approach. Technicians spend significant portions of their time getting their PKS levels completed regardless of whether they are required for the work they perform. To illustrate, consider one of the primary advantages of the team-based approach – technician specialisation. In the HTMBU, for example, the maintenance teams have crews designated to complete specific routine maintenance jobs. As a result, they become adept at the procedures for which they are responsible, improving overall team

performance. However, the PKS system does not reward teams, rather, individuals based on an exhaustive list of qualifications required to increase individual knowledge and skills.

The responsibility for the PKS program is beyond the authority level of the HTMBU. However, alternative incentive programs that reward teams, as opposed to individual performance, are being considered. An appropriate balance must be struck between what the individual needs to do to progress within his/her trade and how his/her performance contributes to that of his team, and, of course, the overall BU's performance. Aligning the PKS system with the team-based approach should result in an improvement in overall team performance. Specific measures should be examined as part of a broader study that is beyond the scope of this research. However, the issue has been raised at organisational focus group meetings and forwarded to higher levels of management within SCL for further consideration.

### *6.6. Summary of Improvements*

The application of the SA methodology resulted in the following improvements to the HTMBU:

(a) Breakdown maintenance data is now being accurately collected allowing for detailed analysis of this important activity.

(b) A significant information shortfall with respect to fleet availability and utilisation, along with individual truck availability, has been identified. (Resolution of this shortfall will be discussed in Chapter 7).

(c) The HTMBU has improved its ability to collect cost data with respect to breakdown maintenance by 50%. Efforts to further improve this are on going.

(d) New activity codes have been created to track important maintenance activities (welding in particular).

(e) The LM reporting system has been streamlined to increase the proportion of time technicians have available for active repair by 4%.

(f) The misalignment of the PKS program with the team-based approach has been highlighted for further study.

Although not considered one of the improvement opportunities, as listed above, the simple fact that the team leaders and technicians have gained an improved appreciation of each other's perspective is considered to be a valuable contribution. This was most true with respect to LM but extends to include the other activities conducted by these two groups.

### *6.7. Conclusions*

From the SCL perspective, the aim of this part of the project was to prove the effectiveness of applying structured analysis in a mining context. The improvements outlined above clearly demonstrate that this was achieved. It is also worth highlighting the importance of taking the correct viewpoint from which to conduct the analysis. Although not wasted, the time spent creating the models from the team leader perspective was essentially a false start. The key in determining the appropriate viewpoint lies in where the actual work under study is being conducted. In this case, it was the maintenance teams who actually

performed the primary work of the BU. The team leaders act in a supervisory capacity with much emphasis placed on meeting external demands. Since the emphasis in this part of the study was on internal activities, the maintenance team's perspective was the most appropriate.

Despite the success of this portion of the study, the greatest value of this type of analysis is derived when it is conducted across organisational boundaries. The limitations imposed by the scope of this study were clearly evident when, for example, the requirement to pursue better data on truck availability and utilisation went beyond the scope of the study since this would require interaction with operations. The success of this phase of the case study resulted in a decision to broaden the scope of the analysis to examine the relationship between operations and maintenance. The results of this study are presented in Chapter 7.

# CHAPTER 7

# 7. A Structured Analysis of Operations and Maintenance at SCL

## 7.1. Introduction

The aim of this phase of the study was to expand the analysis beyond the HTMBU to take a broader look at mine management with emphasis on the interaction between operations and maintenance. SCL is currently phasing out their dragline/bucketwheel operations and focusing on truck/shovel operations for the new Aurora project. Consequently, it was decided to limit the scope of this phase to truck/shovel operations and maintenance.

Shovel/truck production at SCL is concentrated in operations in their North Mine. This is a classic open pit operation that relies heavily on the WENCO dispatch system to assign haul trucks to shovels and collect performance data on the equipment. Due to the nature of the ore, blasting is seldom required except due to freezing during the winter months. At the start of this study, the North Mine had the following shovels in operation:

(a) 1 RH200 hydraulic – 25 $m^3$ capacity bucket

(b) 2 RH400 hydraulic – 46 $m^3$ capacity bucket

(c) 3 BE395B electric – 48 $m^3$ capacity bucket

(d) access to two rental shovels (RH 200) – 25 $m^3$ capacity bucket

Based on the Aurora expansion and a desire to achieve economies of scale, SCL is planning to purchase two P&H 4100TS (47.4 $m^3$ capacity bucket) shovels during the summer

of 1999. Based on the performance of these shovels and other studies, a decision will be made on what type of shovels to use for the Aurora expansion project.

### *7.1.1. Selecting an Appropriate Viewpoint*

Based on the experience gained from Phase 1 of this study, considerable effort was expended in deciding upon the most appropriate viewpoint for the study. The key was to determine which viewpoint had the greatest overall impact on truck/shovel operations. In order to make this important choice, each of the following viewpoints were considered:

(a) Shovel Operator

(b) Truck Operator

(c) Operations Team Leader

(d) Shovel Maintenance Team Leader

(e) Truck Maintenance Team Leader

(f) Truck/Shovel Production Planner

Through observation and interviews with representatives from each of these groups, and one false start, it became clear that the production planner had the greatest degree of influence over the entire process. The false start was based on a model developed for mine operations from the operations team leader perspective. Since the teams working for these leaders were responsible for actually performing the work, this seemed an appropriate viewpoint. The model developed from this viewpoint is presented in Appendix C, diagrams MO-1 (mine operations–1) through MO-7. As the model was being developed it became clear that the operations team leaders had very little contact with either shovel or truck

maintenance. Indeed, the production planner for truck/shovel operations represented the only viewpoint that had a knowledge and ability to impact all of the functions listed above. Therefore, the IDEF0 modelling effort was re-focused on the truck/shovel production planning process from the viewpoint of the truck/shovel production planner.

### *7.2. Scope*

The context diagram for the "as-is" model for this phase of the study has been reproduced below as Figure 7.1. The complete model is presented in Appendix D, diagrams PP1-1 (production planning 1-1) through PP1-4. Interestingly, the as-is modelling effort did not get very far before the need for changes became readily apparent. The purpose of the *Truck/Shovel Production Planning Process* is to balance the truck and shovel schedules to meet production targets in a cost-effective manner. In this study, the planning process was limited to the annual planning cycle.

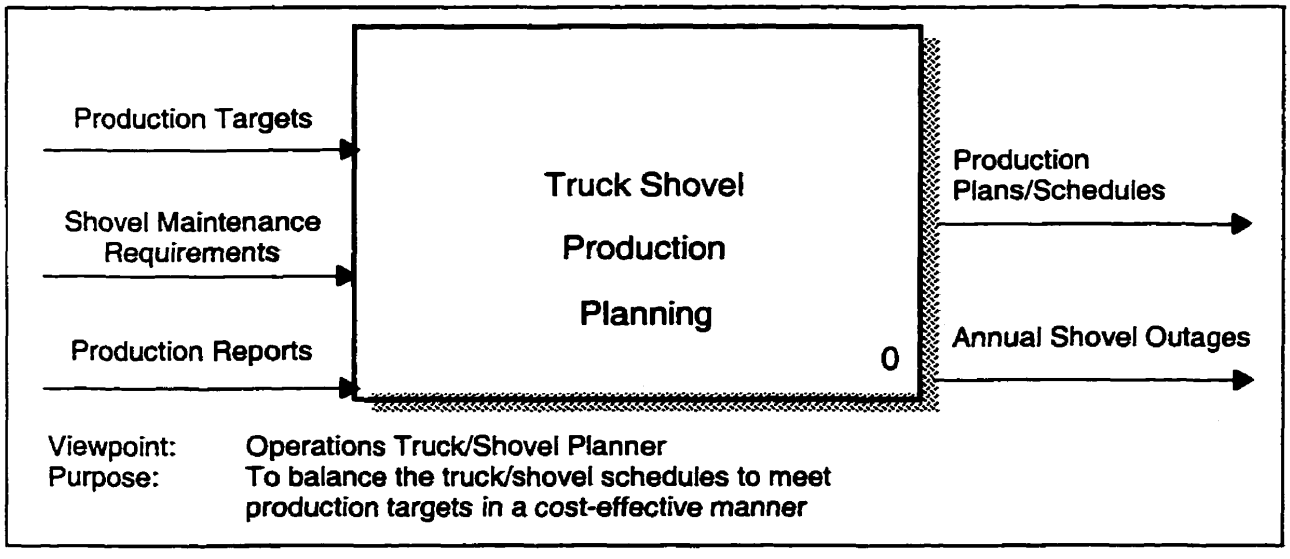


**Figure 7.1: Context Diagram – Truck/Shovel Production Planning (as-is model)**

Note also that the resources and constraints applicable to the planning process were not included in any of the production planning models created for this part of the study. In essence, resource allocation is at the heart of the production planning process. However, within the annual time frame selected for this study the number of shovels and trucks remains relatively constant. Indeed, from the production planner's viewpoint the number of trucks and shovels available is considered more as an input to the process rather than a resource. Similarly, the policy constraints are also fixed and it is beyond the scope of this study to change them. Hence, in order to avoid clutter they were omitted from the diagrams.

### *7.3. Description of the "as-is" Truck/Shovel Production Planning Process*

From the context diagram in Figure 7.1 we see that the production planning process converts *Production Targets*, *Shovel Maintenance Requirements* and *Production Reports* into *Production Plans/Schedules* and *Annual Shovel Outages*. The four primary activities required to make this possible are presented in the level-0 diagram (Figure 7.2). The cyclical and iterative nature of this process is clear from the feedback arrows in the diagram. The activities in the diagram are described as follows:

(a) *Create Annual Production Plan* – Production targets for the coming year are set in the November/December time frame. These approximate targets are broken down into 10-week blocks that take into account the shovel maintenance outages for the coming year.

(b) *10 Week Rolling Planning* – This process creates an outline schedule that shows how the annual production targets will be met based on a series of 10-week targets

(c) *2 Week Rolling Planning* – Detailed shovel assignments are made on a 2-week rolling basis. The resulting schedule is created to meet the production requirements as specified in the more general 10-week schedule.

(d) *Daily Planning* – The daily shovel/truck plan takes into account recent production achievements and unforeseen maintenance requirements to create the detailed production schedule for the next 24 hours.

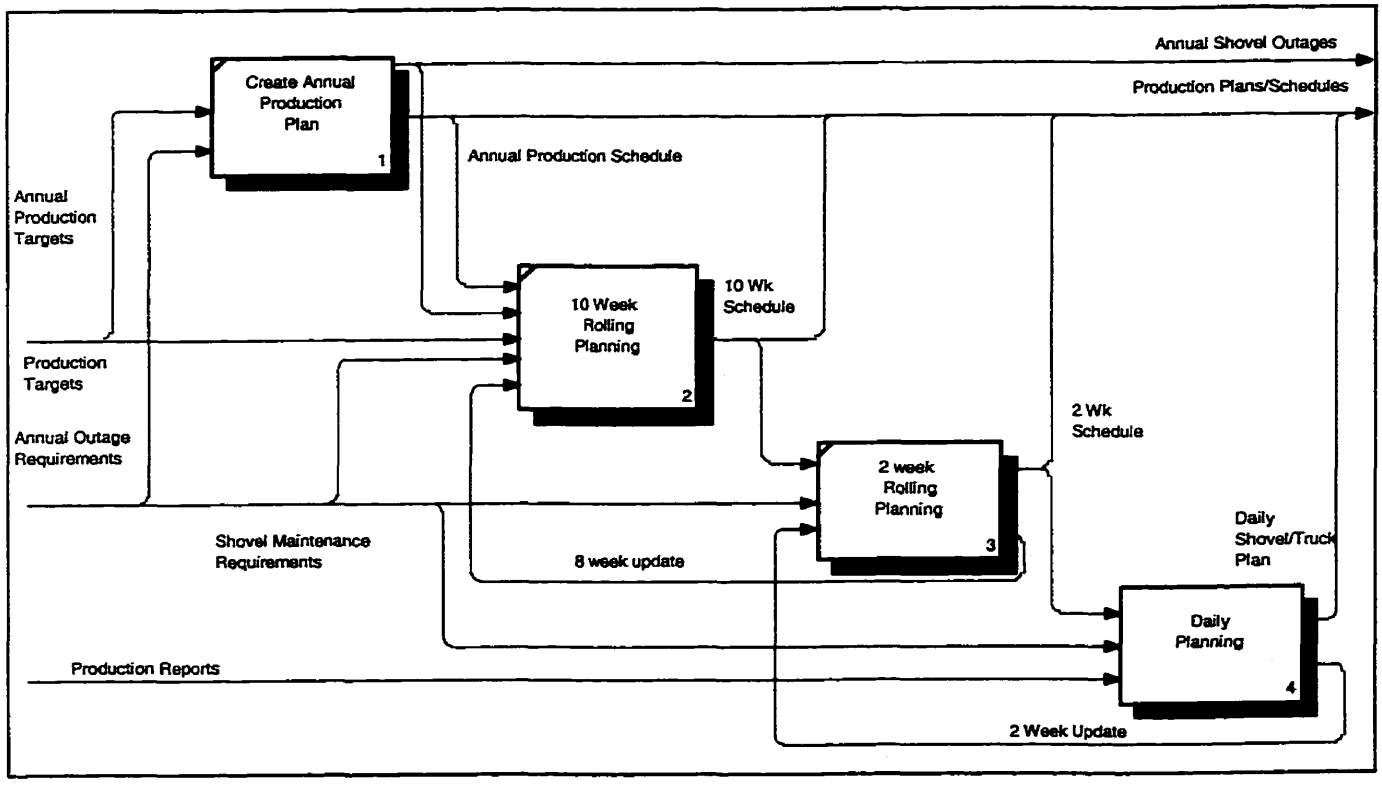


**Figure 7.2: Level-0 Diagram for the as-is Model**

Initial modelling efforts focused on the daily and 2-week rolling planning processes. However, the documentation of the "as-is" system did not get very far before appropriate changes became obvious making the SA a dynamic modelling effort whereby the differences between the "as-is" and "to-be" models became somewhat blurred. Some changes were implemented immediately while others took a period of weeks or months and some continue to evolve. The model presented in Appendix D (diagrams PP1-1 to PP1-4) represent a snapshot of the "as-is" system. These four diagrams illustrate the extent of analysis that was required before changes became obvious.

### *7.4. Analysis and Results*

The recommended changes to the "as-is" (it would be more accurate to describe this as the "as-was") models are reflected in diagrams PP2-1 to PP2-7 presented in Appendix E. Most of the detailed changes occur at the lower levels of the model. The only change to the context diagram from the as-is model was that the input called *Shovel Maintenance Requirements* from Figure 7.1 became *Maintenance Requirements* in the to-be model. This general term includes *Truck Maintenance Requirements* that now form an integral part of the production planning process.

The results of the analysis are based on improvements that have been identified in the following areas:

(a) Improved information flow for decision making

(b) Improved short term production planning process

(c) Improved long term production planning process

(d) Cost Control Strategy

### *7.4.1. Improved Information Flow for Decision Making*

In Chapter 6, section 6.4.1, an information shortfall with respect to truck utilisation and availability was identified. The HTMBU was relying on monthly reports from production for truck fleet availability and had no access to truck fleet utilisation or individual truck availability. When this issue was raised with the production planner who creates the monthly reports, it became clear that this information was readily available.

The WENCO Production Monitoring Control System (PMCS) provides a report generation function that uses the data collected in the pit status master file. This real-time database keeps track of virtually everything that happens with respect to shovel/truck operations. Furthermore, the PMCS interface is easy to use and allows for virtually any type of ad-hoc query. From the maintenance perspective, WENCO was seen as an operations system and therefore had little interest in investigating its capabilities. Consequently, despite the fact that the PMCS system had been available for approximately three years, the HTMBU did not take advantage of its capabilities.

It took approximately 30 minutes to provide PMCS access to one of the workstations in the HTMBU. One of the team leaders became proficient at accessing the program and creating reports in approximately one hour. This effectively eliminated the information shortfall as identified in Chapter 6, section 6.4.1, and as a result has significantly improved

the information available to the HTMBU. A few examples of how this "new" information is being used are worth highlighting.

SCL's fleet of Titan trucks is used to haul rejects from the extraction plant. These trucks are ageing and SCL plans to phase them out of operation over the next couple of years. One of the trucks experienced a major engine failure in November 1998 and the repair cost to replace the engine was estimated in the range of $250,000. Rather than blindly conducting the repair in hopes of maximising availability, the truck maintenance team leader accessed the PMCS to determine if this fifth Titan truck was actually required. Based on the utilisation rates and haul distances required for rejects, the HTMBU leader was able to demonstrate that 4 Titan trucks would be more than adequate to meet the requirement for hauling rejects. When this was presented to operations, they easily accepted the argument since the analysis was based on the WENCO database. As a result, the $250,000 repair was avoided and the failed truck could be used as a source of spare parts for the remaining Titan trucks. This resulted in further savings as both the transmission and tires from the retired truck were used on the vehicles remaining in the fleet.

Other decision-making improvements based on truck maintenance applications of the PMCS have resulted from the ability to track the performance of individual trucks. For example, a considerable amount of effort was expended to improve the availability of a particular Caterpillar 793 truck. The maintenance team that had conducted the work wanted to know if their efforts had been effective. Using PMCS, the maintenance team leader created a report that showed truck availability before and after the repair effort. The

improvement was significant giving positive reinforcement to the team. The fact that this feedback was obtained through the operations dispatch system made the accomplishment more meaningful to the technicians who take pride in providing their services.

A further improvement is based on an initiative to apply statistical process control procedures to the availability performance of individual trucks. Specifically, the PMCS system is being used to create mean and range charts (X bar and R charts) that are plotted for the availability of each vehicle in a fleet for specific intervals. Based on availability benchmarks and the establishment of upper and lower control limits (thresholds), this analysis will show which trucks are trending towards decreased availability. A sample mean chart is presented in Figure 7.3. The chart shows the mean availability for each of the Caterpillar 793 haul trucks over a 6-month period. For this particular chart, the upper and lower control limits were calculated to be 97% and 74% respectively. Since all twenty-one haul trucks are within this range, the process of maintaining truck availability for the 793 fleet is said to be under control. The chart also shows that unit 17-61, although performing above the lower control limit, had the lowest availability (77.7%) for the study period while unit 17-69 had the highest (90.7%). A detailed analysis of the operations and maintenance practices for these two vehicles may well provide insight for improving the overall process. For a detailed description of statistical process control, including the many ways to implement continuous improvement based on its use, see Swift (1995).

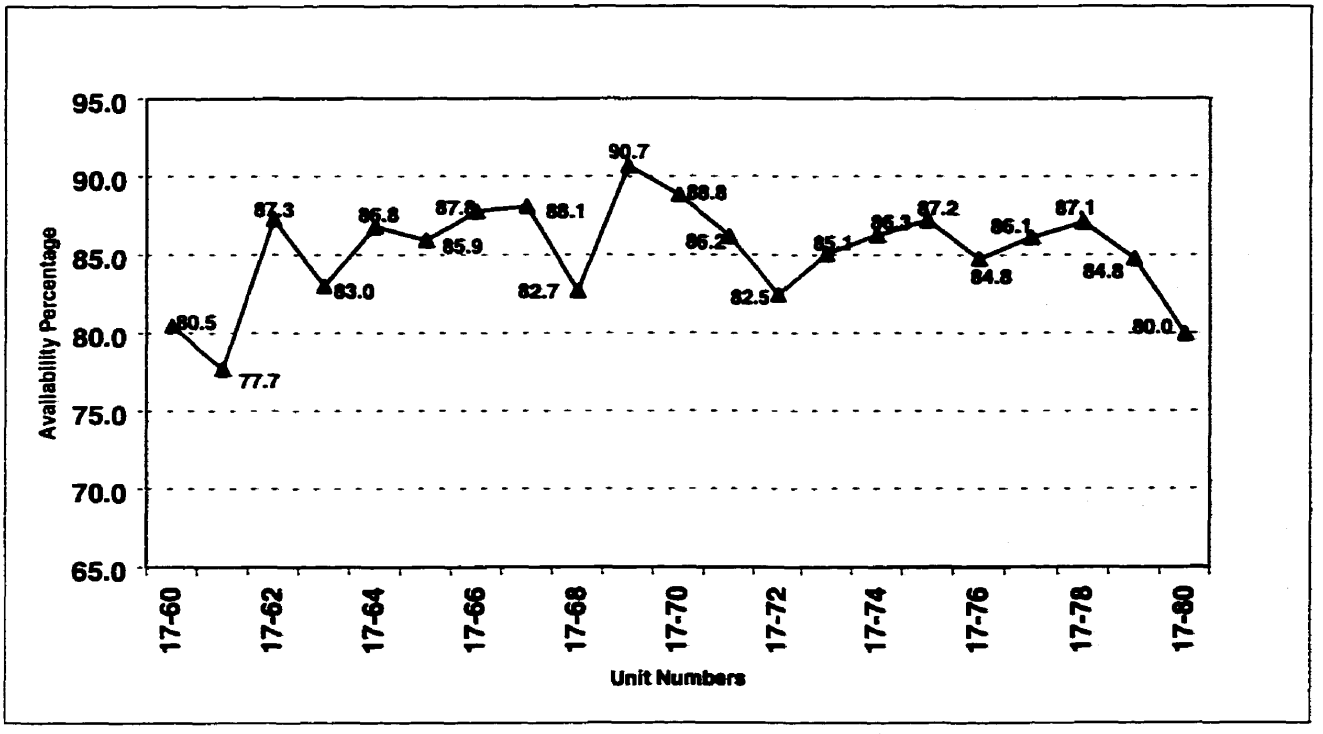


**Figure 7.3: Sample Mean Chart for Truck Availability (793 Fleet, 1/10/98 – 31/3/99)**

In addition to lack of access to the PMCS, the analysis also revealed that truck maintenance was not receiving the *Daily Shovel/Truck Plan*. This detailed plan provides a considerable amount of information on how the next 24 hours worth of production will be achieved along with an outline plan for the coming two weeks. This indicates the demand for trucks as well as planned shovel outages that can be used to better schedule truck maintenance. Truck maintenance is now included as part of the distribution for this plan. More importantly, however, this information shortfall highlighted the fact that truck maintenance was not integrated into the short-term production planning process.

### *7.4.2. Improved Short-term Production Planning Process*

For the purpose of this study, short-term planning includes the period for the coming 10 weeks. SCL uses this period since it corresponds to the order lead-time promised to customers by sales personnel. Failure to meet delivery dates, as agreed to by the sales department, can result in financial penalties. Consequently, every effort is made to meet the confirmed production targets as set out in the 10-week rolling schedule.

Although very important in terms of confirming production targets, the 10-week rolling schedule is only specific in terms of shovel production assignments for the coming 2-week period. Indeed, the bulk of the detailed planning and coordination is achieved through daily and weekly meetings. The as-is daily planning process diagram has been reproduced in Figure 7.4. This process consisted of three meetings that occurred daily at the times indicated in the figure. The *2 week rolling schedule* data store in the diagram includes production targets, pit assignments and planned shovel outages over the next 2-week period. This information exists in a few places, but is centralised on an electronic white board in the planning conference room. All three daily planning meetings take place in this room to allow for easy access to this information. The production planner chairs the *0815 Production Coordination Meeting*. The details of the activities conducted at this meeting are specified further in diagram PP1-4 that has been reproduced as Figure 7.5. The meeting is basically a round table discussion that is used to finalise the shovel/truck plan.

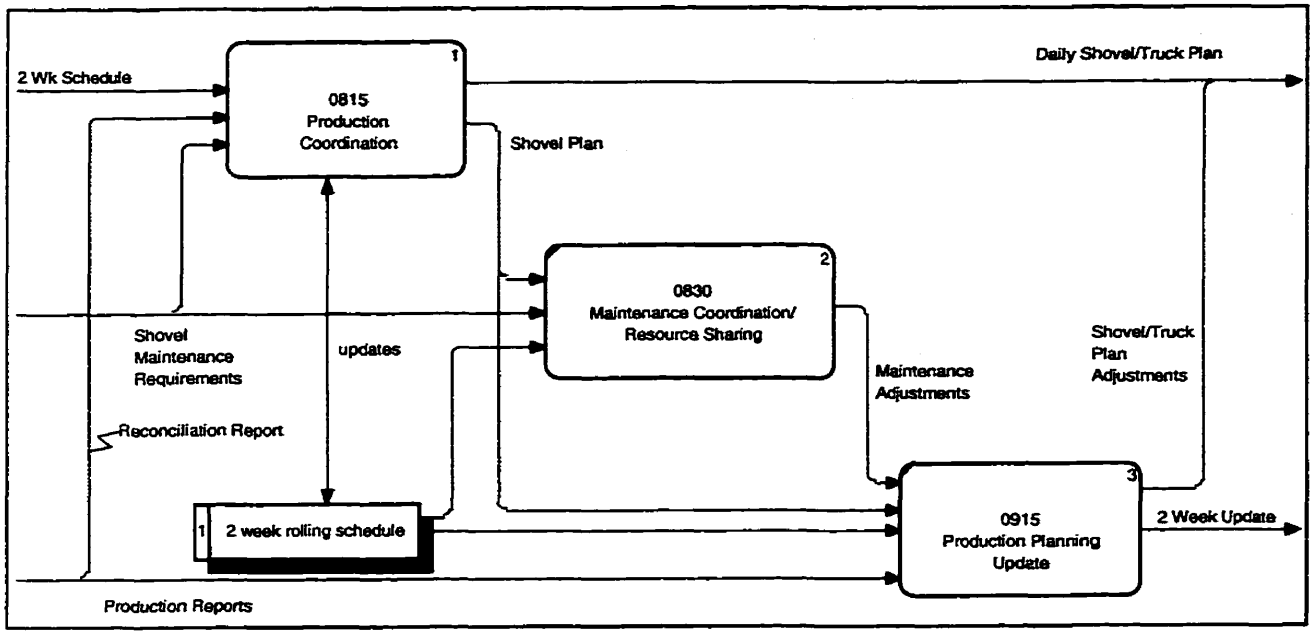


**Figure 7.4: Daily Planning (as-is)**

What became immediately apparent from the analysis of this process was a lack of input from truck maintenance. The coordination that took place was based solely on production performance (*Reconciliation Report*) and the maintenance status of the 6 production shovels (*Shovel Status* and *Shovel Maintenance Requirements*). This is clearly evident in Figure 7.5. Although the primary output from this process is the *Daily Shovel/Truck Plan*, there are no inputs with regards to trucks. A representative from the shovel maintenance business unit presents the *Shovel Maintenance Requirements* at the meetings. In contrast, the HTMBU did not have any representation at the *0815 Production Coordination* daily meetings as part of the as-is system.

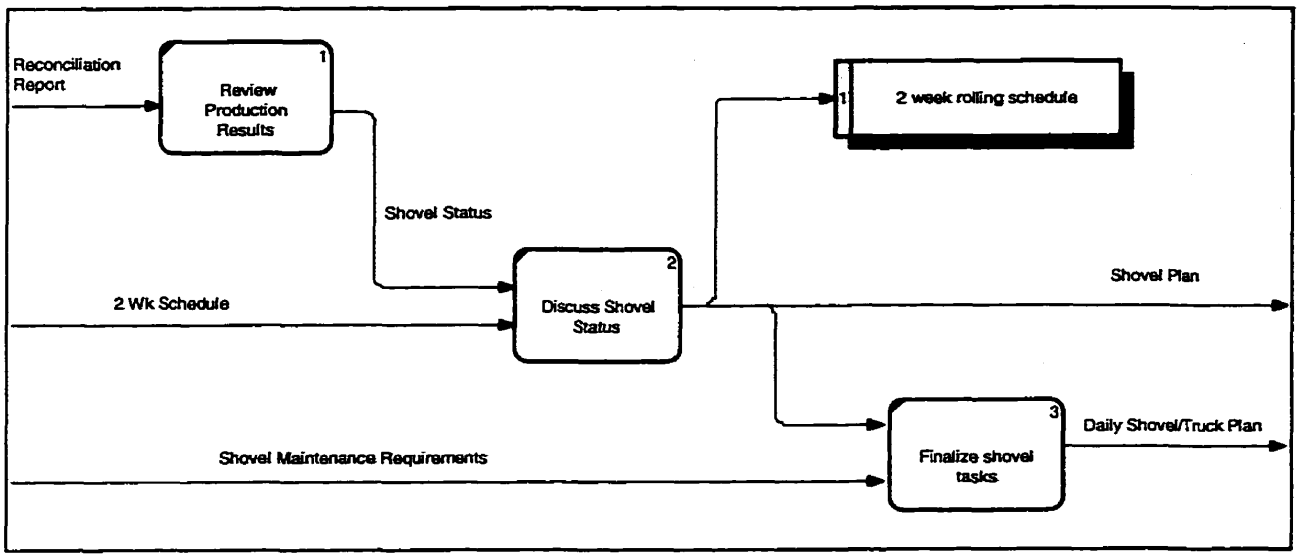


**Figure 7.5: 0815 Production Coordination (as-is)**

The reasons for lack of participation seem to be largely historical. The shovel maintenance group is part of the same BU that is responsible for dragline maintenance. Since draglines have always been represented at this meeting it was natural for shovel maintenance to be represented also. Truck maintenance, on the other hand, was formed into an independent BU that had no historical reason to participate. From the production planner's viewpoint, his task was to simply assign an appropriate number of trucks to each shovel. This initial assignment is part of the *Daily Shovel/Truck Plan* (which, as described above, the HTMBU did not receive). The decision with respect to which trucks are actually assigned is left to the dispatcher who is free to make adjustments based on the current operating environment and any requests that are received from truck maintenance. An interview with one dispatcher revealed that his personal procedure was to grant all truck maintenance requests. In his opinion, "without trucks there is no production, so if maintenance needs a truck to perform a service, they get it." Although this statement was contrary to policy whereby operations is the authority on when trucks are released for

service, truck maintenance personnel confirmed that they are almost never turned down when they request a truck for maintenance. This raised several issues and generated considerable discussion on the relationship between production planning and truck maintenance.

With respect to servicing, the standard procedure was for maintenance to call for a truck at midnight so that it could be steam cleaned and ready for servicing by the day shift starting at 0700 hrs. This meant that the day shift was able to start work immediately generally ensuring that the servicing was completed during one calendar day. It does not take 7 hours to steam clean a haul truck. Indeed, trucks usually sat idle until 0400 hrs waiting to be cleaned resulting in excessive downtime. This was easily fixed by changing the time at which maintenance requested the truck for servicing to 0200 hrs with an understanding that it had to be delivered before 0400 hrs. Since there is at least one truck steam cleaned for servicing each night, this 3-hour increase in the time the truck is available for haulage represents an annual increase of 1095 truck-hours.

The second obvious problem was that the daily production coordination meeting did not include any discussion of truck maintenance requirements. As shown in Figure 7.5, daily planning was limited to considering shovel performance and maintenance. The only time trucks would come up in this discussion was if production targets for a particular shovel had not been met due to a lack of trucks. Similarly, although the shovel maintenance representative played a major role in the coordination effort, there was no representative from truck maintenance even attending the meeting. Furthermore, despite the fact that shovel

outages were part of the *2 week rolling schedule*, the production planner had no access to the maintenance schedule for trucks.

This situation was immediately improved by simply having a truck maintenance representative attend the production planning meetings. Other quick fixes included making the weekly truck maintenance schedule (*7 day window*) available in the production planning conference room. Although helpful, this schedule provided too much detail for the production planner. To remedy this, a new status board for trucks was created and placed in the conference room. This board is updated daily by the truck maintenance representative attending *the 0815 Production Coordination Meeting* and includes the following information listed by truck fleet:

(a) Unit code of trucks that are down.

(b) Reason for the downtime.

(c) Anticipated time the truck will be returned to service.

The changes in daily production coordination are summarised in the to-be model for the same process as presented in Figure 7.6. The revised process fully integrates truck maintenance status into the daily and weekly planning process. Furthermore, the *Daily Shovel/Truck Plan* has been modified to include the truck status information. The to-be model presented in Figure 7.6 is already out of date since improving the process for truck maintenance raised the issue of lack of coordination for critical support equipment. For example, the maintenance status of medium duty bulldozers can have a significant impact on production. If too many bulldozers are down for maintenance, production shovels are

required to waste valuable time keeping their operating surfaces maintained. Medium duty equipment was beyond the scope of this study, but the mine has gone ahead and added a medium duty status board similar to that now in place for trucks. The production planner has also requested that a team leader from medium duty maintenance attend the *0815 Production Coordination Meeting*.

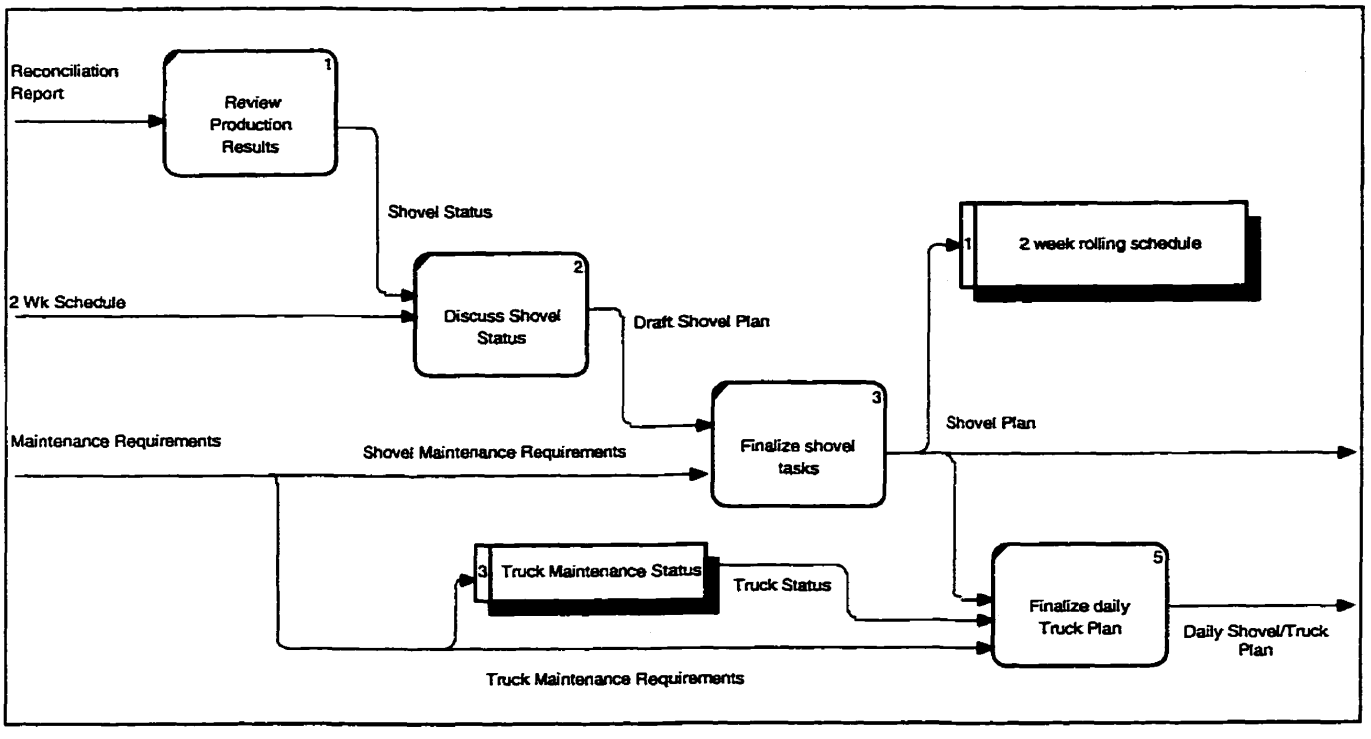


**Figure 7.6: 0815 Production Coordination (to-be)**

In addition to daily representation at the *0815 Production Coordination Meeting*, a member of the HTMBU has been appointed as the liaison between the HTMBU and operations. This individual attends the *0915 Production Planning Update Meeting* (activity 3 in Figure 7.4) along with the operations team leaders. This allows for a direct interface between the leaders responsible for the operation of the trucks with a leader responsible for their maintenance. As a result, a new level of dialogue between the two groups has been

stimulated. Issues such as the impact of operator practices on truck maintenance and the production impact of excessive downtime are discussed daily by leaders in a position to influence day-to-day activities.

This process will continue to evolve. However, the benefits are already significant:

(a) Short-term production planning now includes consideration for truck (and medium duty) maintenance.

(b) Truck maintenance is able to adjust scheduled maintenance to account for production requirements.

(c) Opportune maintenance decisions for trucks can now be planned in advance based on production requirements.

(d) The opportunity for meaningful dialogue between operations and truck maintenance now occurs on a daily basis

The importance of the last bullet can be highlighted with an example. A Cat 793 truck came to maintenance for service and the technicians noticed a significant amount of damage. However, no Loss Control Report (LCR) appeared to have been submitted. Under these circumstances, an operations supervisor is supposed to come and assess the damage and determine which shift is responsible and submit an LCR. On this occasion however, despite several attempts, the supervisor did not come to assess the damage and the technicians became impatient and frustrated. There was concern that the repair cost for this damage would have to be charged to the maintenance cost centre. The HTMBU team leader

responsible for liaison with operations was able to easily difuse the situation the next day at the production planning meeting where the issue was easily resolved.

### *7.4.3. Improved Long-term Production Planning Process*

A key factor in determining the annual production plan is planned shovel outages. Currently, shovel maintenance submits proposed outage requirements to production planning for approval. The annual Production Budget Planning Document reflects the approved schedule. The informal arrangement between shovel maintenance and production is that if the outage requests are approved then the required shovel availability is guaranteed for the year. This process has evolved over several years and appears to be working satisfactorily. Surprisingly, however, there is no similar arrangement for trucks.

The HTMBU planner is responsible for scheduling all services and planned component change-outs for the trucks. He follows a specific process to prepare work orders in advance. The short-term planned maintenance schedule is published as the *7 day window*, but outline plans are prepared for up to 1 year in advance. Unofficially, the rule of thumb is that up to 4 of 38 trucks (excluding the titan fleet that is dedicated to rejects) can be down for maintenance at any given time. This allows for 1 truck down for servicing, 1 down for a component change-out, 1 down for a special project, and 1 down for failure. The planner schedules the truck maintenance work using these guidelines but does not take the planned shovel maintenance schedule into account.

The shovel maintenance function is performed as part of the dragline/bucketwheel and shovel maintenance business unit. When SCL reorganised into business units these functions were grouped because personnel working on the maintenance of draglines and bucketwheels would transition to shovel maintenance when the draglines were phased out. Although sensible from a personnel management perspective, this arrangement created an artificial barrier between two maintenance groups that should have a close working relationship. The resulting lack of communication between shovel and truck maintenance represents an area for significant improvement. Furthermore, given that increased truck size will decrease production flexibility, an integrated approach to shovel and truck maintenance will become increasingly critical in order to avoid lost production due to unscheduled downtime.

As mentioned above, planned shovel outages are negotiated as part of the annual production planning process. In November of each year, the shovel maintenance group submits a proposal to the production planners requesting specific dates for shovel outages for the coming year. These *Annual Shovel Outages* are published in the annual production plan. Just as truck maintenance does not take these outages into account for planning purposes, the shovel outage negotiations do not include any consideration of truck maintenance requirements. Part of the reason for this situation is the fact that SCL has access to on-call rental shovels (2 @ $1000/hr) that can be quickly put into service if the mine is over trucked. Despite the high cost of this practice, it has not resulted in any attempts to coordinate planned maintenance for shovels and trucks.

Several alternatives to achieve the integration between shovel and truck maintenance for long-term planning were examined. The simplest solution involved changing the truck planning cycle from the *7 day window* to a 2-week rolling plan similar to that used for shovels. In essence, a 14-day window that was matched to the 2-week shovel outage plan would allow for easier coordination between the two schedules. For example, if it was known that two shovels would be down for a couple of days in week 2, a major truck component change-out that was planned in week 1 could be delayed to overlap with the shovel outage. Without this coordination, the mine may be under trucked during week 1 and over trucked in week 2. The dispatch system could mitigate the impact of not having enough trucks, but during week 2, the mine would probably end up renting one or two shovels to avoid being over trucked.

The remaining long-term planning for truck maintenance could also be easily mapped to include a *10 week rolling schedule* and *annual outage plan* similar to that prepared for the shovels. Indeed, the production planner has requested this for the next annual planning cycle. The remaining changes, as described in this section, however, have yet to be implemented. This is primarily due to a lack of a sense of urgency to make the changes. The existing system is very convenient for the HTMBU – they basically get to perform planned maintenance whenever they wish, regardless of what is happening with the shovels. The only interface between the two groups from a long-term planning perspective is through the production planner who recognises that this interaction will become increasingly important as haul truck capacity increases. Without this integration, the mine will rent shovels more

often than necessary in the short-term and likely experience significant costs due to lost production in the long-term.

### *7.4.4. Cost Control Strategy*

Morrison (1999) suggests that the primary objective of developments in information technology should be to provide precise activity based financial control of the operation (including maintenance) in real-time. Arguably, however, this capability is a means to an end rather than an end in itself and might better be called the first priority as opposed to primary objective. As Morrison suggests, the resulting precise understanding of the mine's cost structure would make it possible to determine and introduce the most profitable level of automated or tele-remote equipment (or any other innovative enhancement) in the mine. Richardson (1993) would call this part of a "lean and keen" cost management strategy that in addition to investment in new technology would include consistent commitment to exploration and human resource development as a means of reducing long-term costs. The more traditional "lean and mean" cost reduction strategies based on workforce reduction, and reduced investments in exploration and new technology, Richardson argues, only improve cost efficiency in the short-term. Continuation of these strategies will eventually lead to a loss in competitiveness.

Although both Richardson (1993) and Morrison (1999) stress the importance of a precise understanding of the cost structure for the mine, other than Morrison's suggestion for an activity based costing approach, neither author describes how this can be achieved. Part of the difficulty in achieving a "lean and keen" strategy, however, is the lack of a basic

understanding of how each of the activities associated with the mining process contribute to the overall cost. At SCL, the so-called activity based costing approach is based on cost centres derived from accounting convenience as opposed to the way the business is actually conducted. As a result, they do not align well with the basic business processes of the individual business units. This is not surprising since, with the exception of legislated programs such as LM, there is a fundamental lack of documentation on the core business processes in the areas studied at SCL.

Structured Analysis and the creation of as-is models provide an effective way to document existing business activities. Once validated, these models can form the basis for an activity based costing system that applies budgets to activities in the same hierarchical fashion used in the models. Such an approach would provide direct linkage between activities and costs that will allow for the level of cost control Morrison (1999) deems so important.

The improvements outlined in the previous section highlight the importance of sharing information across business units. From a planning perspective, this information sharing has primarily been associated with scheduling information that, when shared, would lead to better coordination of scheduled downtime for shovels and trucks. The resulting, integrated schedules reduce the frequency with which the mine is either over or under trucked. This will result in cost savings because the integrated schedules will decrease the requirement for rental equipment. However, lack of an effective activity based costing approach combined with the business unit structure at SCL make it difficult to measure the

overall cost impact of each of the business units' performance in terms of how each contributes to the cost of a barrel of oil. Future decisions about how to best employ emerging information technology will prove problematic without this understanding.

Currently, many decisions are based on key performance indicators (KPIs) that do not take associated costs into direct account. Consider, for example, one of the standard maintenance KPIs – availability. Operating in isolation and knowing that their performance will be measured with this number, maintenance business units will be inclined to try and make the value as high as possible. Maximising availability, however, may not be an appropriate objective if, for example, operations were not utilising the equipment to take advantage of its availability. Organisational sub-optimisation in this manner can easily result in excessive maintenance costs.

Implementation of an activity based costing approach based on models created through SA would provide an effective means to avoid the types of situations described above. For example, based on accounting data, SCL is able to calculate the costs associated with providing a kiloton of bitumen to extraction. This value is not constant, but changes over time as a function of many variables including performance and operating conditions. If this cost were broken down to reflect each business unit's contribution, every business unit involved could assess their own performance as part of the overall mine's performance. To be of real value, these figures would have to be available in near real-time to act as a basis for joint decision making across business unit boundaries. Furthermore, the cost data could be

used to derive a qualitative method of conveying the current mining costs by activity on a continuous basis to provide feedback on performance. The feedback would have to take into account the mining conditions, but could be as simple as a red, yellow or green signal depending on if costs were low, medium, or high, respectively.

Efforts to derive shared cost performance indicators using the existing cost control system is proving to be difficult but continues to be a priority at SCL. The overall aim is to measure the integrated cost performance across business unit boundaries. Unfortunately however, since the existing cost centres are not based on fully defined activities that comprise the business processes this effort is likely to continue to frustrate more than illuminate. Full implementation of this initiative based on a complete realignment of cost centres to structured models is beyond the scope of this research. However, it has been recommended that one business unit be used for a pilot study. The HTMBU already has several models created and are familiar enough with the technique to complete the modelling effort. The HTMBU budget could then be allocated based on the structured models as a means of testing the effectiveness of the approach. Based on the results of this effort, broader application of the technique could be considered.

### *7.5. Summary of Improvements and Recommendations*

Phase 2 of the case study was based on a SA of the production planning process from the production planner's perspective. This viewpoint represented the only perspective that had the ability to have an impact on all of the business units involved in shovel/truck mining. Many of the improvements were obvious and changes have already been implemented and

continue to evolve. Other initiatives are proving more difficult to implement and will therefore take time to be assessed. Specifically, recommendations and improvements were made in the following areas:

(a) Improved information flow between operations and maintenance that has resulted in improved decision making. For example, the HTMBU has been able to use this information to implement statistical process control procedures for truck availability.

(b) An improved short-term production planning process based on the integration of truck (and medium duty) maintenance considerations.

(c) Improved long-term production planning process based on recommended integration of the annual shovel and truck maintenance plans. This will be implemented for the year 2000.

(d) Cost control strategy aimed at providing near real-time indicators that allow business units to assess their own performance and how that fits into the context of the mine's overall performance.

The benefits associated with these improvements will become even more significant as SCL increases the haul capacity of its trucks. As discussed in Chapter 3, higher capacity haul trucks will make the mine increasingly sensitive to unscheduled truck downtime due to an increase in the costs associated with lost production.

### *7.6. Conclusions*

Although some quantitative measurements were highlighted along with the improvements outlined above, it is difficult to measure the full impact of these improvements because most are qualitative in nature. Recently, however, the improvements to the short-term production planning process were basically turned off due to the fact that the liaison team leader from the HTMBU was on vacation. This occurred before his role in this capacity had been explained to other team leaders who, as a result at that time, were unable to fill in. On his return to work, this individual used the PMCS to compare the availability of the 930E and 793 fleets during periods with and without the integrated short-term planning process in place. The results have been reproduced in Table 7.1.

| | *1/1/99 to 1/15/99 (no process)* | *1/16/99 to 1/31/99 (process in place)* | *1/2/99 to 28/2/99 (process in place)* |
|---|---|---|---|
| 930E Fleet | 74.3% | 88.1% | 89.2% |
| 793 Fleet | 78.0% | 83.2% | 88.5% |

**Table 7.1: Availability Improvements Based on Improved Short-term Planning**

Although there may have been other factors influencing truck maintenance during the period when the new process was not in place, the improvements in availability, as shown in the table, are significant. From a qualitative perspective, prior to the SA, this same leader

would not have known that the PMCS existed and the quantitative analysis would not even have been possible or taken a very long time to complete.

The real benefit from this part of the case study is based on shared information and better communication primarily between the HTMBU and operations but also between the maintenance business units including shovel and medium duty maintenance. The obvious nature of some of the improvements already implemented along with the ease with which they were accomplished provide evidence of the effectiveness of the SA approach. Even an organisation dedicated to continuous improvement such as SCL had some significant information shortfalls that were easily remedied. The most glaring example was based on the HTMBU not being aware of the PMCS facility provided with the WENCO dispatch system. Furthermore, the fact that shovel and truck maintenance were not integrated from either the short-term or long-term planning perspective suggests that in large organisations, integration issues can even exist within maintenance departments.

Perhaps the greatest testament to the success of this part of the project is the fact that this study, that was limited in scope to include only shovels and trucks, actually led to changes for medium duty (support equipment) maintenance as well. Recognising the value of integrating truck maintenance considerations into the short-term production planning process led the production planners to do the same thing for medium duty equipment maintenance.

# CHAPTER 8

## 8. STRUCTURED ANALYSIS OF MINING – A BROADER CONTEXT

### 8.1. Introduction

The case study presented in Chapters 6 and 7 was based on an open pit mine with an oil sand ore body. Although oil sand shows tremendous growth potential for the future, it represents a relatively small proportion of the many different types of mining operation. In this Chapter, the general applicability of the SA methodology to other mining situations will be discussed. This will be accomplished by comparing the differences between the mine chosen for the case study and other mines that may wish to consider similar projects. Applications beyond the mine including an examination of the relationships between the mine and the mill as well as between the mine and OEMs will also be discussed.

### 8.2. SA Application to Other Open Pit Operations

Open pit methods can be applied to virtually any ore body that is close enough to the surface to make the technique profitable. Open pit methods are applied to base metals, coal and gold. With a few exceptions, these mines generally use the shovel/truck production system very similar to that employed at SCL. The main difference between oil sand and these other types of ore is the requirement for blasting. The drill-blast-muck cycle required for most ore types is not applicable to oil sand that can be mined largely without blasting. Without blasting, there is no need for drilling either. One could argue therefore, that tar sand

mining is a much simpler process than that required for other types of ore bodies that require the full drill-blast-muck cycle.

In addition to the extra equipment required for these steps in the process, scheduling is more difficult. Blasting in particular must be coordinated such that there are sufficient mining faces available a safe distance from the blast to ensure a continuous supply of ore. This not only complicates the planning process but also increases the mine's reliance on particular pieces of equipment during critical periods. For example, a failed drill rig that is not repaired in a timely fashion can result in a major slippage to the overall mining sequence. As a result, operations in these mines require a higher degree of planning coordination than would be the case at SCL. Furthermore, the increase in equipment types along with periodic critical reliance on some systems (primarily drills) also makes the maintenance function more difficult. Based on the fact that drills make up 20% of IOCC's mobile equipment fleet (as presented in Table 3.1), it is suggested that the complexity involved to coordinate the operation and maintenance functions compared to SCL increases by at least 25%.

Summarising the comparison between SCL and other surface111 mines we see that, in general, other open pit operations use the same materials handling techniques (shovel/truck) but as a result of the drill-blast-muck cycle have increased complexity in the overall process. This makes planning coordination for both production and maintenance even more critical than would be the case at SCL. In particular, the coordination of production and maintenance schedules would be even more important for other types of open pit operation. For this reason, the SA approach should prove even more beneficial than was

the case for SCL. The case study demonstrated that the SA models could be used to focus on and improve the interactions between processes. This can lead to integrated schedules that strike an appropriate balance between production and maintenance requirements.

### *8.3. Applications to Hard Rock Underground Mining*

The number and types of mobile equipment used in hard-rock underground operations is even greater than that used in open pit. These include:

(a) Production drills,

(b) Development drills,

(c) Diamond drills,

(d) LHDs,

(e) Trucks, and

(f) Conveyors.

Not all mines use all of these types of equipment, but it is generally safe to assume that there is more variety of equipment required for underground hard-rock mining than would be the case for an open pit producing the same amount of ore. In contrast to open pit however, the utilisation rates for this equipment is much lower. Utilisation for underground mobile equipment has been shown to be less than 50% (Hall et al., 1999b) as opposed to the planning figure of approximately 90% used at SCL. A reduction in utilisation results in a dramatic increase in maintenance scheduling flexibility. As a result, the improvements made at SCL, with respect to improved short-term production planning based on a closer integration with maintenance, would have less of an impact on an underground mine.

The reason for low utilisation compared to open pit mines is that underground mines have considerably more constraints to deal with making the overall process more complicated. Problems related to geometry, geology and logistics were discussed in Chapter 4, Section 4.2. It was suggested that underground mine design remains a subjective process based primarily on individual expertise. The overall complexity of the task is demonstrated by the fact that despite the high impact that it has on profit, there is a lack of software tools capable of effectively aiding the mining engineer with the selection of the most appropriate underground mining method. Therefore, rather than focusing on the interaction between operations and maintenance, application of the SA methodology would be better suited to the coordination of the overall mining activities. A SA of the underground mine design process, including how to choose the best mining method, would represent a significant contribution by simply documenting the process and creating a model that could be used for a basis of discussion on how it could be improved. This, in turn, could lead to improved planning and a significant increase in equipment utilisation and productivity.

### *8.4. Integration of Mine and Mill Planning*

This research has looked primarily at relationships within the mine. However, a mine is usually linked to a mill that takes the raw material from the mine in order to make a product. In a similar way that operations depends on maintenance to provide equipment availability, the mill depends on the mine to supply ore. Regardless of whether the operation is open pit or underground, the ability of the mine to supply the quantity and quality of ore necessary to keep the mill satisfied has a huge impact on the profitability of the overall operation. Quantity is easily measured. However, when it comes to quality, as measured by

the grade of the ore, there tends to be disagreement between what the mine says it supplied and what the mill says it received. This scenario creates the potential for friction between the mine and the mill that can result in a relationship gap very similar to the operations/maintenance gap described in Chapter 2.

As discussed in Chapter 4, Section 4.2.1, the mine's ability to provide dependable production grade forecasting on a daily basis for the mill is an important activity that can be very difficult to achieve. The difficulty is directly related to the blending requirements associated with the particular ore being processed. The mill determines these requirements, but depending on the consistency of the extraction process may result in the mill having to request specific grades of raw material on very short notice. When grade requirements change frequently the mine may be forced to create stockpiles of materials of various grades. This is costly as the stockpiles represent in-process inventory. Alternatively, the mine can increase flexibility by planning the production schedule in such a way that ore of various grades is available from different working faces. A broad look at production planning, therefore, should include consideration of the mill's blending requirements.

The interdependencies that exist between the mine and the mill make the relationship between them an excellent candidate for SA. In the same way that an understanding of the information requirements between operations and maintenance was shown to improve their relationship, SA applied in a similar fashion between the mine and the mill could result in an even bigger payoff for the total operation.

### *8.5. Improving Relationships with Equipment/Software Vendors*

As Richardson (1993) points out, backward integration opportunities for mining companies are limited because they are at the start of the value chain. Possible exceptions would be for mines to expand into the equipment manufacturing or even software development businesses. Richardson suggests, however, that the cyclical nature of capital investment in mining and the propensity of mining firms not to buy from their competition make many view equipment manufacturing as a high-risk venture. However, improvements to equipment and software design are critical to sustained improvement in the industry. To ensure these improvements meet the needs of the mine, SA models can be developed and used to help define requirements and evaluate changes. By entering into partnerships with OEMs and software developers, mines can play an active role in the design and development process. Early prototype testing can serve to help ensure new systems meet actual requirements. OEMs can coordinate data from all of the mines that use their equipment to allow for analysis of large samples of data that can be used to benefit all of the participants.

The creation of the Maintenance Monitor function (presented in Chapter 6, Section 6.5.1) as part of the WENCO dispatch system provides an excellent example of how cooperation with vendors can lead to improved products. Based on requirements provided by SCL, WENCO programmers developed "maintenance" software that was necessarily integrated with the "operations" dispatch system that was already in place. The truck dispatch and maintenance monitor functions are both tied to the master pit file ensuring consistency between the two systems. As a result of the collaboration, SCL has the software they need along with the right1 to use it. WENCO has also benefited by creating a product

enhancement that will likely become a key selling feature for future customers. Similar collaborations with equipment manufacturers particularly in the area of CBM equipment could be easily facilitated through the use of SA.

### *8.6. Using SA Models for Activity Based Costing*

A recent innovation (since the mid-1980s) in cost accounting systems is activity based costing (ABC). ABC is a method of assigning overhead costs to products by the identification and use of "cost drivers" (Atkinson et al., 1997). Developed primarily for the manufacturing industry, ABC focuses on the assignment of fixed costs to individual products in an attempt to increase the accuracy of cost data compared to traditional accounting methods leading to improved cost control and, as a result, better decision-making. In this context, ABC is most beneficial where the likelihood of cost distortion among products is high. It is also beneficial where managers can use the more accurate cost information in order to make better decisions with respect to altering strategic factors such as setting a products price or determining an appropriate product mix (Baiden and Zanibbi, 1999). Compared to manufacturing, mining corporations have far fewer products and virtually no ability to influence price that is set on world markets. Despite this, Baiden and Zanibbi suggest that the ABC approach has merit if the cost objective is redefined from focusing on products (as is the case in manufacturing) to focusing on mining method or process. The resulting predictive cost models would therefore include both the direct costs of the mining method as well as those support costs that are driven by the activities that differentiate each method.

Martin (1998) suggested that indirect costs are not only substantial, but are very sensitive to mining method. Using a case study based on an actual gold mine, he showed that cut and fill stoping (CFS) tended to have indirect costs of at least 40% of total costs compared to the longhole stoping (LHS) method that had indirect costs as high as 80%. He further suggested a relationship between indirect costs, tonnage and grade. In particular, Martin showed that with CFS, the proportion of indirect costs increases with tonnage. For LHS, increased tonnage and higher grades both tended to increase indirect costs. The importance of making the mining method selection decision based on accurate cost data is underscored by Baiden and Zanibbi by referring to the cost behaviour over the life cycle stages of a mine as reproduced in Figure 8.1.

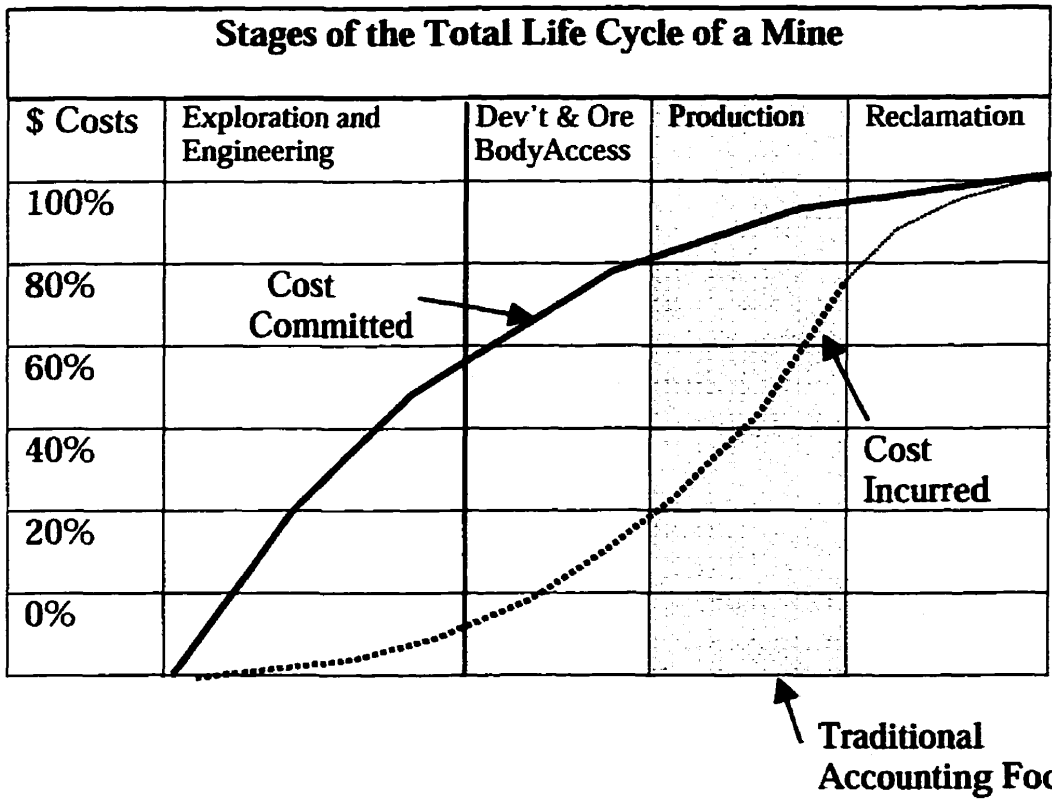


**Figure 8.1: Cost Behaviour over the Life Cycle of a Mine (Baiden and Zanibbi, 1999)**

Mining method decisions are made primarily in the *Exploration and Engineering Phase*, but can be changed early in the *Development and Ore Body Access*. As shown in the figure, the cost actually incurred to make this selection is very small. However, it has a huge impact in terms of locking in the design and, as a result, committed funds for the remainder of the mine's life cycle. ABC applied in a predictive way during the first two phases can help to ensure that the decisions made take the total cost impact into account. A necessary step prior to implementing ABC would be to prepare detailed descriptions of the activities that make up each of the mining methods being considered. The SA methodology is perfectly suited for this task. In addition to facilitating a shared understanding of what makes up the mining method selection process, the graphical depiction provides the perfect framework for activity based costing. Costs can be estimated in the same hierarchical fashion as the diagrams in the model.

# CHAPTER 9

## 9. CONCLUSIONS

The primary motivation behind this research was recognition of the fact that mining corporations appear to be struggling with the effective application of information technology. Rather than leading to better integration between operations and maintenance, the implementation of stand-alone systems used to increase departmental efficiencies are in some cases reducing overall mine performance. Using SCL as a case study, the SA methodology was applied to improve overall mine performance through better communication and coordination between operations and maintenance.

Although many of the areas identified for improvement did not require a SA to be performed, the models served three important functions. First, the models were used to get agreement upon what the business processes actually were. Referring to the diagrams quickly rectified any misunderstanding. Second, alternative to-be models were used to clearly describe the options available for improvement. In particular, they stimulated the creativity of those involved as boxes and arrows could easily be added or removed in order to describe new ideas. Third, and perhaps most important, after the researcher left, the models remained to clearly documentwhat had actually been achieved.

### 9.1. Summary of Original Contributions

Original contributions as a result of this research are:

(a) The introduction of the operations/maintenance gap concept highlighting the requirement for close coordination and integration of these two equally important groups.

(b) Recognition that the argument for improved productivity through economies of scale needs to include consideration of maintenance impacts. Using simulation, it was shown in Chapter 3 that increased costs associated with lost production due to unscheduled downtime could potentially offset the production cost savings upon which the decision to purchase higher capacity equipment was based.

(c) The applications of the SA methodology to the heavy truck maintenance function at an open pit mine.

(d) The applications of SA to the production planning process at an open pit mine.

(e) The introduction of SA as a methodology for formalising information requirements in a mining context.

### *9.2. Benefits*

The general benefits associated with the application of SA in a mining context as demonstrated by this research include:

(a) The introduction of a methodology for improving performance through improved information flow. Although this improvement may be difficult to measure, it will be based on improved decisions that generally result in increased profits.

(b) A means of evaluating organisational restructuring especially with respect to the impact of new equipment or information technology.

(c) A straightforward method to document existing processes and procedures that can assist with training and decrease the risks associated with losing key personnel.

(d) Allowing mines to effectively determine their information requirements against which software solutions can be evaluated.

(e) Providing a mechanism for discussing and evaluating change.

The direct benefits to SCL as a result of the case study are:

(a) The HTMBU has improved its ability to collect cost data with respect to breakdown maintenance by 50%. Efforts to continue to improve in this area are on going.

(b) The LM reporting system has been streamlined to increase the proportion of time technicians have available for active repair by 4%.

(c) Improved information flow between operations and maintenance resulting in improved decision making. For example, the HTMBU has been able to use newfound information to implement statistical process control procedures for truck availability.

(d) An improved short-term production planning process based on the integration of truck (and medium duty) maintenance considerations.

(e) An improved long-term production planning process based on recommended integration of the annual shovel and truck maintenance plans. This will be implemented for the year 2000.

The benefits associated with these improvements will become even more significant as SCL increases the haul capacity of its trucks making the mine increasingly sensitive to unscheduled truck downtime.

### *9.3. Future Work*

Future work would include:

(a) Applying the SA methodology to other types of mining operations.

(b) Using the SA approach to improve the integration and coordination between the mine and the mill.

(c) Applying the SA methodology to improve the information flow between OEMs and mines. Once the OEMs have a detailed understanding of the mine's information requirements with respect to equipment performance, they can act as a central repository able to conduct analysis using sample data from all mines using the same equipment.

(d) Using SA as the basis for the effective design of an enterprise wide information system for mining. The level of effort that would be required to complete this analysis would be substantially greater than that required for the current study. However, the structured models could be used to

define the information system architecture that would be a critical step in successfully implementing a total mining system.

(e) Applying SA to help formulate an appropriate activity based costing structure that could be used to improve the way support costs are factored into decision making at all levels from mine design through production control.

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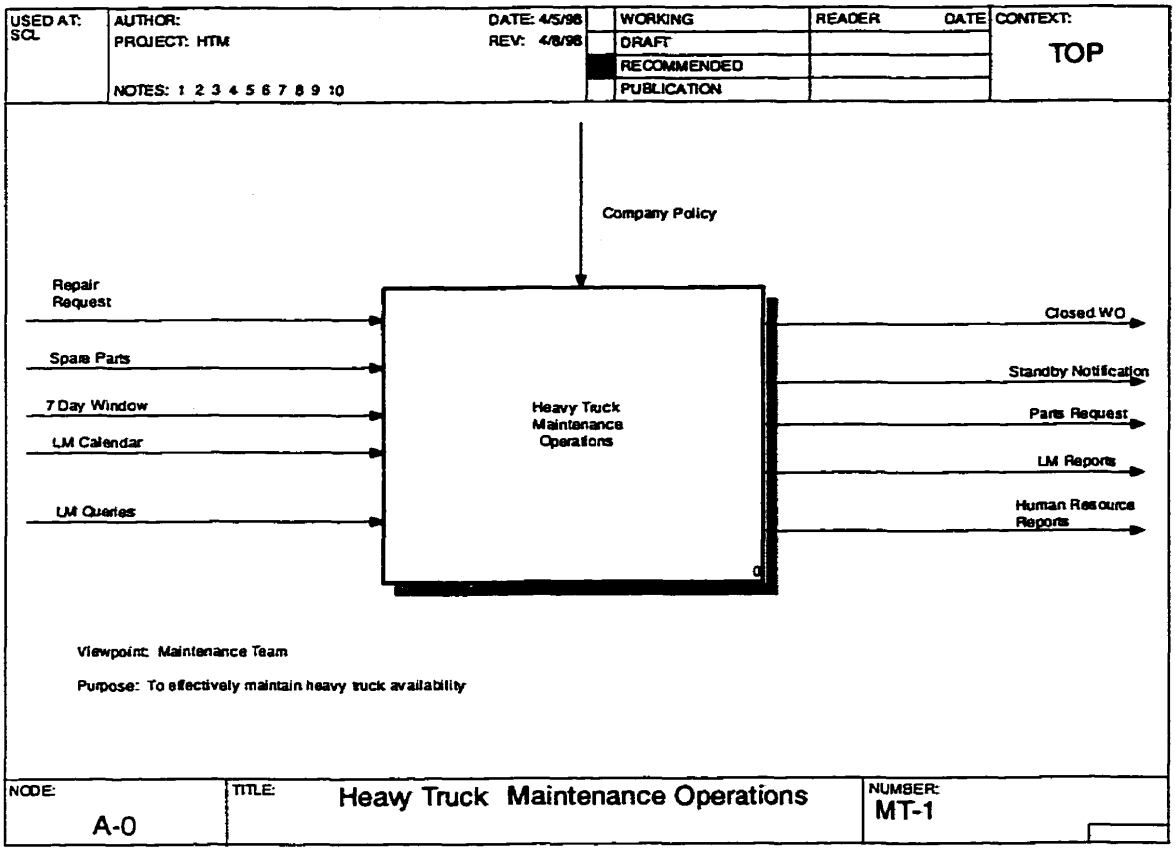
# APPENDIX A

## HEAVY TRUCK MAINTENANCE OPERATIONS: MAINTENANCE TEAM VIEWPOINT (MT-1 TO MT-14)




## REPORT FOR DIAGRAM: A-0, HEAVY TRUCK MAINTENANCE OPERATIONS

Activity Name: Heavy Truck Maintenance Operations
Activity Definition: all efforts undertaken by the maintenance teams of the HTBMU to effectively maintain heavy truck availability

Link Name: Parts Request
Link Definition: Several types of parts requests exist. SITs are completed for warehouse parts. If the part needs to be ordered, a Purchase requisition is generated and sent to appropriate vendor.

Link Name: Closed WO
Link Definition: This represents the WO form that is fully completed from the mechanics perspective. He may or may not close the WO on IMMPOWER, however all of the required information is on the hard copy

Link Name: Spare Parts
Link Definition: Represented by a packing slip. May come from warehouse or vendors.

Link Name: 7-Day Window
Link Definition: Represents all scheduled work for one week scheduled by day.

Link Name: Standby Notification
Link Definition: When maintenance activity is completed, truck is put on standby using 99 code on WENCO. This means the truck is ready to be picked up by a driver and returned to operations.

Link Name: Repair Request
Link Definition: any request arriving at the HTMBU for failure maintenance.

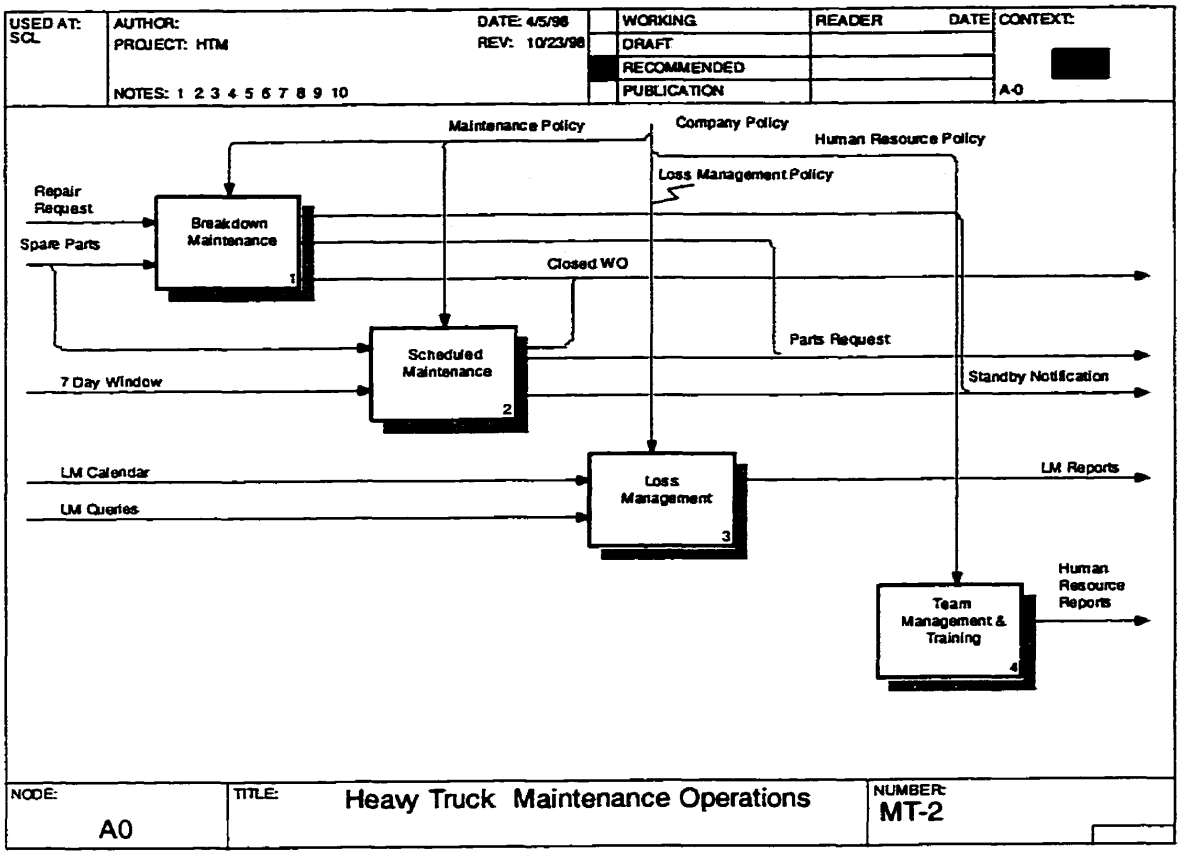
Link Name: LM Reports
Link Definition: represents all reports generated IAW the LM program.

Link Name: LM Calendar
Link Definition: Specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

Link Name: Company Policy
Link Definition: Represents all policies to which the Heavy Truck Maintenance Unit is subjected

Link Name: LM Queries
Link Definition: Represents any requests for information on LCRs, incidents, and status of LM reports etc.

Link Name: Human Resource Reports
Link Definition: all reports submitted IAW human resource policy.




## REPORT FOR DIAGRAM: A0, HEAVY TRUCK MAINTENANCE OPERATIONS

Activity Name: Breakdown Maintenance

Activity Name: Scheduled Maintenance

Activity Name: Loss Management
Activity Definition: A systematic approach toward the elimination of incidents and the reduction of risks to people, production equipment and the environment.

Activity Name: Team Management & Training
Activity Definition: All non-maintenance activities other than loss management. Include, for example operational peer assessments, Pay for Knowledge and skills. (Note this is based on the individual, not the team - slight misalignment. Task group participation, special projects.

Link Name: Parts Request
Link Definition: Several types of parts requests exist. SITs are completed for warehouse parts. If the part needs to be ordered, a Purchase requisition is generated and sent to appropriate vendor.

Link Name: Closed WO
Link Definition: This represents the WO form that is fully completed from the mechanics perspective. He may or may not close the WO on IMMPOWER, however all of the required information is on the hard copy

Link Name: Spare Parts
Link Definition: Represented by a packing slip. May come from warehouse or vendors.

Link Name: 7-Day Window
Link Definition: Represents all scheduled work for one week scheduled by day.

Link Name: Standby Notification
Link Definition: When maintenance activity is completed, truck is put on standby using 99 code on WENCO. This means the truck is ready to be picked up by a driver and returned to operations.

Link Name: Repair Request
Link Definition: any request arriving at the HTMBU for failure maintenance.

Link Name: LM Reports
Link Definition: represents all reports generated IAW the LM program.

Link Name: LM Calendar
Link Definition: Specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

Link Name: Company Policy
Link Definition: Represents all policies to which the Heat Truck Maintenance Unit is subjected

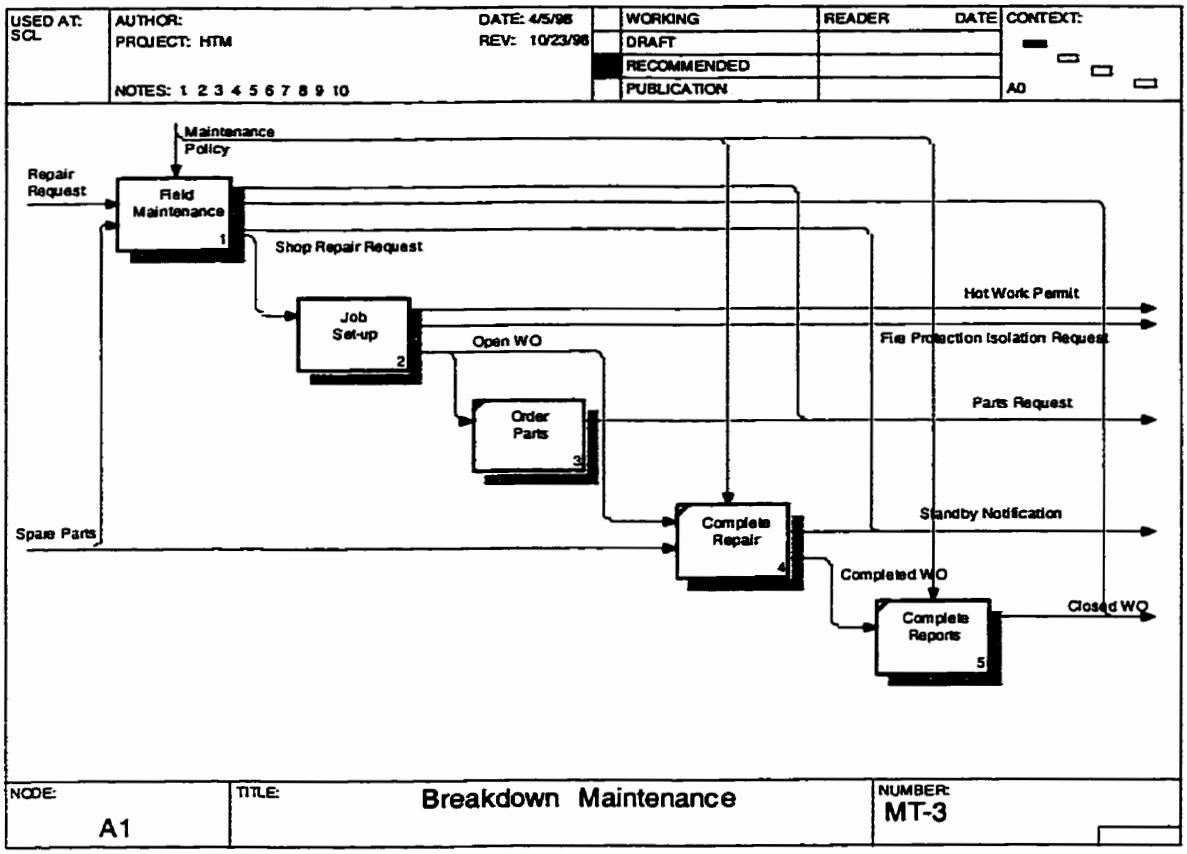
Link Name: Maintenance Policy

Link Name: Human Resource Policy

Link Name: Loss Management Policy

Link Name: LM Queries
Link Definition: Represents any requests for information on LCRs, incidents, and status of LM reports etc.

Link Name: Human Resource Reports
Link Definition: all reports submitted IAW human resource policy.




## REPORT FOR DIAGRAM: A1, BREAKDOWN MAINTENANCE

Activity Name: Field Maintenance
Activity Definition: Field technician responds to trouble call, conducts a fault diagnosis in the field. Result is NFF, repaired in situ or the driver is instructed to take the vehicle to the maintenance bay.

Activity Name: Job Set-up
Activity Definition: Contact person arranges for technician(s) to be assigned to the task. The truck is steam cleaned if necessary. The assigned technician drafts the work order and reviews the parts manuals and procedures and drafts the Work order on the IMMPOWER system. Hot Work permits and isolation reports are completed if necessary

Activity Name: Order Parts

Activity Name: Complete Repair

Activity Name: Complete Reports

Link Name: Parts Request
Link Definition: Several types of parts requests exist. SITs are completed for warehouse parts. If the part needs to be ordered, a Purchase requisition is generated and sent to appropriate vendor.

Link Name: Hot Work Permit
Link Definition: Hot Safe Work Permit required for welding jobs.

Link Name: Open WO
Link Definition: Represents a unique WO opened for each maintenance action. Required for all scheduled maintenance and Breakdown maintenance costing more than $200.

Link Name: Closed WO
Link Definition: This represents the WO form that is fully completed from the mechanics perspective. He may or may not close the WO on IMMPOWER, however all of the required information is on the hard copy

Link Name: Completed WO

Link Name: Spare Parts
Link Definition: Represented by a packing slip. May come from warehouse or vendors.

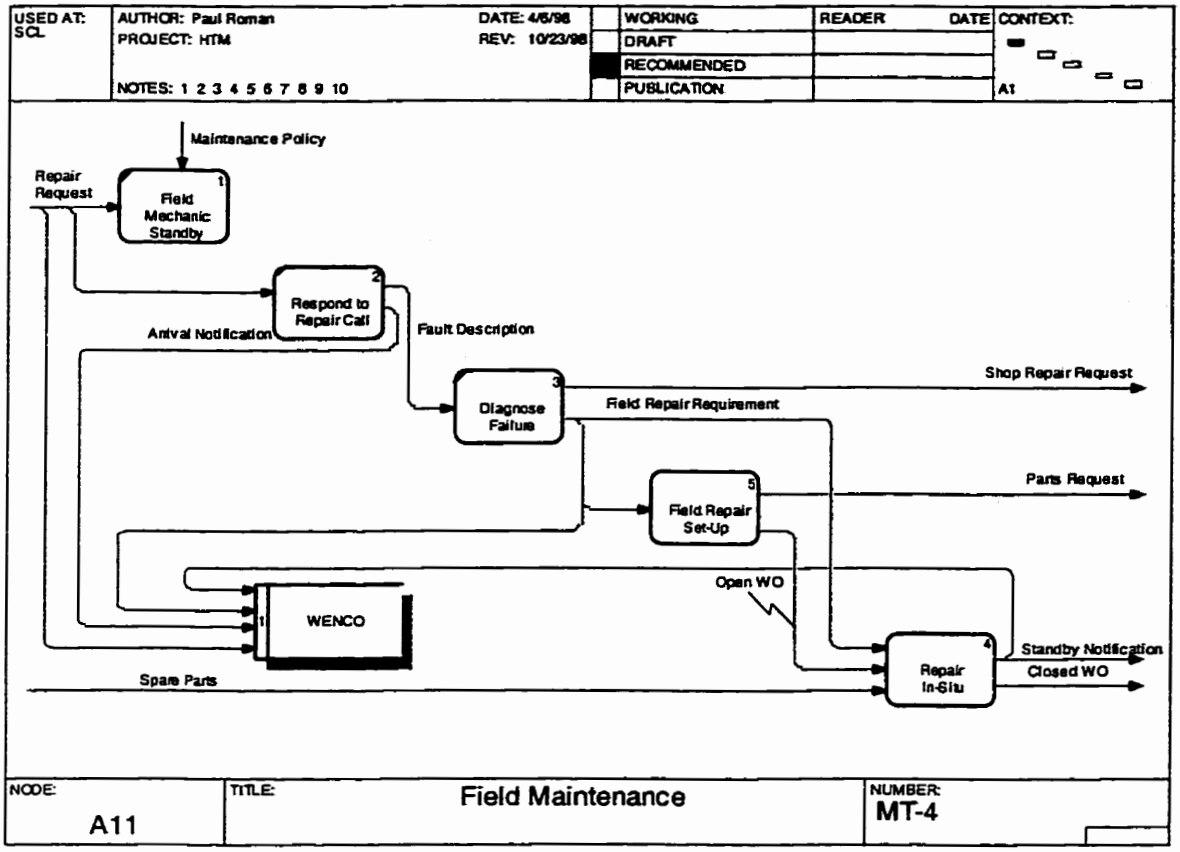
Link Name: Shop Repair Request
Link Definition: If the diagnosis indicates that Field repair is not possible, the field mechanic contacts the shop contact person to arrange for shop repair. The WENCO system is updated with code M53 - shop repair.

Link Name: Fire Protection Isolation Request
Link Definition: Form necessary to suppress fire protection system to allow for maintenance

Link Name: Standby Notification
Link Definition: When maintenance activity is completed, truck is put on standby using 99 code on WENCO. This means the truck is ready to be picked up by a driver and returned to operations.

Link Name: Repair Request
Link Definition: any request arriving at the HTMBU for failure maintenance.

Link Name: Maintenance Policy




## REPORT FOR DIAGRAM: A11, FIELD MAINTENANCE

Activity Name: Field Mechanic Standby
Activity Definition: Normally two field mechanics on-call for breakdowns trouble call is assigned to one of the mechanics based on agreements made between them. Normally take turns.

Activity Name: Respond to Repair Call
Activity Definition: Assigned field mechanic drives to the site of the breakdown

Activity Name: Diagnose Failure
Activity Definition: On arrival, the field mechanic discusses the problem with the operator and conducts a fault diagnoses. The WENCO system should be updated to code M51 indicating that the mechanic has arrived and is diagnosing the fault.

Activity Name: Field Repair Set-up
Activity Definition: When diagnosis indicates that an in-situ repair can be completed, he has to order and pick up any parts required, generate a work order if the parts will cost more than $200 or if there will be a CORE returned to the warehouse (Note, some disagreement on this

amount, one field mech. thought $1000). This may also involve getting his partner to help with the job. Must access IMMPOWER to request and open a WO. This requires the field mechanic to return to the shop to conduct paper work while the truck remains down (wasted administrative downtime). Procedurally easy to improve - have blank paper copies of WOs with numbers already assigned. Then paper work is done AFTER the truck is returned to service.

Activity Name: Repair In-Situ
Activity Definition: If the diagnosis indicates that the fault is something that can be repaired by the field mechanic, then he conducts the repair. If spare parts are required, the mechanic drives in to pick them up or calls for his partner to get the parts. The M52 code should be input into WENCO system indicating a field repair is underway.

Link Name: Parts Request
Link Definition: Several types of parts requests exist. SITs are completed for warehouse parts. If the part needs to be ordered, a Purchase requisition is generated and sent to appropriate vendor.

Link Name: Open WO
Link Definition: Represents a unique WO opened for each maintenance action. Required for all scheduled maintenance and Breakdown maintenance costing more than $200.

Link Name: Closed WO
Link Definition: This represents the WO form that is fully completed from the mechanics perspective. He may or may not close the WO on IMMPOWER, however all of the required information is on the hard copy

Link Name: Spare Parts
Link Definition: Represented by a packing slip. May come from warehouse or vendors.

Link Name: Shop Repair Request
Link Definition: If the diagnosis indicates that Field repair is not possible, the field mechanic contacts the shop contact person to arrange for shop repair. The WENCO system is updated with code M53 - shop repair.

Link Name: Standby Notification
Link Definition: When maintenance activity is completed, truck is put on standby using 99 code on WENCO. This means the truck is ready to be picked up by a driver and returned to operations.

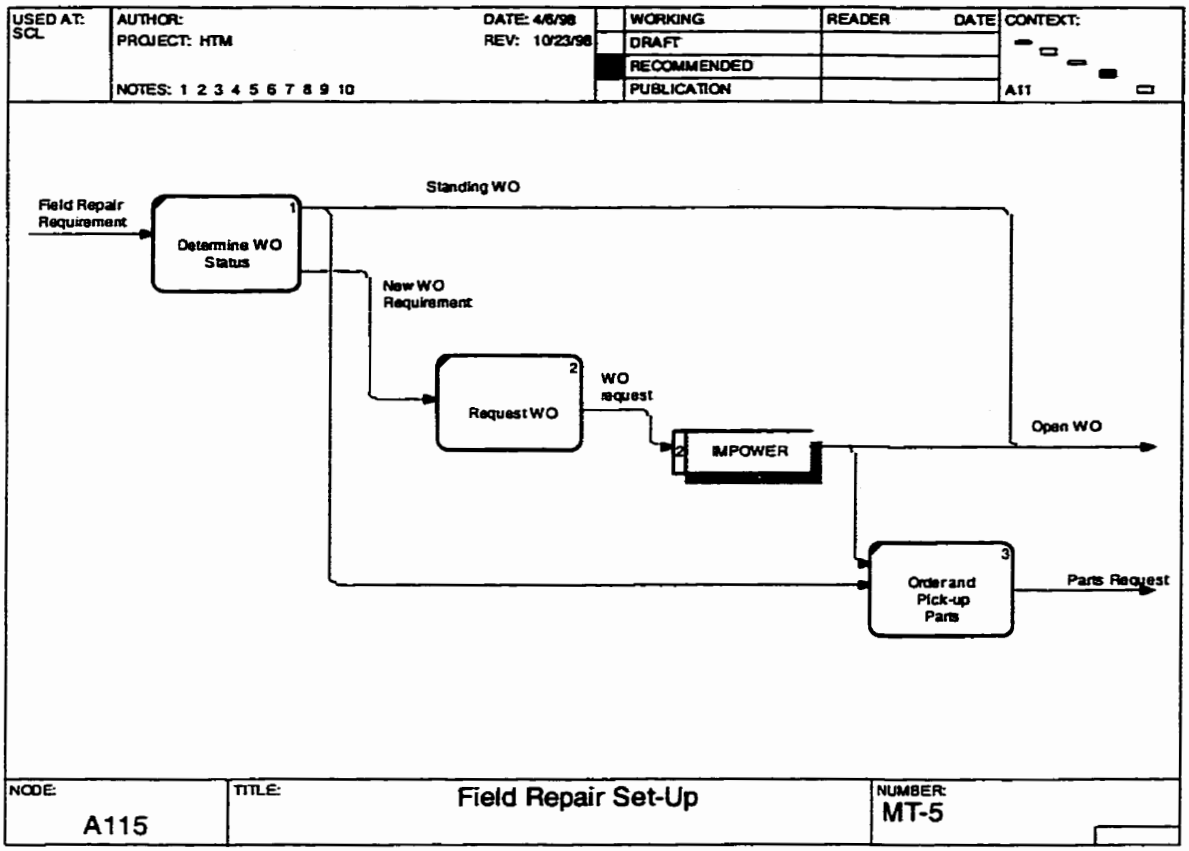
Link Name: Arrival Notification
Link Definition: On arrival, the WENCO system is updated with the M51 code.

Link Name: Fault Description
Link Definition: Upon arrival, the truck operator gives a detailed description of the nature of the fault.

Link Name: Repair Request
Link Definition: any request arriving at the HTMBU for failure maintenance.

Link Name: Maintenance Policy

Link Name: Field Repair Requirement




## REPORT FOR DIAGRAM: A115, FIELD REPAIR SET-UP

Activity Name: Determine WO Status
Activity Definition: Job is assigned to a standing WO for minor work (if less than 1000 $ or does not involve a core). Otherwise a new work order must be generated from IMMPOWER.

Activity Name: Request WO
Activity Definition: For work in excess of $1,000. Requires the technician to return to the shop to access IMMPOWER.

Activity Name: Order and Pick-up Parts
Activity Definition: Often the partner mechanic will pick up the parts using a SIT.

Link Name: Parts Request
Link Definition: Several types of parts requests exist. SITs are completed for warehouse parts. If the part needs to be ordered, a Purchase requisition is generated and sent to appropriate vendor.

Link Name: Open WO

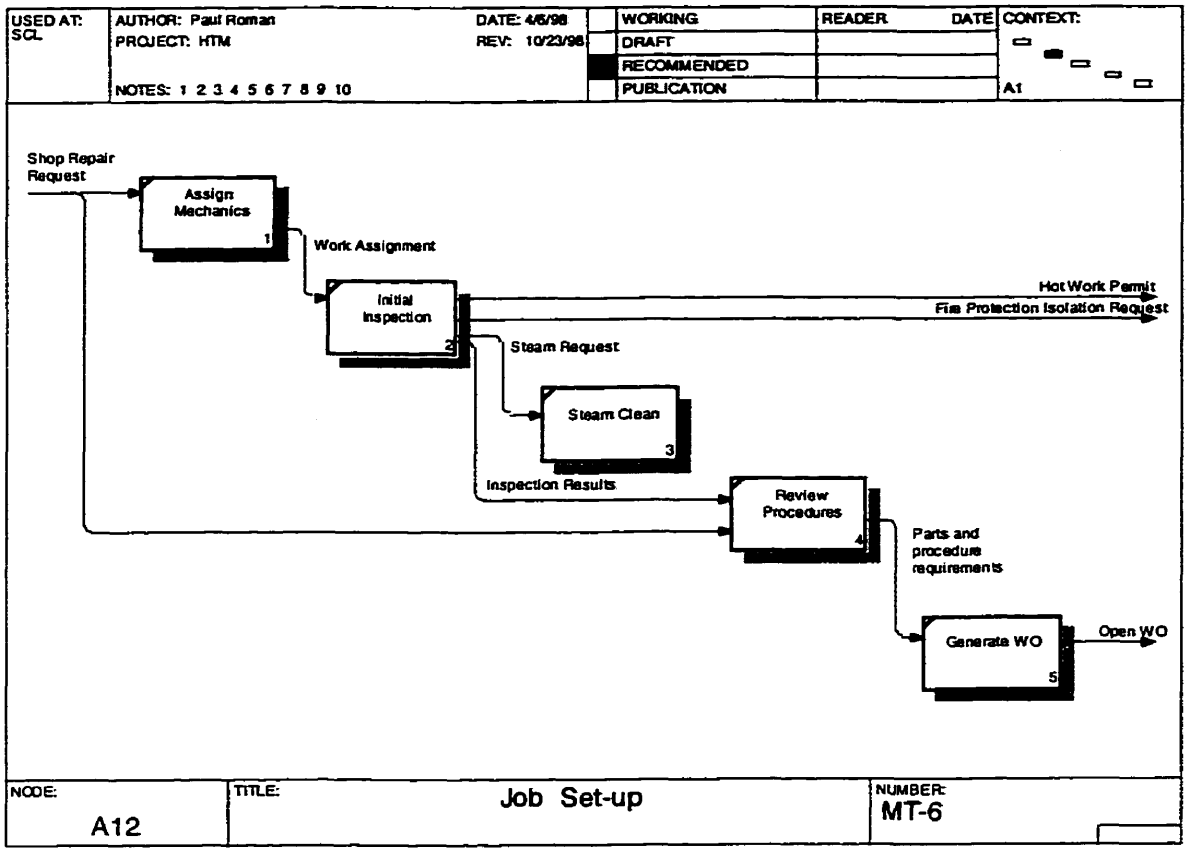
Link Definition: Represents a unique WO opened for each maintenance action. Required for all scheduled maintenance and Breakdown maintenance costing more than $200.

Link Name: WO request

Link Name: Standing WO
Link Definition: For Field maintenance of a minor nature, standing WOs are used. Note that these open WOs by-pass IMMPOWER.

Link Name: New WO Requirement

Link Name: Field Repair Requirement




## REPORT FOR DIAGRAM: A12, JOB SET-UP

Activity Name: Assign Mechanics
Activity Definition: Contact person arranges for job to be assigned and which Bay will be used.

Activity Name: Initial Inspection
Activity Definition: An initial inspection is conducted, normally by the assigned technician to determine if there is a requirement to steam clean the truck. Based on the inspection, required forms for welding or fire protection are completed.

Activity Name: Steam Clean
Activity Definition: The truck is driven to A and steam cleaned by the contractor if necessary.

Activity Name: Review Procedures
Activity Definition: The truck manuals are reviewed to determine parts that are required for the job. The warehouse system may be accessed (via terminal or through a phone call) to determine if the parts are available.

Activity Name: Generate WO

Link Name: Hot Work Permit
Link Definition: Hot Safe Work Permit required for welding jobs.

Link Name: Open WO
Link Definition: Represents a unique WO opened for each maintenance action. Required for all scheduled maintenance and Breakdown maintenance costing more than $200.

Link Name: Shop Repair Request
Link Definition: If the diagnosis indicates that Field repair is not possible, the field mechanic contacts the shop contact person to arrange for shop repair. The WENCO system is updated with code M53 - shop repair.

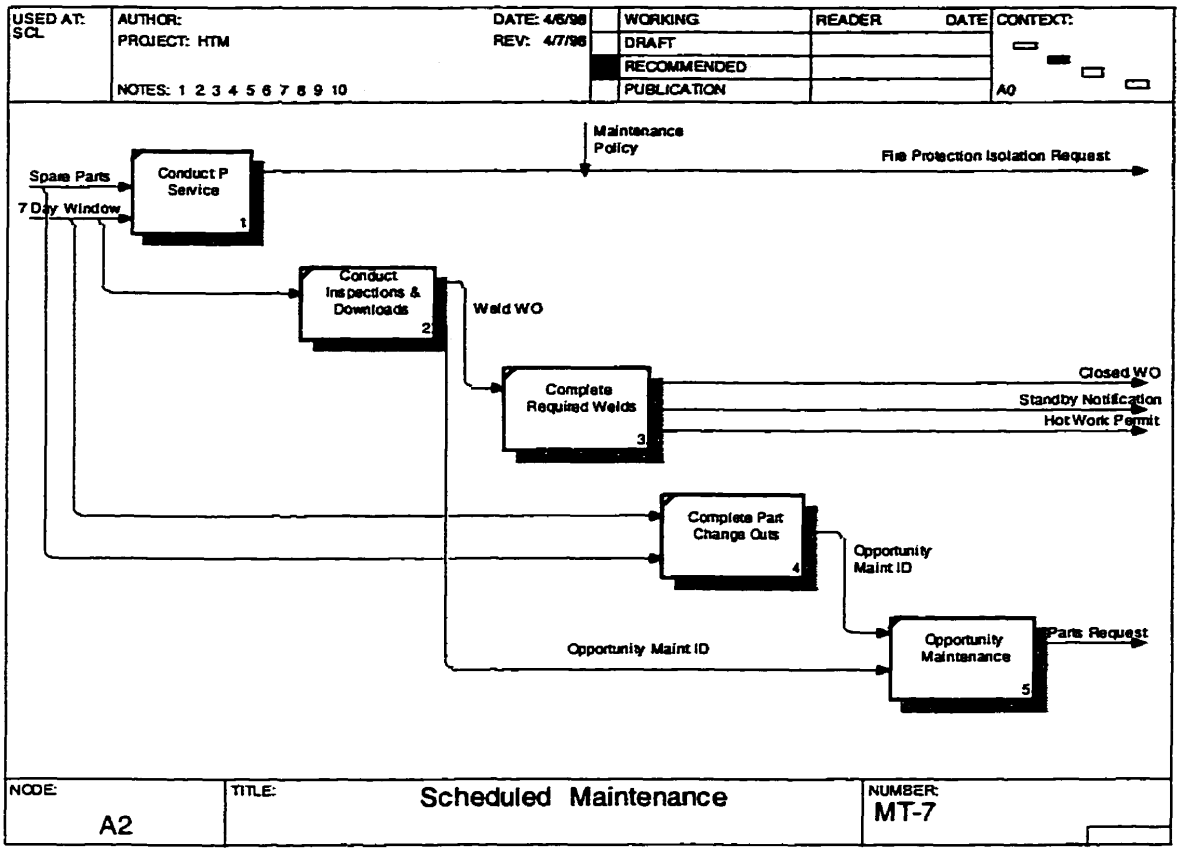
Link Name: Fire Protection Isolation Request
Link Definition: Form necessary to suppress fire protection system to allow for maintenance

Link Name: Work Assignment
Link Definition: May include 1 or several technicians.

Link Name: Steam Request

Link Name: Inspection Results

Link Name: Parts and procedure requirements




## REPORT FOR DIAGRAM: A2, SCHEDULED MAINTENANCE

Activity Name: Conduct P Service
Activity Definition: Includes calling for the vehicle at 3am. Having steam cleaned from 3 - 730 ready for day shift. Then P1, 2,3 or 4 as specified by the WO.

Activity Name: Conduct Inspections & Downloads
Activity Definition: Includes weld inspections ECAPS system inspection and VIMS downloads. New WOs are created if necessary. If possible, this work is conducted concurrently with the service.

Activity Name: Complete Required Welds
Activity Definition: If welding inspection indicates weld requirement, the work is completed. Note, if possible, this work is conducted concurrently.

Activity Name: Complete Part Change Outs
Activity Definition: Based on the PCR (preventive component replacement) program. Separate WO if scheduled. WO generated for opportune PCR.

Activity Name: Opportunity Maintenance

Link Name: Parts Request
Link Definition: Several types of parts requests exist. SITs are completed for warehouse parts. If the part needs to be ordered, a Purchase requisition is generated and sent to appropriate vendor.

Link Name: Hot Work Permit
Link Definition: Hot Safe Work Permit required for welding jobs.

Link Name: Closed WO
Link Definition: This represents the WO form that is fully completed from the mechanics perspective. He may or may not close the WO on IMMPOWER, however all of the required information is on the hard copy

Link Name: Spare Parts
Link Definition: Represented by a packing slip. May come from warehouse or vendors.

Link Name: Fire Protection Isolation Request
Link Definition: Form necessary to suppress fire protection system to allow for maintenance

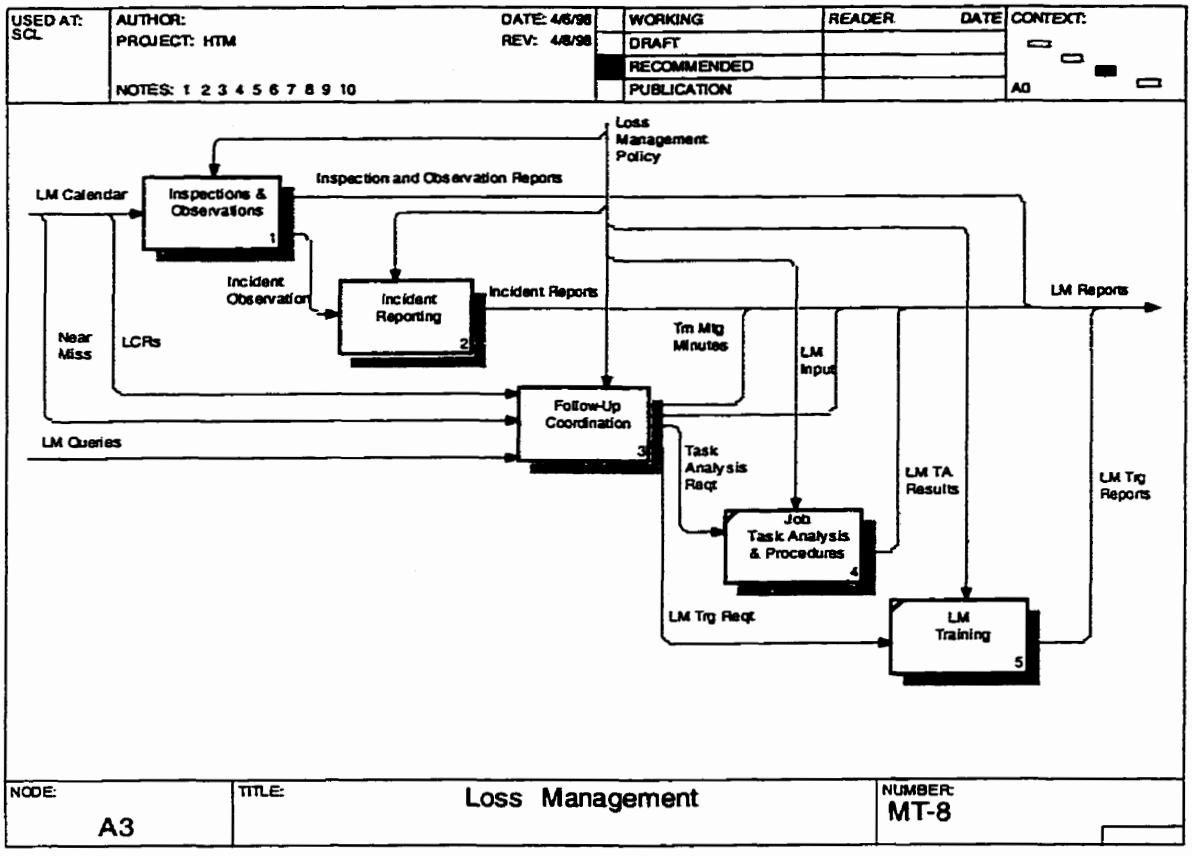
Link Name: 7-Day Window
Link Definition: Represents all scheduled work for one week scheduled by day.

Link Name: Standby Notification
Link Definition: When maintenance activity is completed, truck is put on standby using 99 code on WENCO. This means the truck is ready to be picked up by a driver and returned to operations.

Link Name: Weld WO
Link Definition: As a result of the welding inspection, welding WO is generated as required.

Link Name: Opportunity Maint ID

Link Name: Maintenance Policy




## REPORT FOR DIAGRAM: A3, LOSS MANAGEMENT

Activity Name: Inspections & Observations
Activity Definition: All normally scheduled Inspections and observations. Includes those initiated by the teams and the team leaders and managers.

Activity Name: Incident Reporting
Activity Definition: Includes LCRs and near miss reporting.

Activity Name: Follow-up Coordination
Activity Definition: Includes monthly team meetings, LCR review during line-up. Annual Audits both internal and external.

Activity Name: Job Task Analysis & Procedures
Activity Definition: Based on Syncrude STA system whereby the inventory is reviewed annually, tasks are weighted and scored. Critical tasks are identified and procedures developed.

Activity Name: LM Training
Activity Definition: Includes orientations

Link Name: Incident Reports
Link Definition: Include LCRs and near misses

Link Name: LM Reports
Link Definition: represents all reports generated IAW the LM program.

Link Name: Inspection and Observation Reports
Link Definition: Reports generated from monthly, weekly and daily inspections and observations. Inspections are conducted on equipment and work areas; observations are made on procedures.

Link Name: LM Calendar
Link Definition: Specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

Link Name: Loss Management Policy

Link Name: Tm Mtg Minutes

Link Name: LM Queries
Link Definition: Represents any requests for information on LCRs, incidents, and status of LM reports etc.

Link Name: LM Trg Reports

Link Name: Task Analysis Reqt

Link Name: LM Trg Reqt

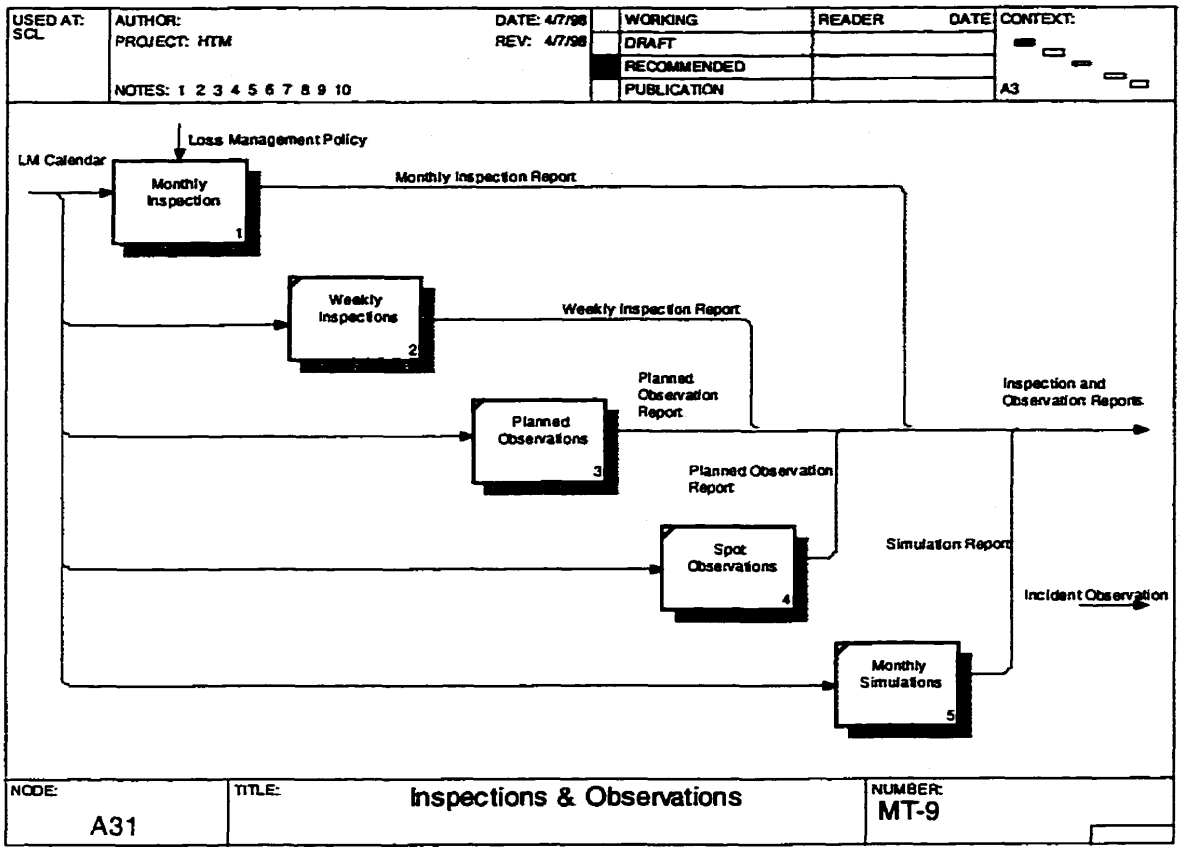
Link Name: LM TA Results

Link Name: Incident Observation
Link Definition: Any incident that is required to be reported IAW the LM guidelines.

Link Name: LCRs

Link Name: LM Input

Link Name: Near Miss




## REPORT FOR DIAGRAM: A31, INSPECTIONS & OBSERVATIONS

Activity Name: Monthly Inspection
Activity Definition: Each team must conduct a detailed inspection of the maintenance facility. This is coordinated so that each team is required to do the inspection once per quarter. Since there are 4 teams, the net result is one detailed inspection per month.

Activity Name: Weekly Inspections

Activity Name: Planned Observations
Activity Definition: The objective of task observation is to observe tasks while they are being performed to ensure that tasks are performed safely, efficiently, and in compliance with established standards.

Activity Name: Spot Observations

Activity Name: Monthly Simulations

Link Name: Inspection and Observation Reports

Link Definition: Reports generated from monthly, weekly and daily inspections and observations. Inspections are conducted on equipment and work areas; observations are made on procedures.

Link Name: LM Calendar
Link Definition: Specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

Link Name: Weekly Inspection Report

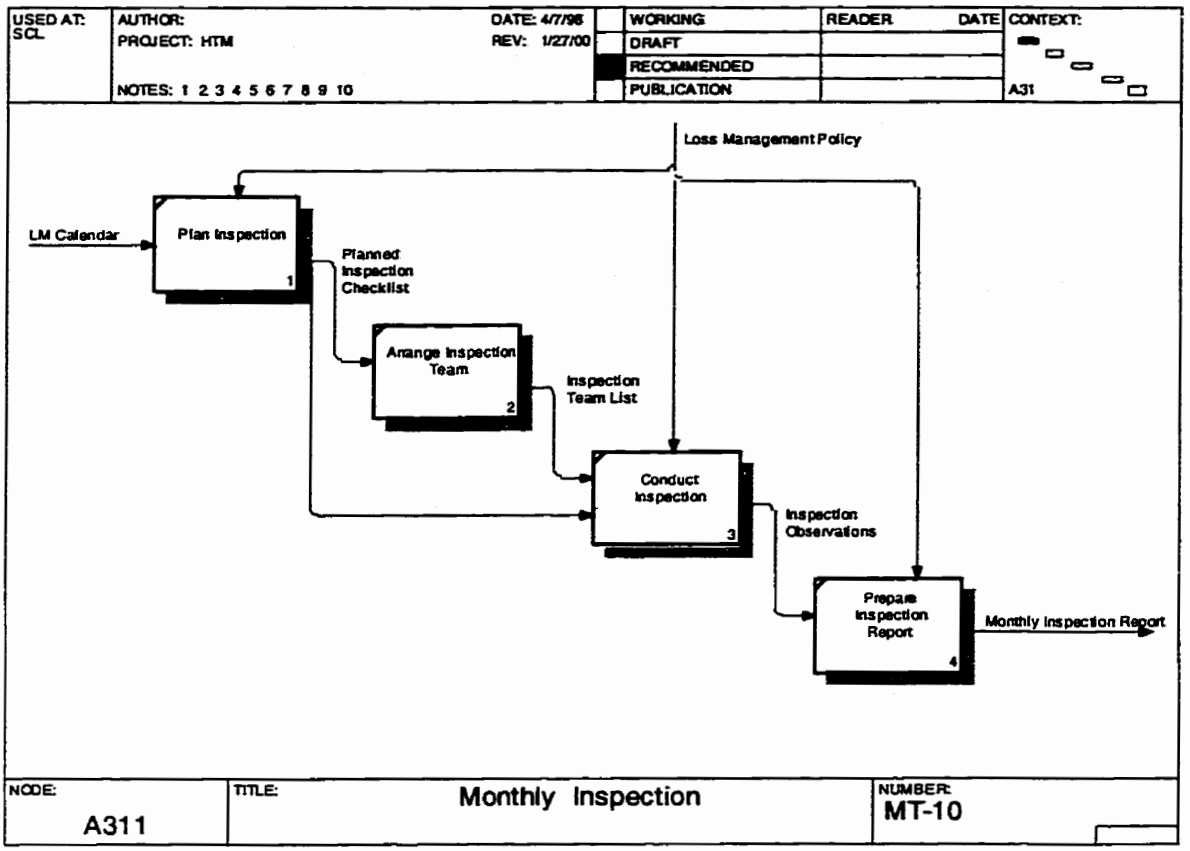
Link Name: Monthly Inspection Report

Link Name: Simulation Report

Link Name: Loss Management Policy

Link Name: Planned Observation Report

Link Name: Incident Observation
Link Definition: Any incident that is required to be reported IAW the LM guidelines.




## REPORT FOR DIAGRAM: A311, MONTHLY INSPECTION

Activity Name: Plan Inspection

Activity Name: Arrange Inspection Team
Activity Definition: Normally a lead inspector plus one team leader and two other inspector technicians.

Activity Name: Conduct Inspection

Activity Name: Prepare Inspection Report

Link Name: LM Calendar
Link Definition: Specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

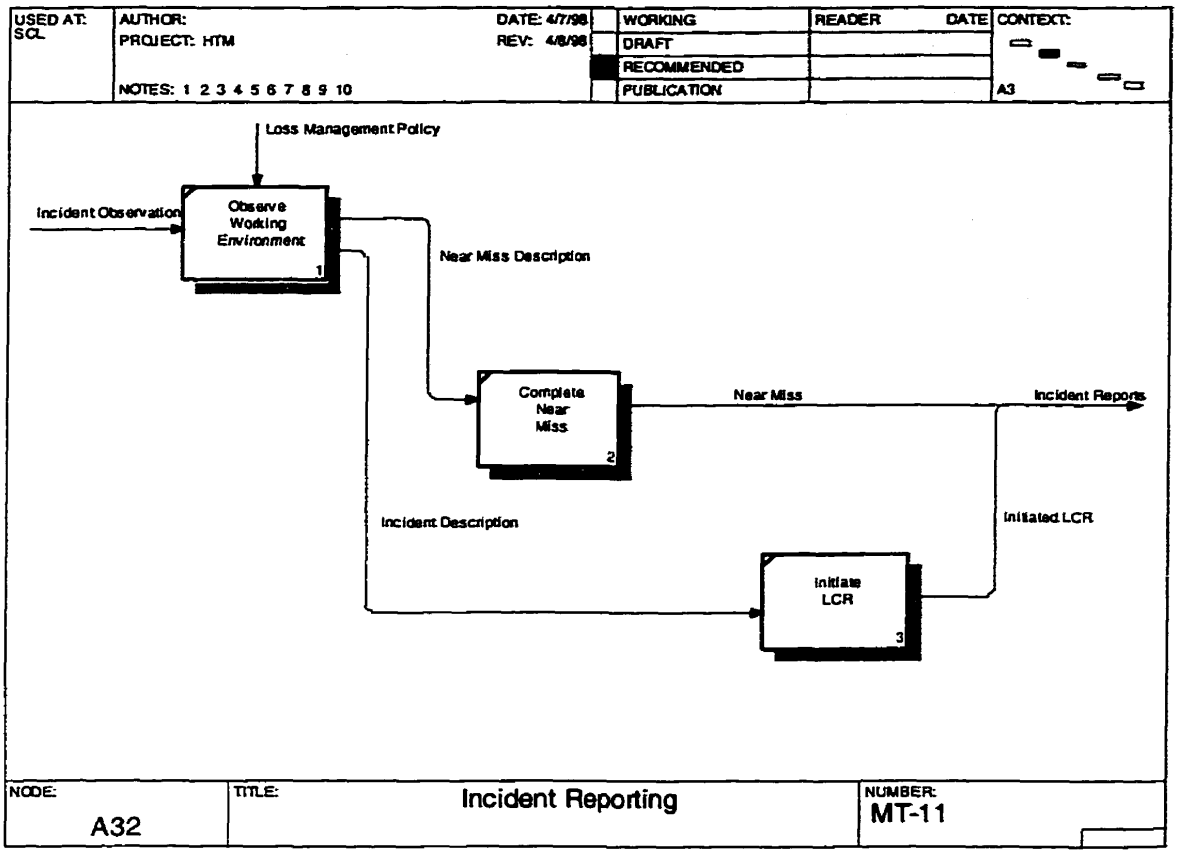
Link Name: Monthly Inspection Report

Link Name: Loss Management Policy

Link Name: Planned Inspection Checklist

Link Name: Inspection Team List

Link Name: Inspection Observations




## REPORT FOR DIAGRAM: A32, INCIDENT REPORTING

Activity Name: Observe Working Environment

Activity Name: Complete Near Miss

Activity Name: Initiate LCR

Link Name: Incident Reports
Link Definition: Include LCRs and near misses

Link Name: Loss Management Policy

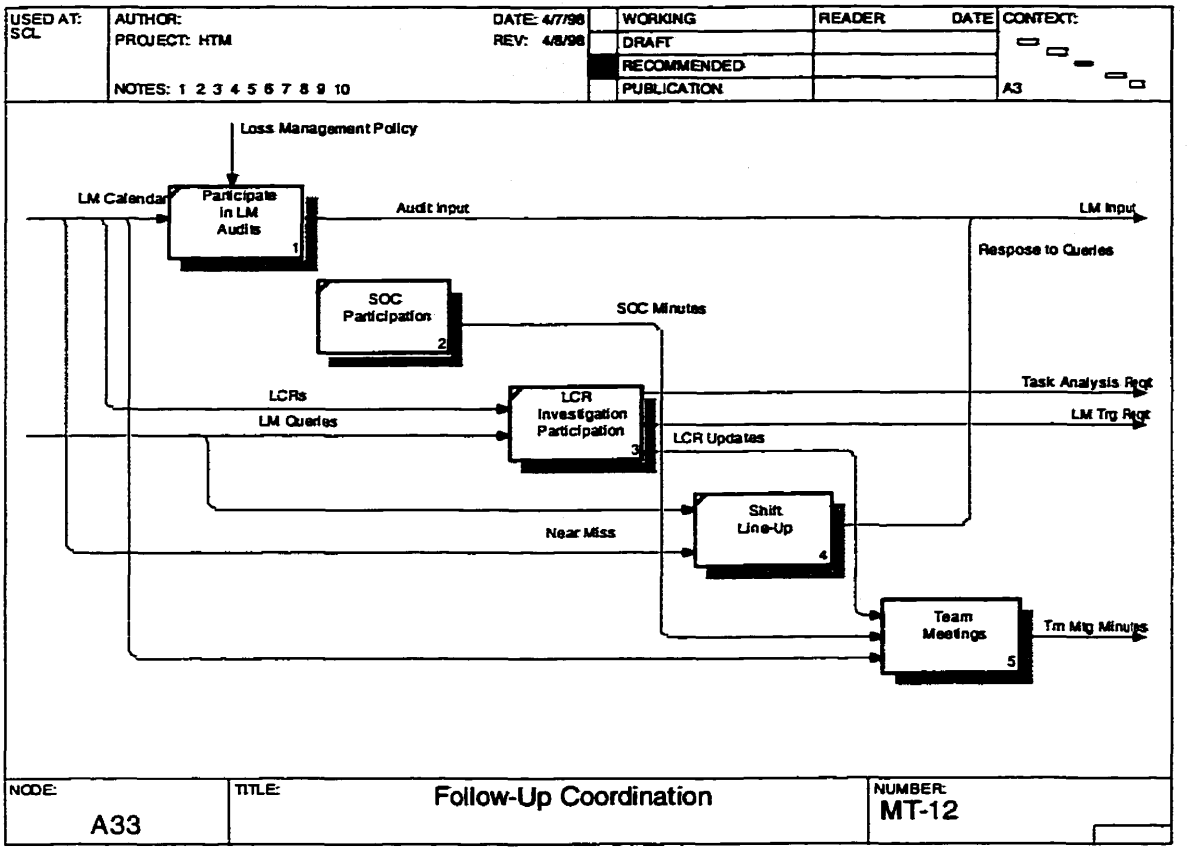
Link Name: Incident Observation
Link Definition: Any incident that is required to be reported IAW the LM guidelines.

Link Name: Initiated LCR

Link Name: Incident Description

Link Name: Near Miss Description

Link Name: Near Miss




## REPORT FOR DIAGRAM: A33, FOLLOW-UP COORDINATION

Activity Name: Participate in LM Audits
Activity Definition: Includes formal audits both internal and external. Mgmt tours also fall under this category

Activity Name: SOC Participation
Activity Definition: Represents participation on Syncrude Safe Operating Committee

Activity Name: LCR Investigation Participation

Activity Name: Shift Line-up

Activity Name: Team Meetings

Link Name: LM Calendar
Link Definition: Specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

Link Name: Loss Management Policy

Link Name: Tm Mtg Minutes

Link Name: LM Queries
Link Definition: Represents any requests for information on LCRs, incidents, and status of LM reports etc.

Link Name: Task Analysis Reqt

Link Name: LM Trg Reqt

Link Name: SOC Minutes

Link Name: Audit Input

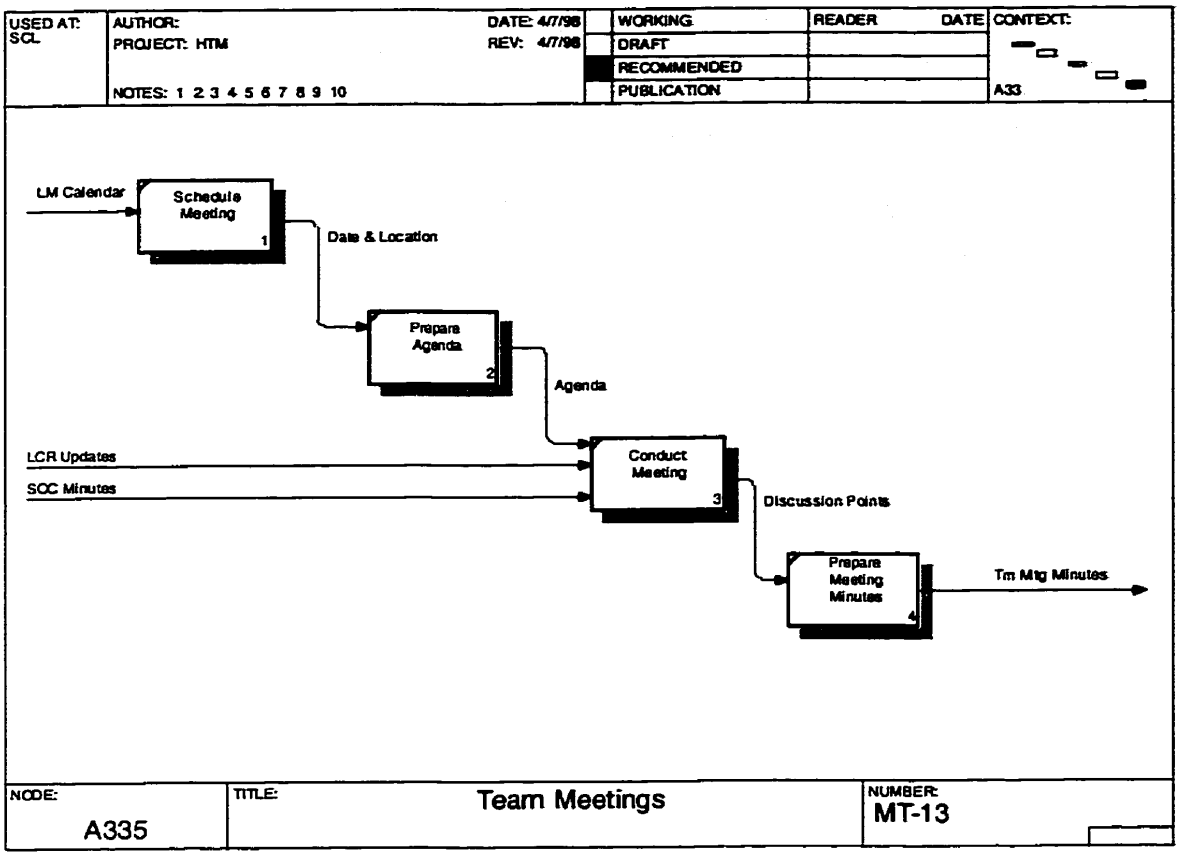
Link Name: LCRs

Link Name: LM Input

Link Name: Response to Queries

Link Name: LCR Updates

Link Name: Near Miss




## REPORT FOR DIAGRAM: A335, TEAM MEETINGS

Activity Name: Schedule Meeting

Activity Name: Prepare Agenda

Activity Name: Conduct Meeting

Activity Name: Prepare Meeting Minutes

Link Name: LM Calendar
Link Definition: Specifies the LM activities that are to be scheduled during the calendar month. This would include, for example, safety inspections and management walkthroughs.

Link Name: Tm Mtg Minutes

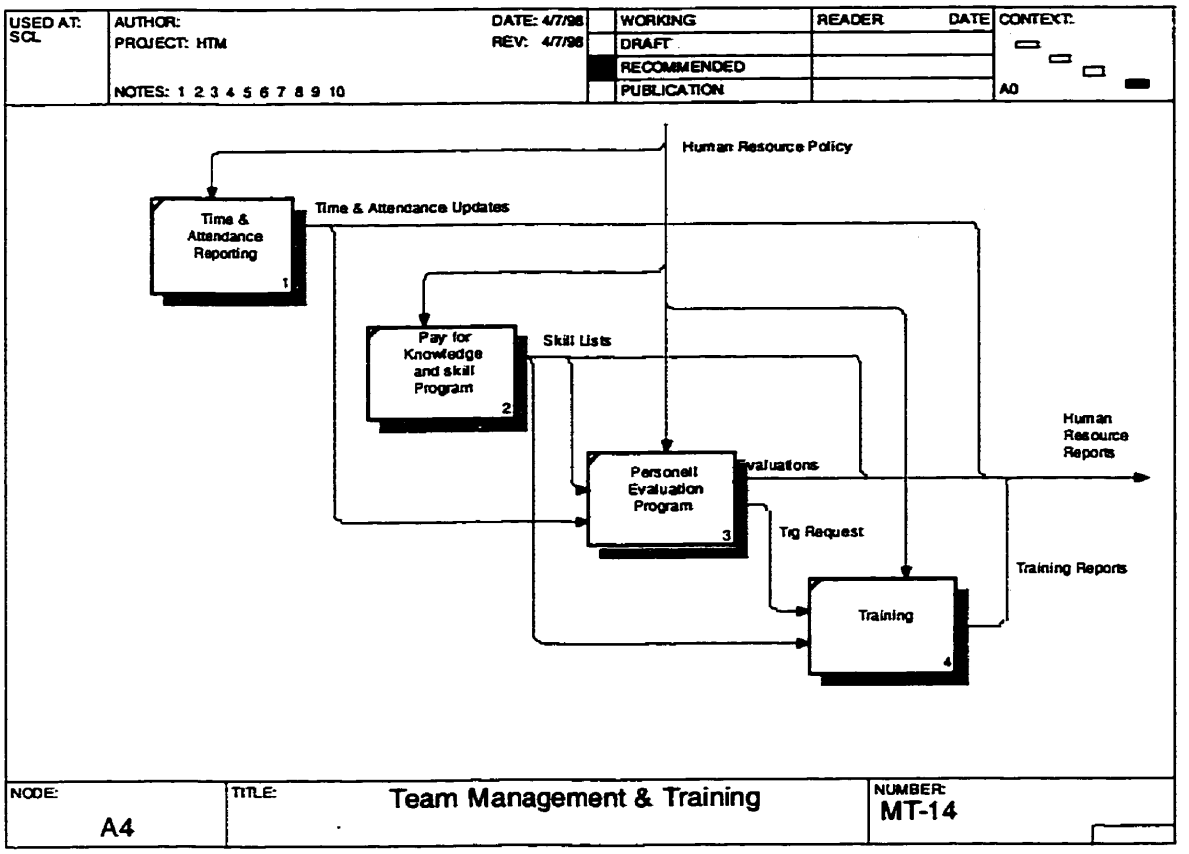
Link Name: SOC Minutes

Link Name: LCR Updates

Link Name: Date & Location

Link Name: Agenda

Link Name: Discussion Points




## REPORT FOR DIAGRAM: A4, TEAM MANAGEMENT & TRAINING

Activity Name: Time & Attendance Reporting

Activity Name: Pay for Knowledge and skill Program
Activity Definition: System in place for individuals to advance from entry level to block 5 based on demonstrable skill set.

Activity Name: Personnel Evaluation Program
Activity Definition: Includes peer evaluations and stewardship meetings with team leaders.

Activity Name: Training
Activity Definition: All trg accept for Loss Management Training

Link Name: Human Resource Policy

Link Name: Human Resource Reports
Link Definition: all reports submitted IAW human resource policy.

Link Name: Training Reports

Link Name: Evaluations

Link Name: Skill Lists

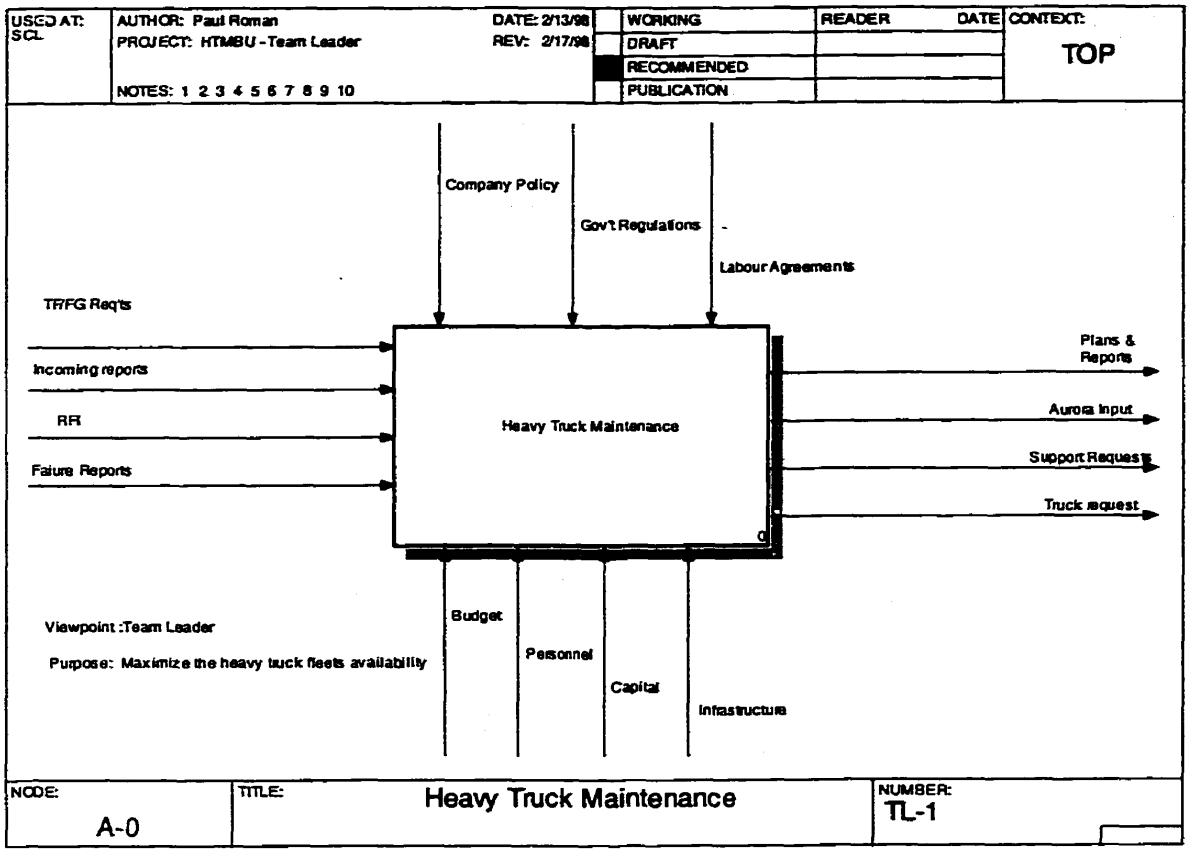
Link Name: Time & Attendance Updates

Link Name: Trg Request

# APPENDIX B

## HEAVY TRUCK MAINTENANCE OPERATIONS: TEAM LEADER'S VIEWPOINT

## (TL-1 TO TL-11)




## REPORT FOR DIAGRAM: A-0, HEAVY TRUCK MAINTENANCE

Activity Name: Heavy Truck Maintenance

Link Name: Company Policy
Link Definition: Company policy includes all required processes that the Truck Business Unit is required to adhere to.

Link Name: Gov't Regulations
Link Definition: Includes all legislated requirements to which Syncrude must comply.

Link Name: Labour Agreements
Link Definition: This includes the collective agreement with Syncrude Labour

Link Name: Incoming reports
Link Definition: Represents all reports that enter the business unit. These can be external reports for example, Finnig's annual report as pulled off of the Internet or any internal Syncrude reports

Link Name: Budget
Link Definition: Represents financial constraints on the business unit

Link Name: Personnel
Link Definition: Represents the limited human resources available to the business unit

Link Name: Capital
Link Definition: Represents the limited amount of capital resources available to the business unit.

Link Name: Infrastructure
Link Definition: Represents all non-capital assets available to the business unit.

Link Name: Plans & Reports
Link Definition: Represents all plans and reports, both formal and informal that are communicated in some way externally to the business unit. Includes annual Business plan.

Link Name: Aurora Input
Link Definition: Represents all information provided to the Aurora project team

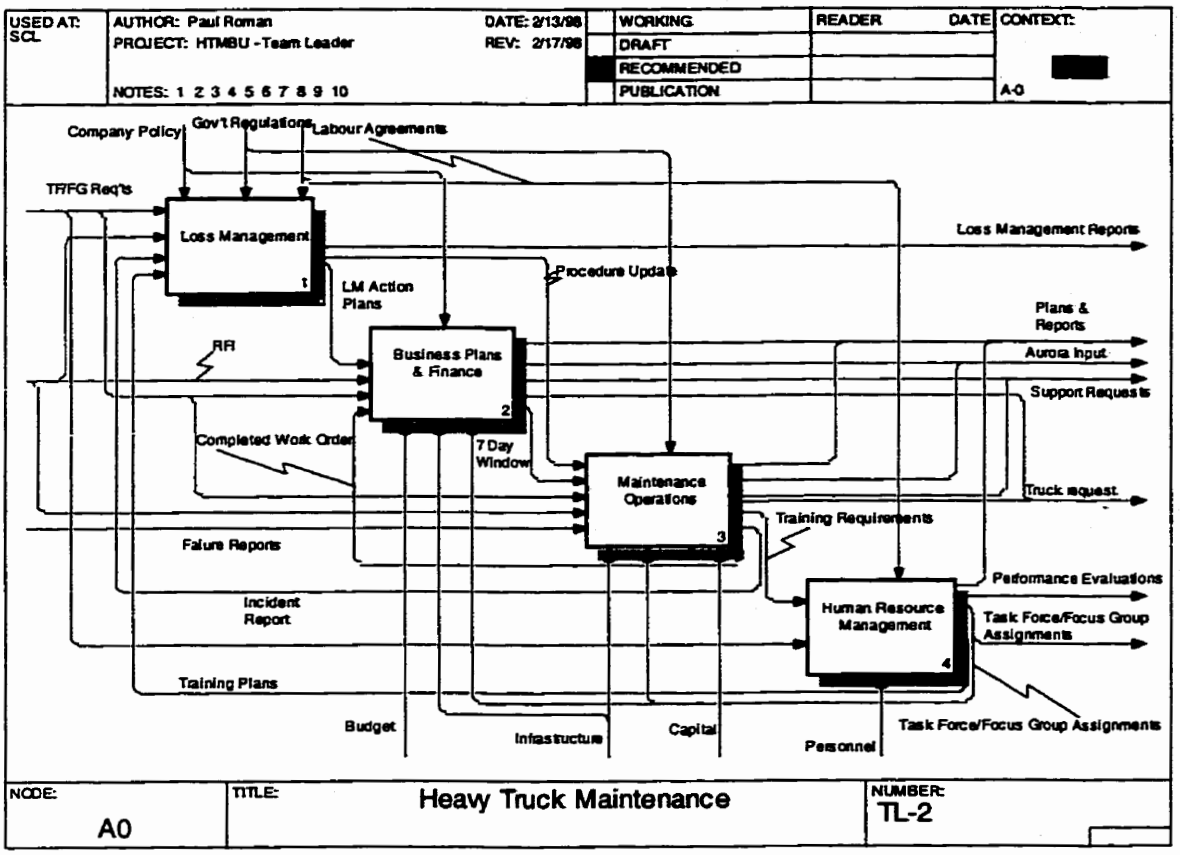
Link Name: Support Requests
Link Definition: Represents all requests for support outside of the business unit. Support may come from other Syncrude assets or from external organisations. A Contract Work Authorisation request for example. Parts requests from the warehouse coming from Plans or maintenance are other examples

Link Name: Failure Reports
Link Definition: Represents unscheduled maintenance requests from the field. These are generally made to the on shift field technician teams who are dispatched to the equipment location to either repair or arrange for pick-up of the failed truck.

Link Name: Truck request
Link Definition: Represents requests to operations for opportune or scheduled maintenance. Also pre-planning for major downtime requirements. Frame updates, engine changes etc.

Link Name: RFI

Link Name: TF/FG Req'ts




## REPORT FOR DIAGRAM: A0, HEAVY TRUCK MAINTENANCE

Activity Name: Loss Management

Activity Name: Business Plans & Finance

Activity Name: Maintenance Operations

Activity Name: Human Resource Management

Link Name: Company Policy
Link Definition: Company policy includes all required processes that the Truck Business Unit is required to adhere to.

Link Name: Gov't Regulations
Link Definition: Includes all legislated requirements to which Syncrude must comply.

Link Name: Labour Agreements
Link Definition: This includes the collective agreement with Syncrude Labour

Link Name: Loss Management Reports

Link Name: Budget
Link Definition: Represents financial constraints on the business unit

Link Name: Personnel
Link Definition: Represents the limited human resources available to the business unit

Link Name: Capital
Link Definition: Represents the limited amount of capital resources available to the business unit.

Link Name: Infrastructure
Link Definition: Represents all non-capital assets available to the business unit.

Link Name: Plans & Reports
Link Definition: Represents all plans and reports, both formal and informal that are communicated in some way externally to the business unit. Includes annual Business plan.

Link Name: Aurora Input
Link Definition: Represents all information provided to the Aurora project team

Link Name: Support Requests
Link Definition: Represents all requests for support outside of the business unit. Support may come from other Syncrude assets or from external organisations. A Contract Work Authorisation request for example. Parts requests from the warehouse coming from Plans or maintenance are other examples

Link Name: Training Plans
Link Definition: Represents training plans created in response to procedure changes from loss management revisions

Link Name: Training Requirements
Link Definition: Resulting from procedure changes or identified individual training requirements

Link Name: Procedure Update
Link Definition: Procedural changes to be implemented as a result of loss management identified problems. Part of continuous improvement

Link Name: Failure Reports
Link Definition: Represents unscheduled maintenance requests from the field. These are generally made to the on shift field technician teams who are dispatched to the equipment location to either repair or arrange for pick-up of the failed truck.

Link Name: Task Force/Focus Group Assignments

Link Definition: Much of the BUs effort is dedicated to continuous improvement. These improvements are accomplished through focus groups and task forces. These groups can be internal to the BU or the BU may have representation on a group that crosses BUs

Link Name: Completed Work Order
Link Definition: Represents completed scheduled or unscheduled maintenance.

Link Name: Performance Evaluations
Link Definition: These are submitted as part of the Syncrude evaluation procedures

Link Name: 7-Day Window
Link Definition: This is the summary of a week's worth of scheduled maintenance activity. It is printed and posted prominently on the shop floor.

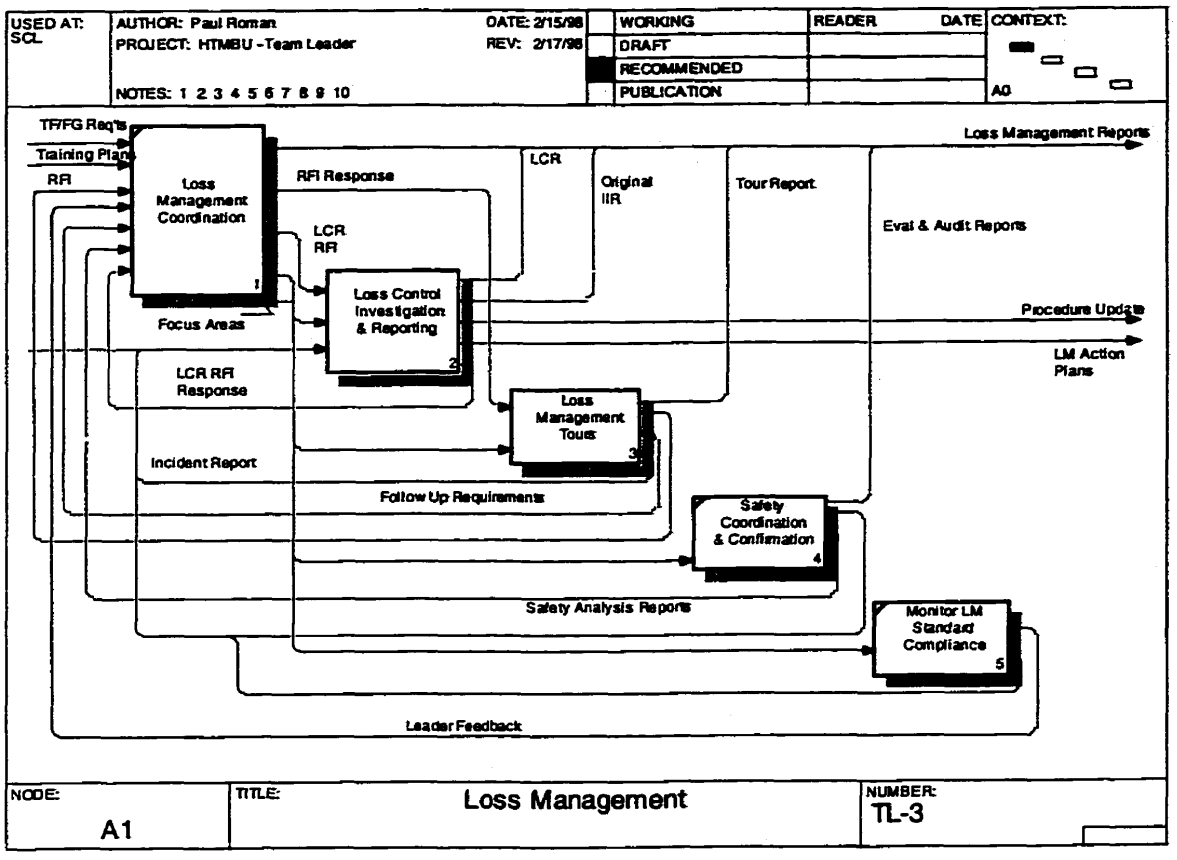
Link Name: Truck request
Link Definition: Represents requests to operations for opportune or scheduled maintenance. Also pre-planning for major downtime requirements. Frame updates, engine changes etc.

Link Name: LM Action Plans
Link Definition: LCR or investigation actions that require Business Planning and implementation.

Link Name: RFI

Link Name: TF/FG Req'ts

Link Name: Incident Report




## REPORT FOR DIAGRAM: A1, LOSS MANAGEMENT

Activity Name: Loss Management Coordination

Activity Name: Loss Control Investigation & Reporting

Activity Name: Loss Management Tours
Activity Definition: Includes all inspections and observations required that are not a formal part of the existing safety program. For example, Management/leader tours conducted to confirm that the safety program is being implemented.

Activity Name: Safety Coordination & Confirmation
Activity Definition: The safety function in LM is to monitor the existing safety program to ensure it is being implemented and to identify shortfalls and suggest improvements to the program. For example, safety audits.

Activity Name: Monitor LM Standard Compliance
Activity Definition: Daily leader activities aimed at ensuring the LM program is being implemented.

Link Name: Loss Management Reports

Link Name: Training Plans
Link Definition: Represents training plans created in response to procedure changes from loss management revisions

Link Name: Procedure Update
Link Definition: Procedural changes to be implemented as a result of loss management identified problems. Part of continuous improvement

Link Name: LCR
Link Definition: The LCR is a dynamic document that goes through two stages of completion

Link Name: LM Action Plans
Link Definition: LCR or investigation actions that require Business Planning and implementation.

Link Name: RFI

Link Name: TF/FG Req'ts

Link Name: Safety Analysis Reports
Link Definition: Represents concerns raised through safety audits, inspections etc that need to be addressed by loss management. For example, recognising housekeeping as an area needed for overall improvement across the BU or Division.

Link Name: Focus Areas
Link Definition: As a result of previous inspections, LM coordination may indicate areas to emphasise during safety audits. Also includes coaching on intent, level of thoroughness and quality expected.

Link Name: Tour Report
Link Definition: Summary of what was observed during the tour. For example a leader or managers observations.

Link Name: Follow Up Requirements
Link Definition: As a result of the management tour, some immediate follow-up may be directed through LM coordination.

Link Name: Evaluation & Audit Reports

Link Name: Leader Feedback

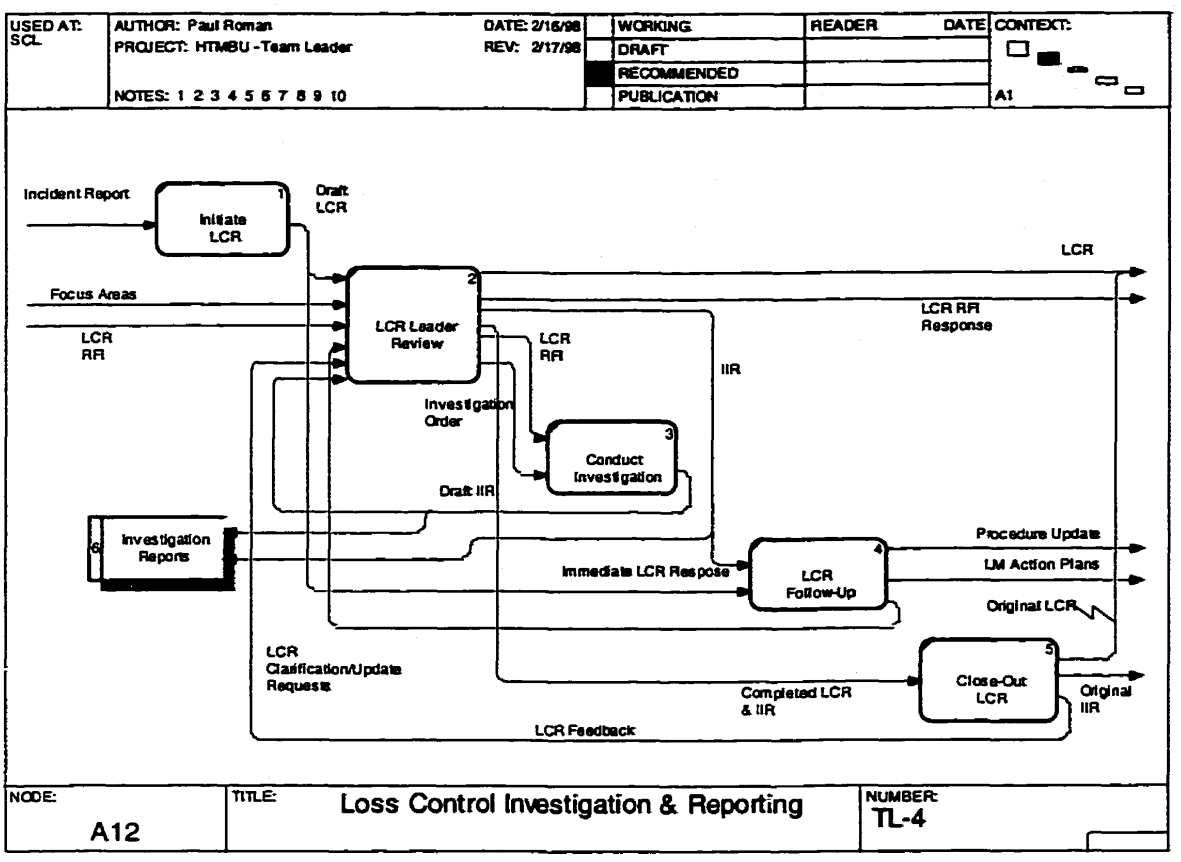
Link Name: RFI Response

Link Name: Incident Report

Link Name: Original IIR

Link Name: LCR RFI

Link Name: LCR RFI Response




## REPORT FOR DIAGRAM: A12, LOSS CONTROL INVESTIGATION & REPORTING

Activity Name: Initiate LCR
Activity Definition: Initial formal reporting of an incident.

Activity Name: LCR Leader Review
Activity Definition: All review activity taken by BU leaders.

Activity Name: Conduct Investigation
Activity Definition: All actions taken to determine the root cause of an incident and required actions necessary to prevent re-occurrence.

Activity Name: LCR Follow-Up
Activity Definition: All actions taken to ensure that the incident does not re-occur including a review of the incident with all BU members.

Activity Name: Close-out LCR

Link Name: Procedure Update

Link Definition: Procedural changes to be implemented as a result of loss management identified problems. Part of continuous improvement

Link Name: LCR
Link Definition: The LCR is a dynamic document that goes through two stages of completion

Link Name: LM Action Plans
Link Definition: LCR or investigation actions that require Business Planning and implementation.

Link Name: Focus Areas
Link Definition: As a result of previous inspections, LM coordination may indicate areas to emphasise during safety audits. Also includes coaching on intent, level of thoroughness and quality expected.

Link Name: IIR
Link Definition: Incident Investigation Report required to close off serious or major LCRs.

Link Name: Incident Report

Link Name: Investigation Order

Link Name: LCR Clarification/Update Requests
Link Definition: Represents any request for information on the status of an LCR. Initiated by managers, people assigned to carry out actions.

Link Name: Draft IIR
Link Definition: Draft Incident Investigation Report

Link Name: Draft LCR

Link Name: Immediate LCR Response

Link Name: Completed LCR & IIR

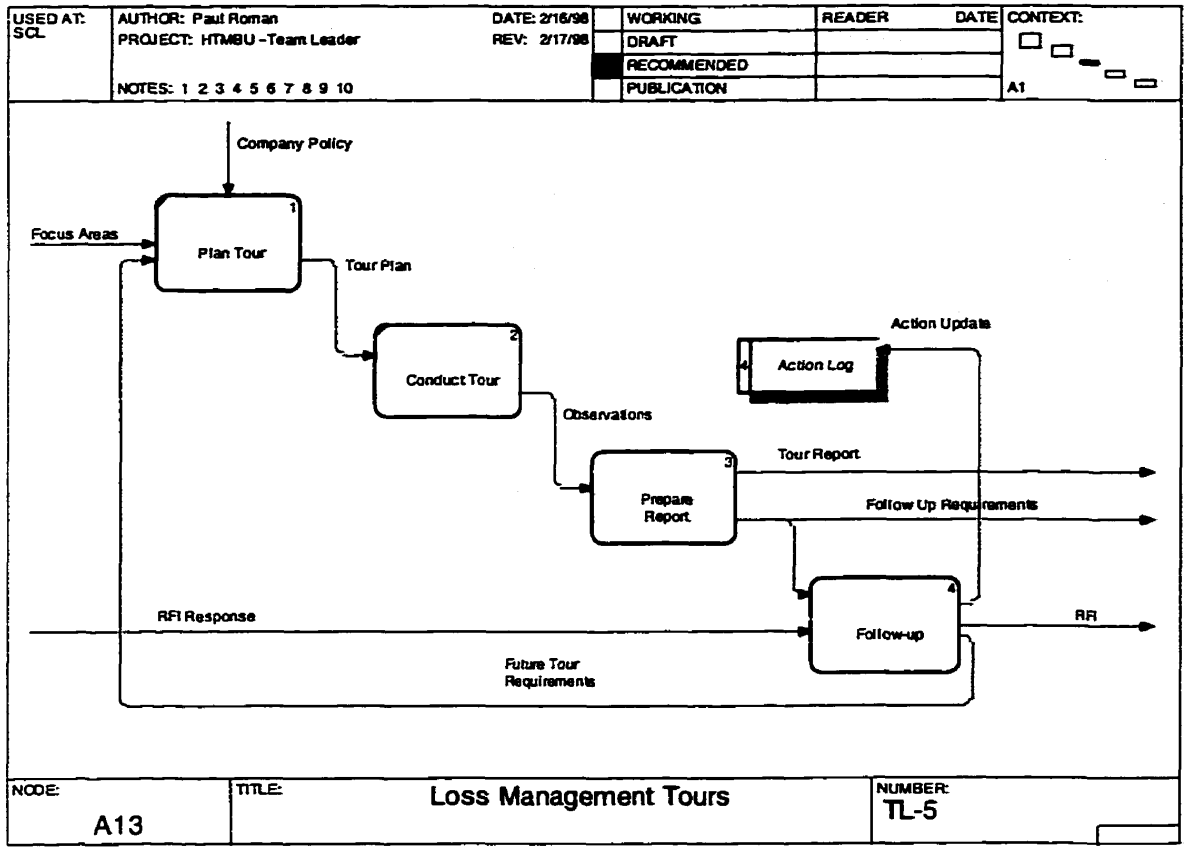
Link Name: Original IIR

Link Name: Original LCR

Link Name: LCR Feedback
Link Definition: Represents positive feedback on close out of an LCR. May also be direction for further action required before close out.

Link Name: LCR RFI

Link Name: LCR RFI Response




## REPORT FOR DIAGRAM: A13, LOSS MANAGEMENT TOURS

Activity Name: Plan Tour

Activity Name: Conduct Tour

Activity Name: Prepare Report

Activity Name: Follow-up

Link Name: Company Policy
Link Definition: Company policy includes all required processes that the Truck Business Unit is required to adhere to.

Link Name: RFI

Link Name: Focus Areas
Link Definition: As a result of previous inspections, LM coordination may indicate areas to emphasise during safety audits. Also includes coaching on intent, level of thoroughness and quality expected.

Link Name: Tour Report
Link Definition: Summary of what was observed during the tour. For example a leader or managers observations.

Link Name: Follow Up Requirements
Link Definition: As a result of the management tour, some immediate follow-up may be directed through LM coordination.

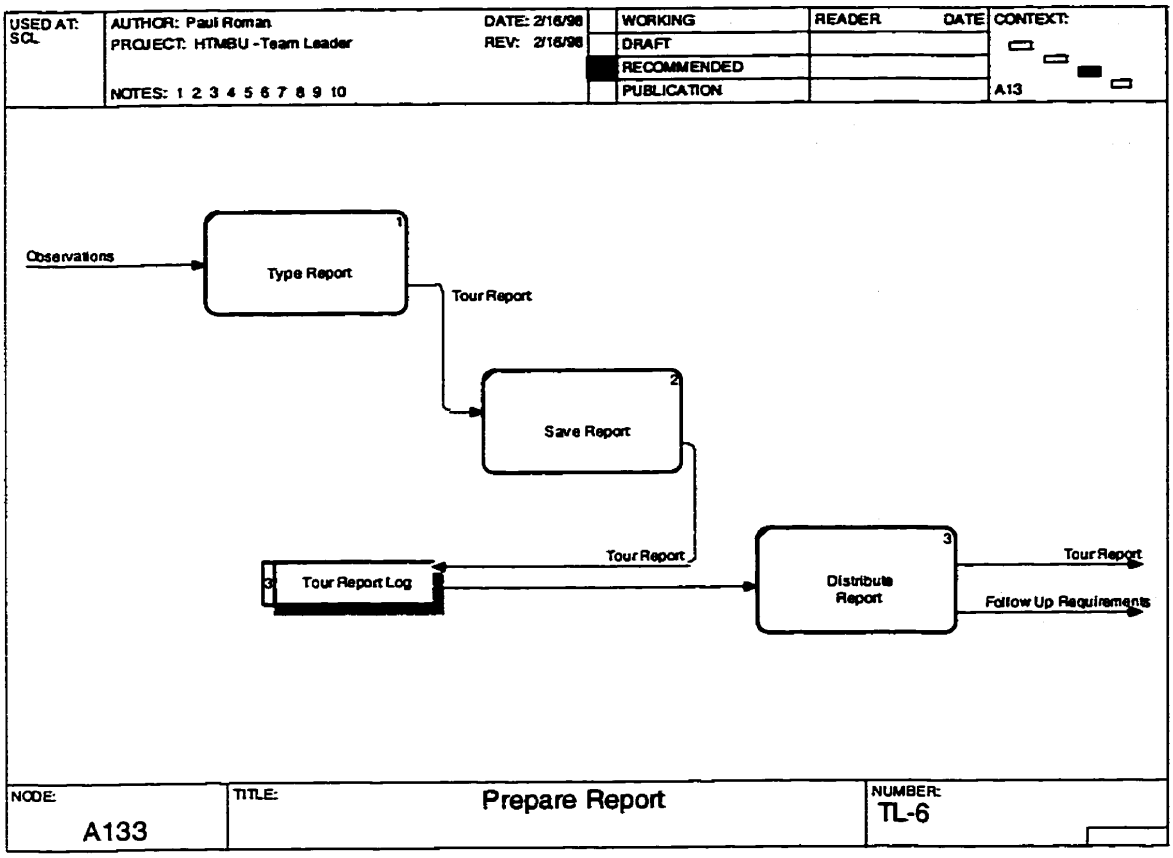
Link Name: Tour Plan

Link Name: Observations

Link Name: Future Tour Requirements
Link Definition: Required when tour results are unsatisfactory and manager or leader wants to conduct the same tour in the near future or implement a special focus for a subsequent tour

Link Name: RFI Response

Link Name: Action Update




## REPORT FOR DIAGRAM: A133, PREPARE REPORT

Activity Name: Type Report

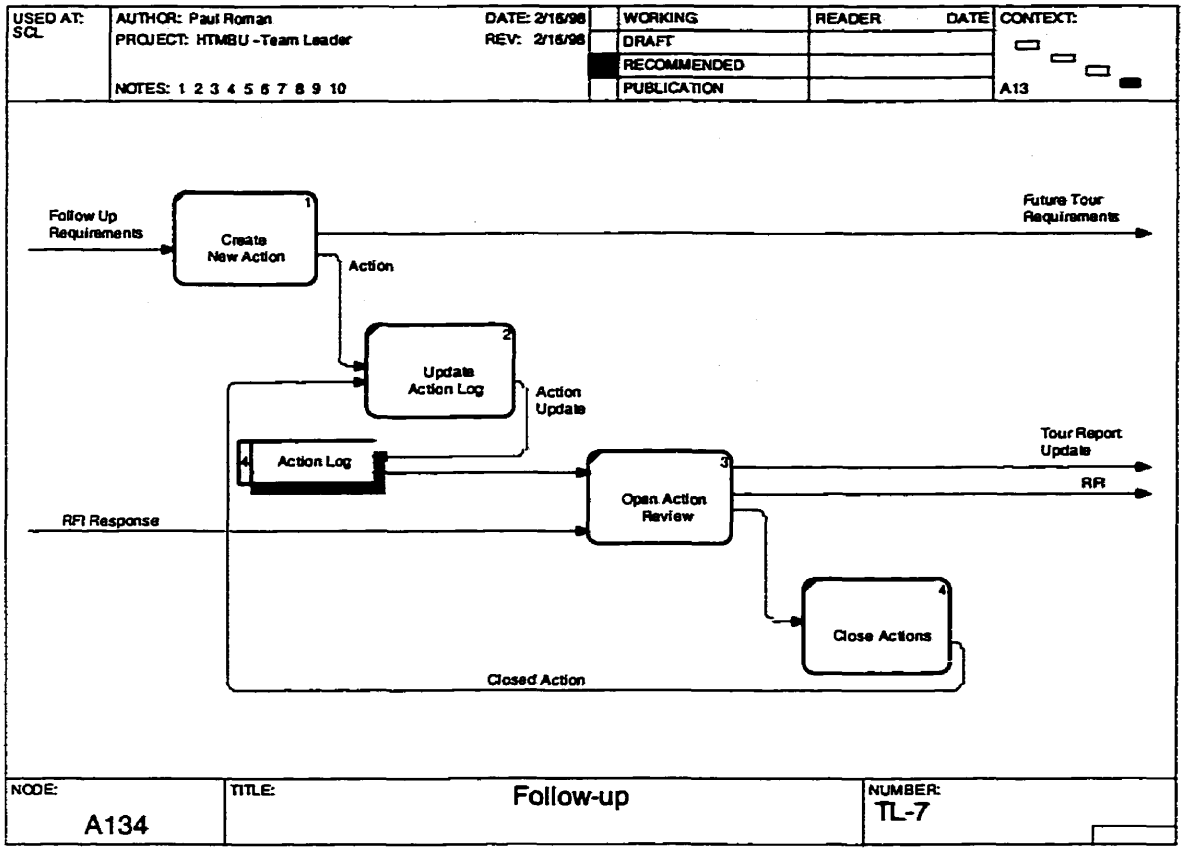
Activity Name: Save Report

Activity Name: Distribute Report
Activity Definition: Report is sent via email to all concerned, detailing the specific actions required. Note that action does not imply corrective action. Could also include positive reinforcement for procedures being followed well.

Link Name: Tour Report
Link Definition: Summary of what was observed during the tour. For example a leader or managers observations.

Link Name: Follow Up Requirements
Link Definition: As a result of the management tour, some immediate follow-up may be directed through LM coordination.

Link Name: Observations




## REPORT FOR DIAGRAM: A134, FOLLOW-UP

Activity Name: Create New Action

Activity Name: Update Action Log

Activity Name: Open Action Review

Activity Name: Close Actions

Link Name: RFI

Link Name: Follow Up Requirements
Link Definition: As a result of the management tour, some immediate follow-up may be directed through LM coordination.

Link Name: Action

Link Name: Future Tour Requirements

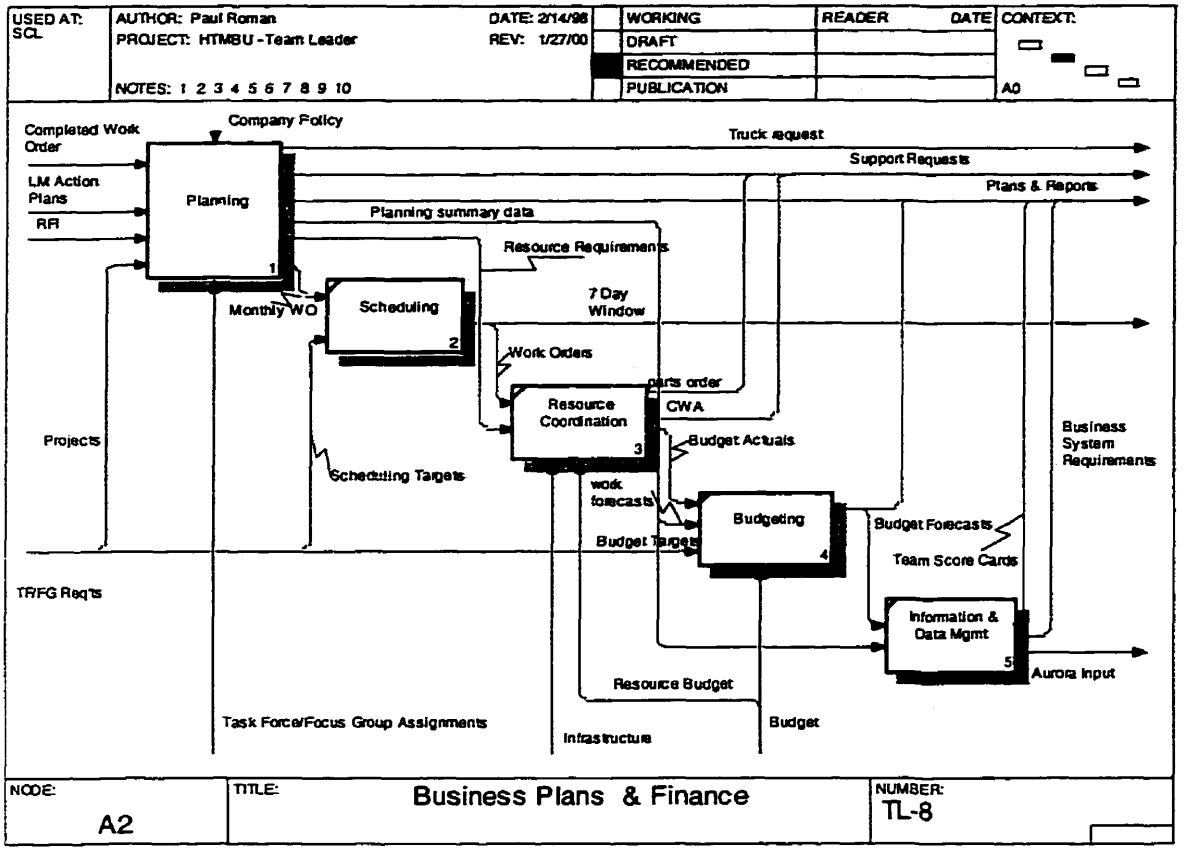
Link Definition: Required when tour results are unsatisfactory and manager or leader wants to conduct the same tour in the near future or implement a special focus for a subsequent tour

Link Name: RFI Response

Link Name: Action Update

Link Name: Closed Action

Link Name: Tour Report Update




## REPORT FOR DIAGRAM: A2, BUSINESS PLANS & FINANCE

Activity Name: Planning

Activity Name: Scheduling

Activity Name: Resource Coordination
Activity Definition: This activity includes all efforts to coordinate non-personnel resources. This includes: the component replacement program, Set-up of new equipment procedures, parts ordering, monitoring condition and location of major spare parts, updating IMMPOWER, initiation and management of warranty claims, Initiation and monitor of CWAs, new contract requests, vendor interfacing

Activity Name: Budgeting

Activity Name: Information & Data Mgmt
Activity Definition: Includes several processes to facilitate interface requirements with other BUs and external entities. Also includes efforts to improve IS infrastructure

Link Name: Company Policy

Link Definition: Company policy includes all required processes that the Truck Business Unit is required to adhere to.

Link Name: Budget
Link Definition: Represents financial constraints on the business unit

Link Name: Infrastructure
Link Definition: Represents all non-capital assets available to the business unit.

Link Name: Plans & Reports
Link Definition: Represents all plans and reports, both formal and informal that are communicated in some way externally to the business unit. Includes annual Business plan.

Link Name: Aurora Input
Link Definition: Represents all information provided to the Aurora project team

Link Name: Support Requests
Link Definition: Represents all requests for support outside of the business unit. Support may come from other Syncrude assets or from external organisations. A Contract Work Authorisation request for example. Parts requests from the warehouse coming from Plans or maintenance are other examples

Link Name: Work Orders
Link Definition: Scheduled maintenance work orders note for critical tasks, work order includes procedure checklist.

Link Name: Task Force/Focus Group Assignments
Link Definition: Much of the BUs effort is dedicated to continuous improvement. These improvements are accomplished through focus groups and task forces. These groups can be internal to the BU or the BU may have representation on a group that crosses BUs

Link Name: Completed Work Order
Link Definition: Represents completed scheduled or unscheduled maintenance.

Link Name: Monthly WO
Link Definition: Includes all scheduled maintenance Work orders to be completed for the month

Link Name: Resource Budget

Link Name: parts order
Link Definition: Orders are placed to the warehouse for in stock items, through Finning for items not in warehouse

Link Name: CWA

Link Definition: Contract work authorisation submitted to contracts for work that can not be effectively completed by the Business Unit

Link Name: Budget Forecasts
Link Definition: There are several different forecasts. Monthly, quarterly and year end.

Link Name: Projects
Link Definition: All new projects are evaluated by planning. These could be proposals from team leaders or Syncrude initiatives outside of the BU

Link Name: Scheduling Targets
Link Definition: These targets can relate to projects or any other type of deadline driven activity.

Link Name: Budget Targets
Link Definition: These targets could represent Syncrude driven cost reduction initiatives or internal BU efforts to reduce costs as part of a project

Link Name: Team Score Cards
Link Definition: Represents current status of the monthly score card for each team.

Link Name: Business System Requirements
Link Definition: Any identified shortcomings or opportunities resulting from the continual review of existing business systems are identified as requirements. These may result in projects to assess or improve existing systems or implement new systems.

Link Name: Resource Requirements
Link Definition: Includes work to be contracted out and major part requirements

Link Name: 7-Day Window
Link Definition: This is the summary of a week's worth of scheduled maintenance activity. It is printed and posted prominently on the shop floor.

Link Name: Budget Actuals

Link Name: Planning summary data
Link Definition: represents informal access to planning data and information necessary to coordinate compliance with action plans and to respond to Aurora planning requests

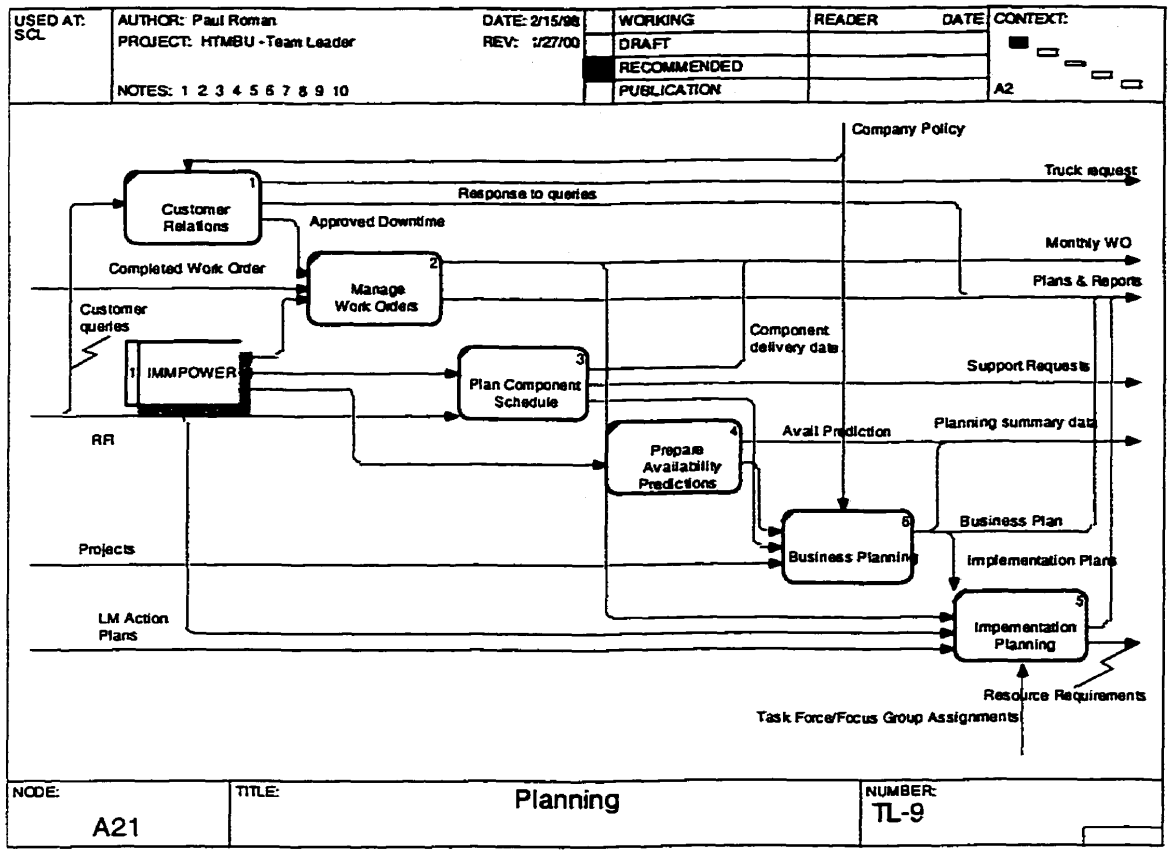
Link Name: Truck request
Link Definition: Represents requests to operations for opportune or scheduled maintenance. Also pre-planning for major downtime requirements. Frame updates, engine changes etc.

Link Name: work forecasts
Link Definition: Represents future work anticipated to be completed in the coming FY. Required for budget forecasting.

Link Name: LM Action Plans
Link Definition: LCR or investigation actions that require Business Planning and implementation.

Link Name: RFI

Link Name: TF/FG Req'ts




## REPORT FOR DIAGRAM: A21, PLANNING

Activity Name: Customer Relations
Activity Definition: All dealings with operations aimed at negotiating for maintenance time on the trucks. This may be opportunity maintenance. Also includes answers to queries to operations

Activity Name: Manage Work Orders

Activity Name: Plan Component Schedule

Activity Name: Prepare Availability Predictions

Activity Name: Business Planning

Activity Name: Implementation Planning

Link Name: Company Policy
Link Definition: Company policy includes all required processes that the Truck Business Unit is required to adhere to.

Link Name: Plans & Reports
Link Definition: Represents all plans and reports, both formal and informal that are communicated in some way externally to the business unit. Includes annual Business plan.

Link Name: Support Requests
Link Definition: Represents all requests for support outside of the business unit. Support may come from other Syncrude assets or from external organisations. A Contract Work Authorisation request for example. Parts requests from the warehouse coming from Plans or maintenance are other examples

Link Name: Task Force/Focus Group Assignments
Link Definition: Much of the BUs effort is dedicated to continuous improvement. These improvements are accomplished through focus groups and task forces. These groups can be internal to the BU or the BU may have representation on a group that crosses BUs

Link Name: Completed Work Order
Link Definition: Represents completed scheduled or unscheduled maintenance.

Link Name: Monthly WO
Link Definition: Includes all scheduled maintenance Work orders to be completed for the month

Link Name: Projects
Link Definition: All new projects are evaluated by planning. These could be proposals from team leaders or Syncrude initiatives outside of the BU

Link Name: Resource Requirements
Link Definition: Includes work to be contracted out and major part requirements

Link Name: Planning summary data
Link Definition: represents informal access to planning data and information necessary to coordinate compliance with action plans and to respond to Aurora planning requests

Link Name: Approved Downtime

Link Name: Component delivery date

Link Name: Customer queries
Link Definition: Generally request for updates on completion times for maintenance

Link Name: Response to queries

Link Name: Truck request
Link Definition: Represents requests to operations for opportune or scheduled maintenance. Also pre-planning for major downtime requirements. Frame updates, engine changes etc.

Link Name: Business Plan

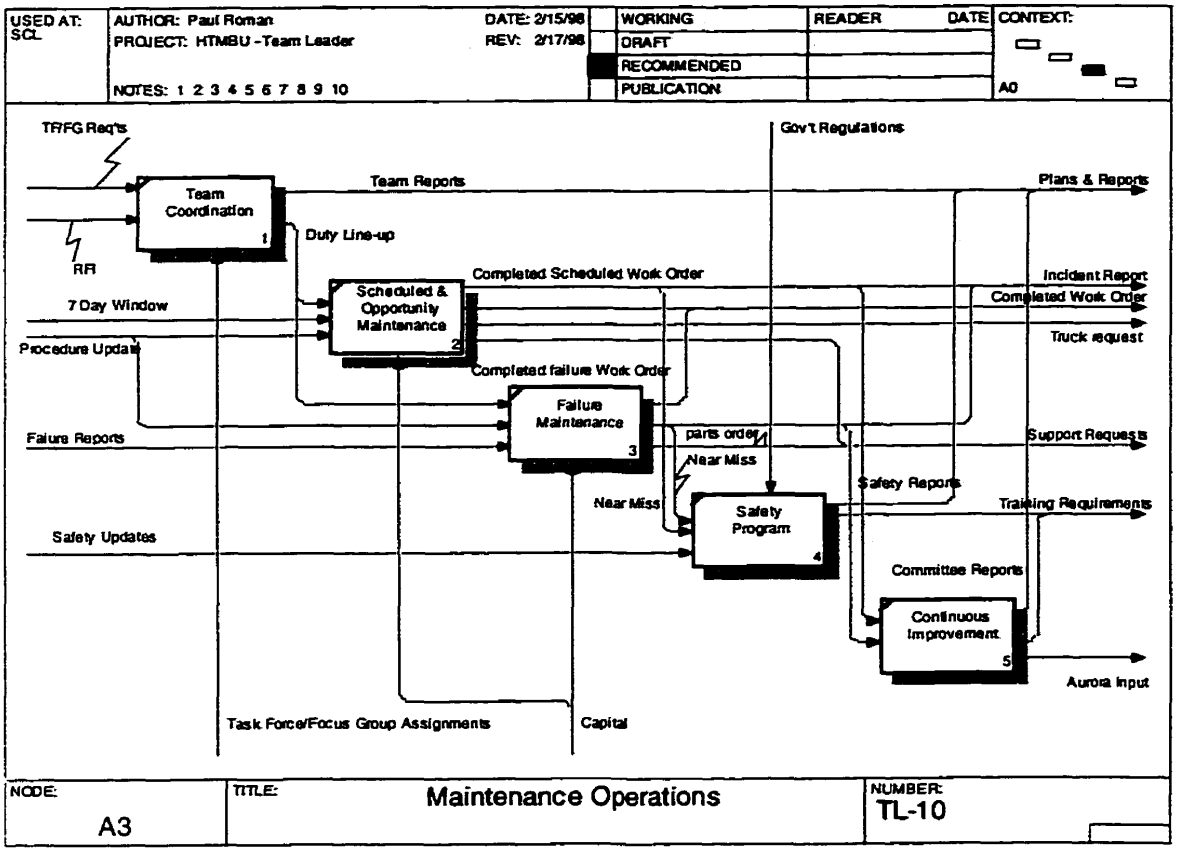
Link Name: LM Action Plans
Link Definition: LCR or investigation actions that require Business Planning and implementation.

Link Name: Implementation Plans

Link Name: RFI

Link Name: Avail Prediction

Data store Name: IMMPOWER
Data store Definition: Database System for resource coordination. Maintenance Work Order Database




## REPORT FOR DIAGRAM: A3, MAINTENANCE OPERATIONS

Activity Name: Team Coordination
Activity Definition: This activity includes all work necessary to assign team personnel to specific tasks, the coordination of necessary overtime and contractor work, as well as participation on various committees external to maintenance operations such ad planning review meetings. This is done on a day to day basis but reviewed and updated at monthly group meetings.

Activity Name: Scheduled & Opportunity Maintenance
Activity Definition: Scheduled maintenance consists of all pre-planned maintenance actions conducted on the heavy trucks. This includes all maintenance conducted that is not a direct result of equipment failure.

Activity Name: Failure Maintenance
Activity Definition: Failure maintenance is any maintenance action that is required due to equipment breakdown. By its very nature, this work is not scheduled and must be either worked in to the currently scheduled maintenance based on the 7-day window, or contracted out.

Activity Name: Safety Program
Activity Definition: The Truck Maintenance BU has a comprehensive safety program as part of the Syncrude safety program. Activities include: Safety talks, spot observations, inspections, emergency simulations, pre-use checks and risk assessment

Activity Name: Continuous Improvement
Activity Definition: Most of the non-maintenance work is dedicated to continuous improvement. Activities include: Theme of the month briefings, task force or committee meetings, task analysis of existing procedures and practices and team training.

Link Name: Gov't Regulations
Link Definition: Includes all legislated requirements to which Syncrude must comply.

Link Name: Capital
Link Definition: Represents the limited amount of capital resources available to the business unit.

Link Name: Plans & Reports
Link Definition: Represents all plans and reports, both formal and informal that are communicated in some way externally to the business unit. Includes annual Business plan.

Link Name: Aurora Input
Link Definition: Represents all information provided to the Aurora project team

Link Name: Support Requests
Link Definition: Represents all requests for support outside of the business unit. Support may come from other Syncrude assets or from external organisations. A Contract Work Authorisation request, for example. Parts requests from the warehouse coming from Plans or maintenance are other examples

Link Name: Training Requirements
Link Definition: Resulting from procedure changes or identified individual training requirements

Link Name: Procedure Update
Link Definition: Procedural changes to be implemented as a result of loss management identified problems. Part of continuous improvement

Link Name: Failure Reports
Link Definition: Represents unscheduled maintenance requests from the field. These are generally made to the on shift field technician teams who are dispatched to the equipment location to either repair or arrange for pick-up of the failed truck.

Link Name: Task Force/Focus Group Assignments

Link Definition: Much of the BUs effort is dedicated to continuous improvement. These improvements are accomplished through focus groups and task forces. These groups can be internal to the BU or the BU may have representation on a group that crosses BUs

Link Name: Completed Work Order
Link Definition: Represents completed scheduled or unscheduled maintenance.

Link Name: parts order
Link Definition: Orders are placed to the warehouse for in stock items, through Finning for items not in warehouse

Link Name: 7-Day Window
Link Definition: This is the summary of a week's worth of scheduled maintenance activity. It is printed and posted prominently on the shop floor.

Link Name: Duty Line-up
Link Definition: Represents the assignment of work teams to work orders

Link Name: Completed failure Work Order
Link Definition: For failure or non-scheduled maintenance

Link Name: Completed Scheduled Work Order
Link Definition: For scheduled maintenance

Link Name: Committee Reports
Link Definition: Some committee or task force efforts are conducted within the maintenance teams. This arrow represents their reports that could be written or oral.

Link Name: Safety Reports
Link Definition: All reports generated as part of the Safety Program. These include inspection reports, simulation reports, observations, and Risk assessment group reports.

Link Name: Near Miss
Link Definition: A type of incident report that is safety related.

Link Name: Safety Updates
Link Definition: Represents Safe operating committee meeting minutes as well as urgent bulletins

Link Name: Team Reports
Link Definition: These include: Time & Attendance Overtime, Contractor workforce observations, vendor interface observations, etc. It also includes handover activities between shifts.

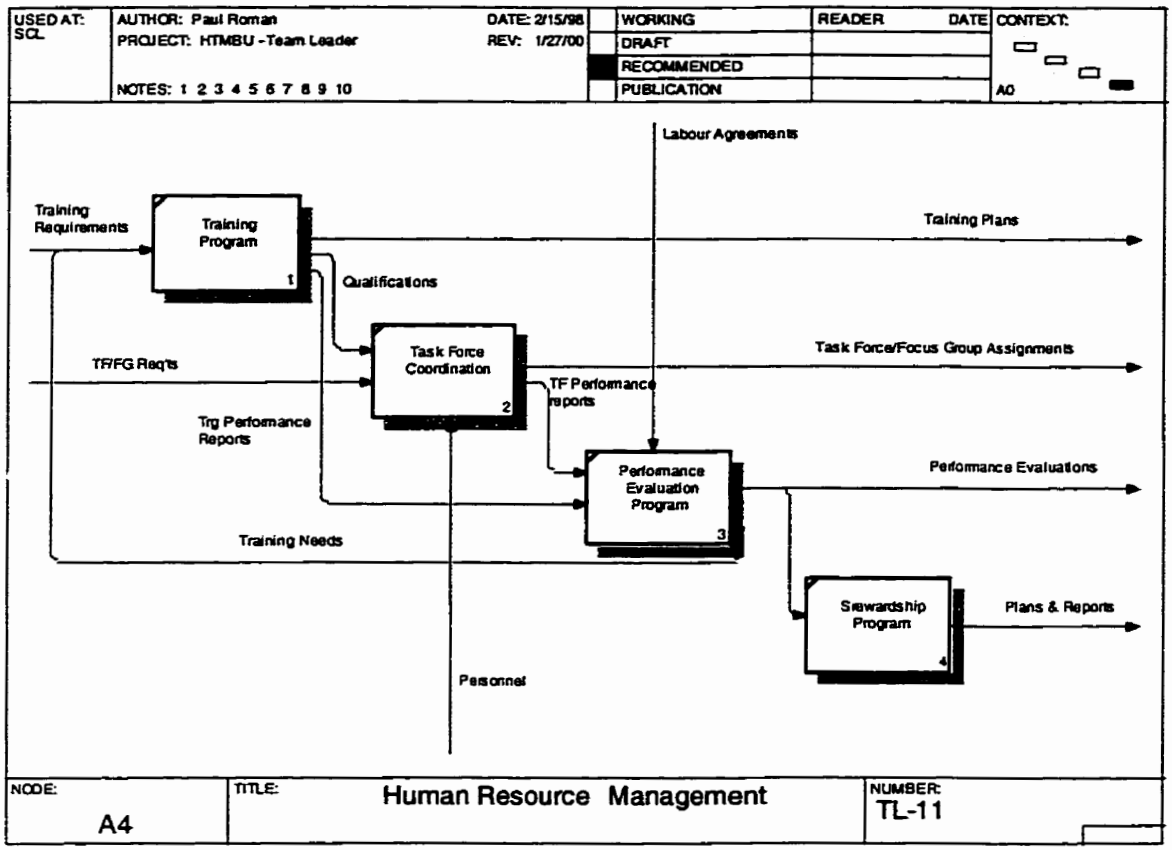
Link Name: Truck request

Link Definition: Represents requests to operations for opportune or scheduled maintenance. Also pre-planning for major downtime requirements. Frame updates, engine changes etc.

Link Name: RFI

Link Name: TF/FG Req'ts

Link Name: Incident Report




## REPORT FOR DIAGRAM: A4, HUMAN RESOURCE MANAGEMENT

Activity Name: Training Program

Activity Name: Task Force Coordination

Activity Name: Performance Evaluation Program

Activity Name: Stewardship Program

Link Name: Labour Agreements
Link Definition: This includes the collective agreement with Syncrude Labour

Link Name: Personnel
Link Definition: Represents the limited human resources available to the business unit

Link Name: Plans & Reports
Link Definition: Represents all plans and reports, both formal and informal that are communicated in some way externally to the business unit. Includes annual Business plan.

Link Name: Training Plans
Link Definition: Represents training plans created in response to procedure changes from loss management revisions

Link Name: Training Requirements
Link Definition: Resulting from procedure changes or identified individual training requirements

Link Name: Task Force/Focus Group Assignments
Link Definition: Much of the BUs effort is dedicated to continuous improvement. These improvements are accomplished through focus groups and task forces. These groups can be internal to the BU or the BU may have representation on a group that crosses BUs

Link Name: Performance Evaluations
Link Definition: These are submitted as part of the Syncrude evaluation procedures

Link Name: Qualifications
Link Definition: Represents training qualifications of personnel

Link Name: TF Performance reports

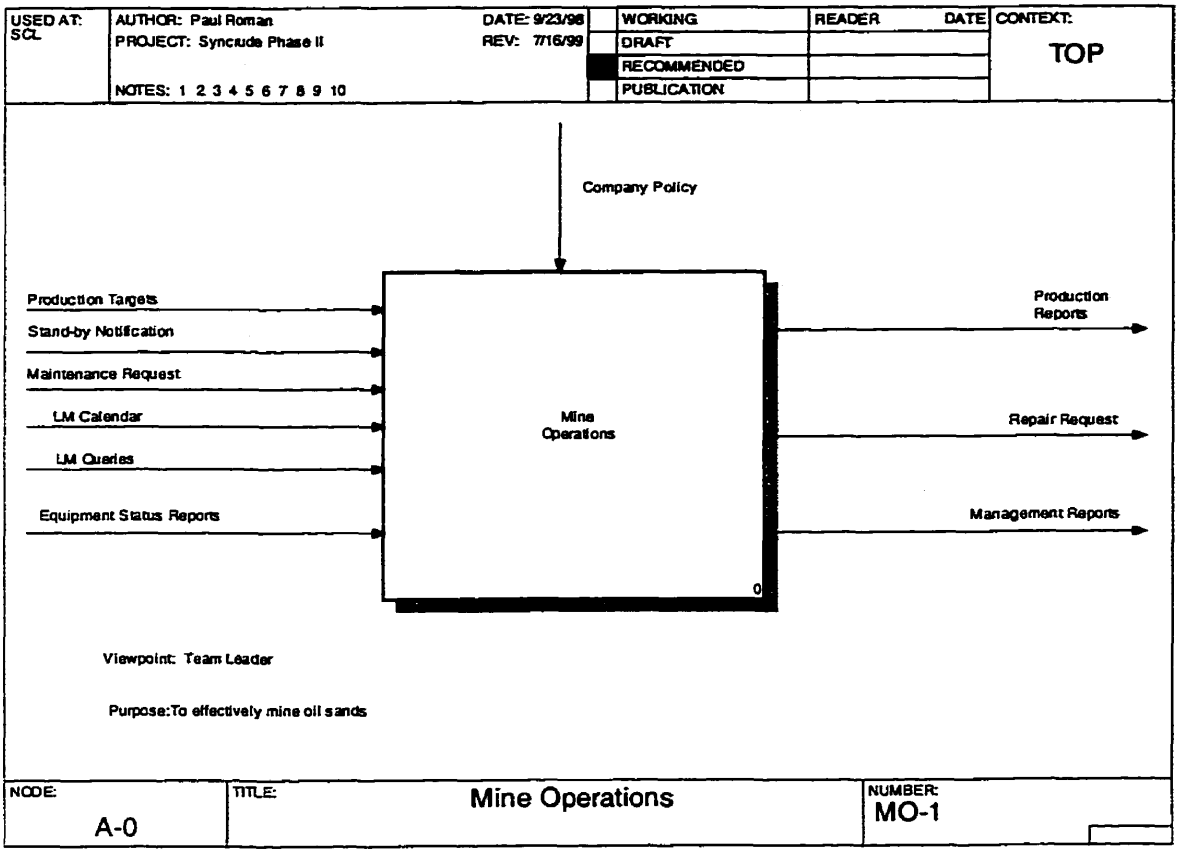
Link Name: Trg Performance Reports

Link Name: Training Needs
Link Definition: identified individual trg needs or individual requests for training

Link Name: TF/FG Req'ts

# APPENDIX C

## MINE OPERATIONS: TEAM LEADER'S VIEWPOINT (MO-1 TO MO-7)




## REPORT FOR DIAGRAM: A-0, MINE OPERATIONS

Activity Name: Mine Operations
Activity Definition: All activities required to move ore from the mine to extraction

Link Name: Production Targets
Link Definition: Production targets come from extraction and upgrading demands. They are provided on an annual basis but are broken down all the way to per day production targets.

Link Name: Production Reports
Link Definition: All reports including daily, weekly, monthly and annually that report tonnages sent to extraction.

Link Name: Repair Request
Link Definition: Radio call from dispatch to field mechanic.

Link Name: Stand-by Notification
Link Definition: Contact person or field mechanic to notify operations that the truck is ready to return to service. This can be achieved with a phone call as well as WENCO update code 99

Link Name: Management Reports

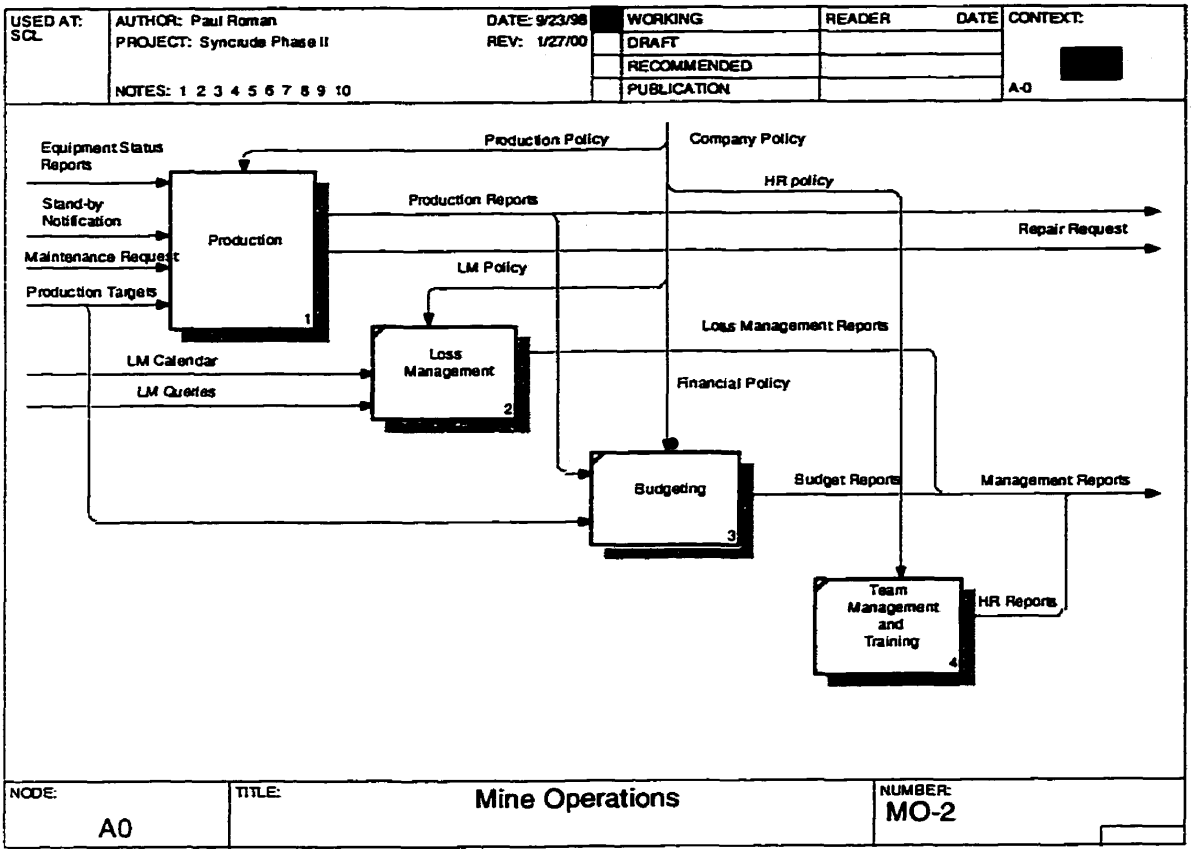
Link Name: Maintenance Request
Link Definition: Includes: 7 day window from HD trucks. 21-day plan from shovels for trucks, telephone call to dispatch for opportune ans. P1-5 services.

Link Name: LM Calendar
Link Definition: Loss Management Calendar LM activities and requirements

Link Name: LM Queries
Link Definition: Loss Management queries, usually from management requesting status etc.

Link Name: Company Policy

Link Name: Equipment Status Reports
Link Definition: Reports are provided by both Shovel and Truck maintenance. Reports are generated by IMMPOWER for shovels and maintenance monitor for trucks.




## REPORT FOR DIAGRAM: A0, MINE OPERATIONS

Activity Name: Production
Activity Definition: All activities required to provide ore to extraction

Activity Name: Loss Management

Activity Name: Budgeting

Activity Name: Team Management and Training

Link Name: Production Targets
Link Definition: Production targets come from extraction and upgrading demands. They are provided on an annual basis but are broken down all the way to per day production targets.

Link Name: Production Reports
Link Definition: All reports including daily, weekly, monthly and annually that report tonnages sent to extraction.

Link Name: Repair Request

Link Definition: Radio call from dispatch to field mechanic.

Link Name: Stand-by Notification
Link Definition: Contact person or field mechanic to notify operations that the truck is ready to return to service. This can be achieved with a phone call as well as WENCO update code 99

Link Name: Management Reports

Link Name: Maintenance Request
Link Definition: Includes: 7 day window from HD trucks. 21-day plan from shovels for trucks, telephone call to dispatch for opportune ans. P1-5 services.

Link Name: Loss Management Reports

Link Name: Budget Reports

Link Name: HR Reports

Link Name: LM Calendar
Link Definition: Loss Management Calendar LM activities and requirements

Link Name: LM Queries
Link Definition: Loss Management queries, usually from management requesting status etc.

Link Name: Company Policy

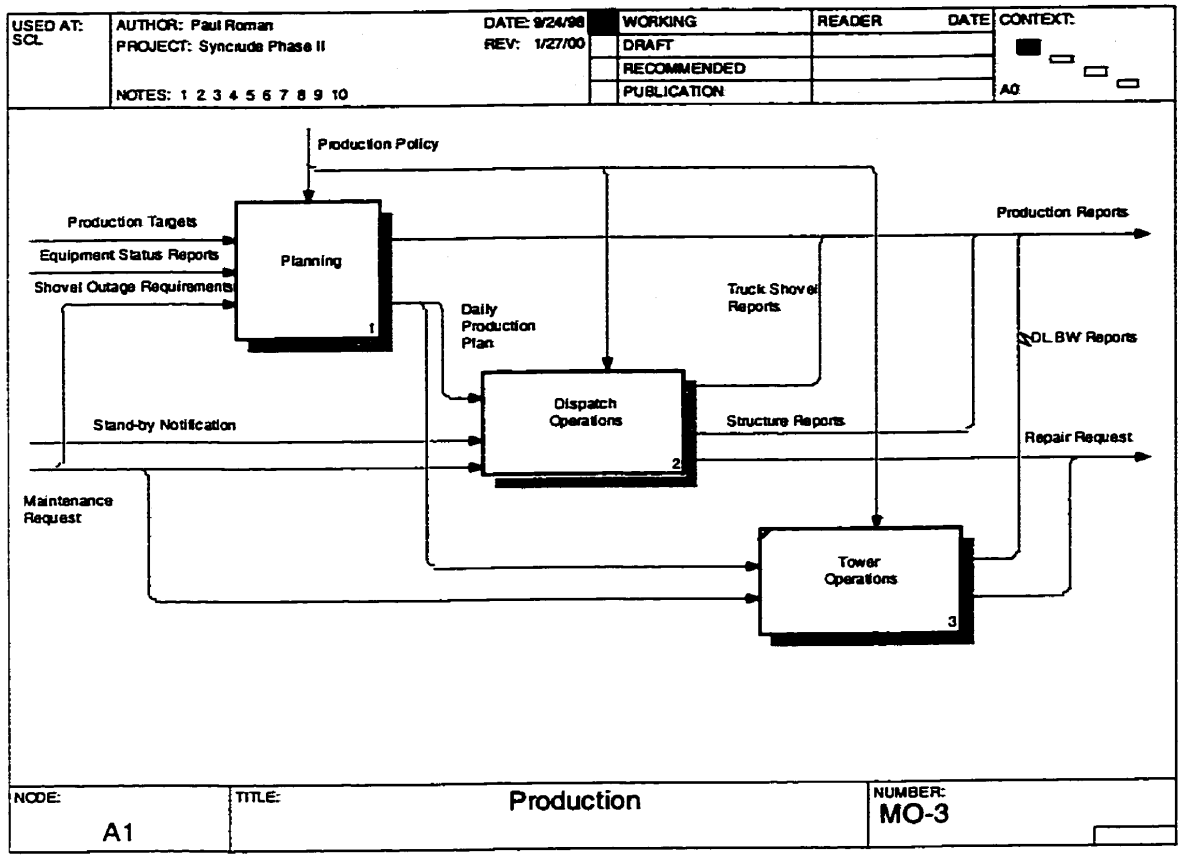
Link Name: HR policy

Link Name: Financial Policy

Link Name: LM Policy

Link Name: Production Policy

Link Name: Equipment Status Reports
Link Definition: Reports are provided by both Shovel and Truck maintenance. Reports are generated by IMMPOWER for shovels and maintenance monitor for trucks.




## REPORT FOR DIAGRAM: A1, PRODUCTION

Activity Name: Planning

Activity Name: Dispatch Operations

Activity Name: Tower Operations

Link Name: Production Targets
Link Definition: Production targets come from extraction and upgrading demands. They are provided on an annual basis but are broken down all the way to per day production targets.

Link Name: Production Reports
Link Definition: All reports including daily, weekly, monthly and annually that report tonnages sent to extraction.

Link Name: Repair Request
Link Definition: Radio call from dispatch to field mechanic.

Link Name: Stand-by Notification

Link Definition: Contact person or field mechanic to notify operations that the truck is ready to return to service. This can be achieved with a phone call as well as WENCO update code 99

Link Name: Maintenance Request
Link Definition: Includes: 7 day window from HD trucks. 21-day plan from shovels for trucks, telephone call to dispatch for opportune ans. P1-5 services.

Link Name: Production Policy

Link Name: Truck Shovel Reports

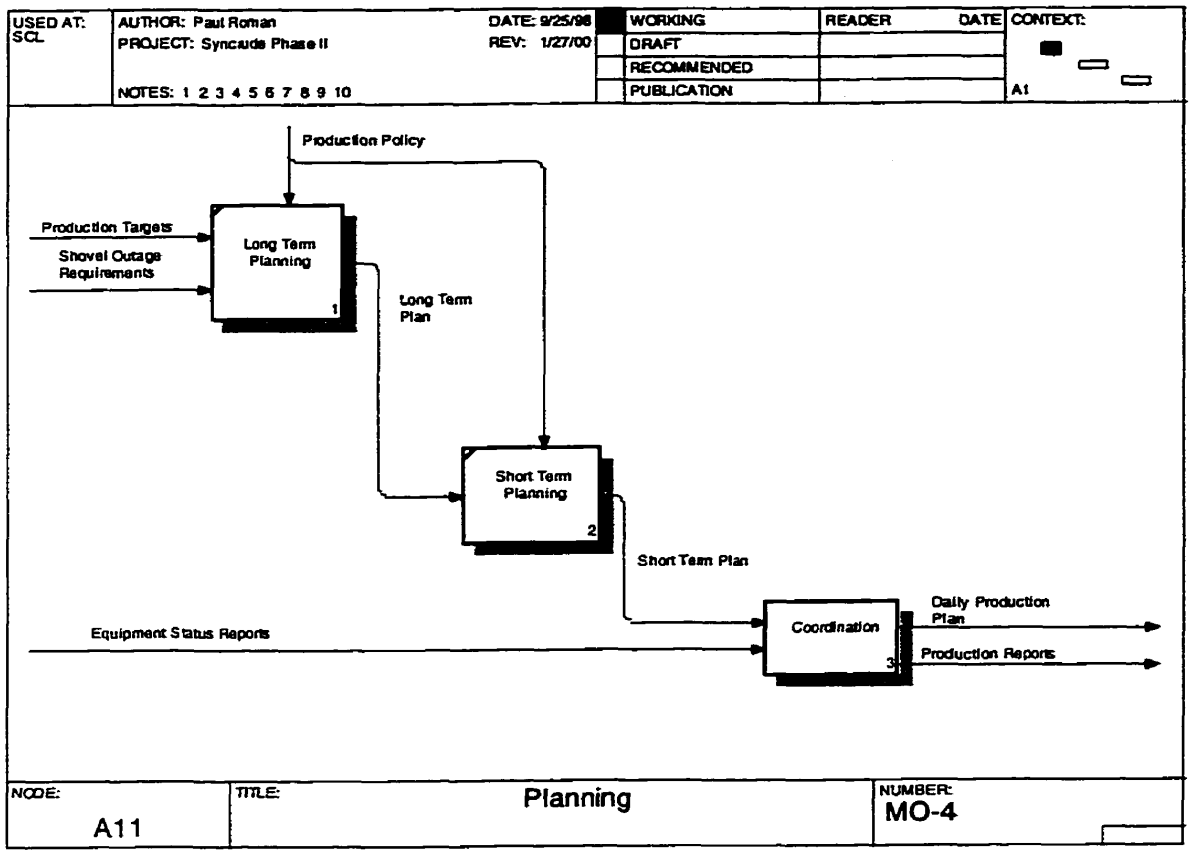
Link Name: DL BW Reports
Link Definition: Dragline and Bucketwheel Reports

Link Name: Daily Production Plan
Link Definition: Several documents are used to convey the daily plan and the shift plan. One key document is the shovel/truck daily plan.

Link Name: Structure Reports

Link Name: Shovel Outage Requirements
Link Definition: Includes: 7 day window from HD trucks. 21-day plan from shovels for trucks, telephone call to dispatch for opportune ans. P1-5 services. Annual shovel outage request from shovel maintenance.

Link Name: Equipment Status Reports
Link Definition: Reports are provided by both Shovel and Truck maintenance. Reports are generated by IMMPOWER for shovels and maintenance monitor for trucks.




## REPORT FOR DIAGRAM: A11, PLANNING

Activity Name: Long Term Planning

Activity Name: Short Term Planning
Activity Definition: This activity takes the 8 week rolling schedule for shovel outages and production targets to firm up the next 2 weeks. This is done primarily during two meetings that are held at 11:00AM Monday and 1:00 PM Tuesday.

Activity Name: Coordination

Link Name: Production Targets
Link Definition: Production targets come from extraction and upgrading demands. They are provided on an annual basis but are broken down all the way to per day production targets.

Link Name: Production Reports
Link Definition: All reports including daily, weekly, monthly and annually that report tonnages sent to extraction.

Link Name: Production Policy

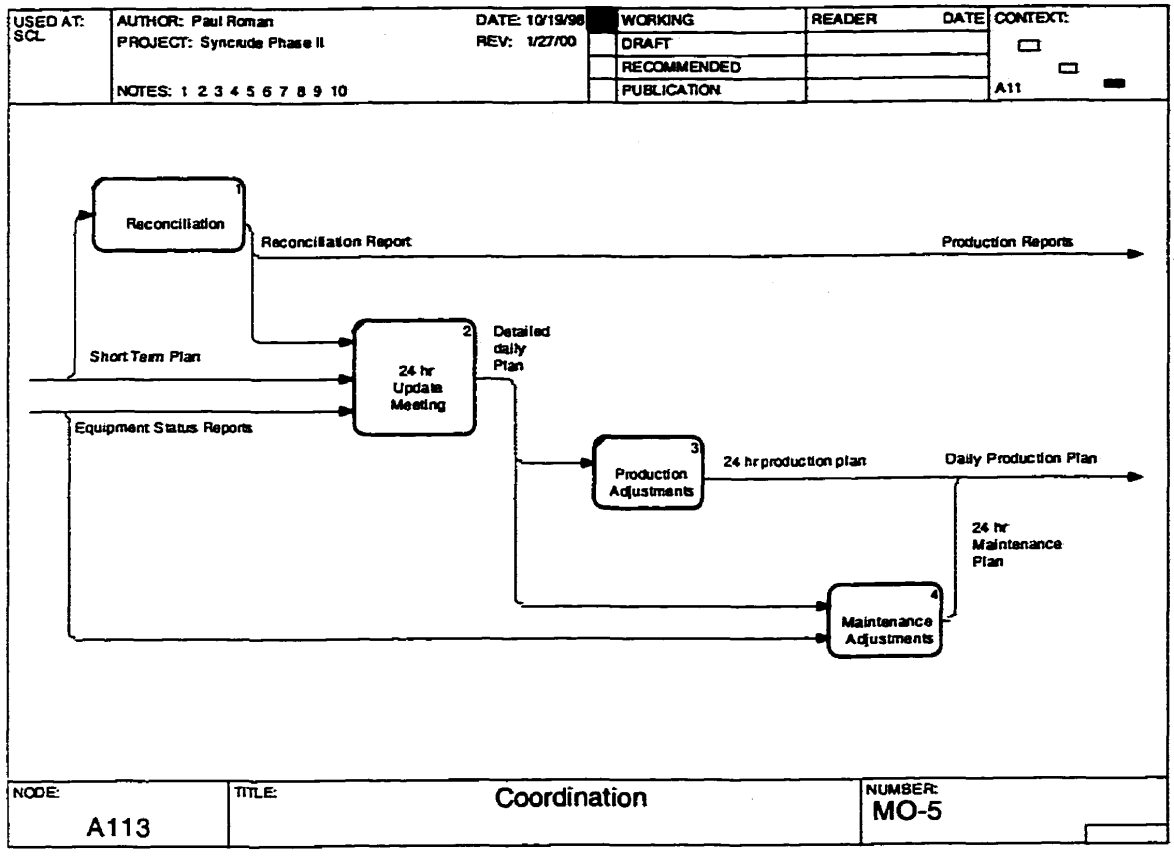
Link Name: Long Term Plan
Link Definition: This plan includes production targets and planned shovel outages as negotiated with shovel maintenance. It is very general for the year but more specifically includes the 8 week rolling schedule

Link Name: Short Term Plan
Link Definition: Represents the agreed to 2 week rolling schedule

Link Name: Daily Production Plan
Link Definition: Several documents are used to convey the daily plan and the shift plan. One key document is the shovel/truck daily plan.

Link Name: Shovel Outage Requirements
Link Definition: Includes: 7 day window from HD trucks. 21-day plan from shovels for trucks, telephone call to dispatch for opportune ans. P1-5 services. Annual shovel outage request from shovel maintenance.

Link Name: Equipment Status Reports
Link Definition: Reports are provided by both Shovel and Truck maintenance. Reports are generated by IMMPOWER for shovels and maintenance monitor for trucks.




## REPORT FOR DIAGRAM: A113, COORDINATION

Activity Name: Reconciliation
Activity Definition: Create reconciliation Report

Activity Name: 24 hr Update Meeting
Activity Definition: Occurs daily at 0815. Mike Hopkins attended by both operations and maintenance chairs meeting. The meeting occurs in the war room that has several important schedule files on electronic white boards. Reconciliation report is discussed

Activity Name: Production Adjustments

Activity Name: Maintenance Adjustments
Activity Definition: Currently, these adjustments are primarily for shovels only.

Link Name: Production Reports
Link Definition: All reports including daily, weekly, monthly and annually that report tonnages sent to extraction.

Link Name: Short Term Plan

Link Definition: Represents the agreed to 2 week rolling schedule

Link Name: Daily Production Plan
Link Definition: Several documents are used to convey the daily plan and the shift plan. One key document is the shovel/truck daily plan.

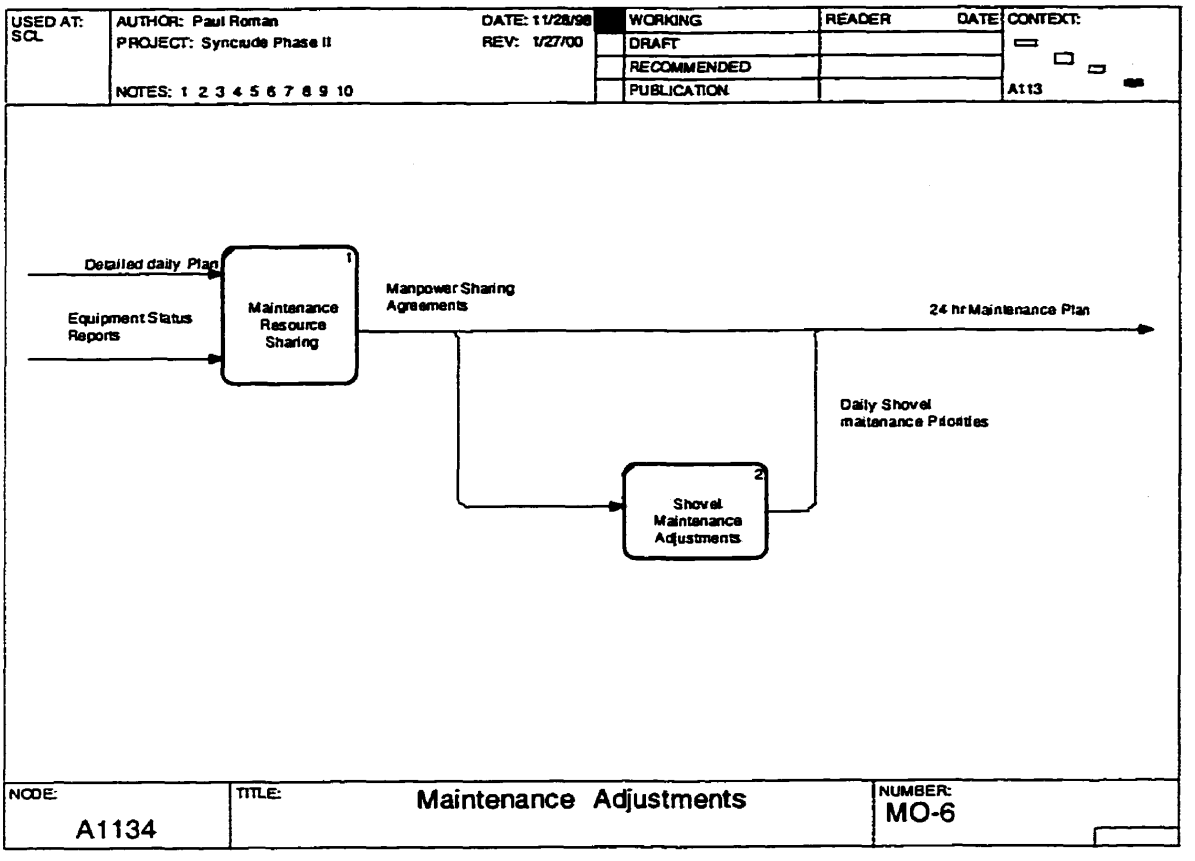
Link Name: Reconciliation Report
Link Definition: Lists daily targets and actuals and calculates shortages or overages. +/_ deltas

Link Name: Detailed daily Plan

Link Name: 24-hr production plan

Link Name: 24 hr Maintenance Plan

Link Name: Equipment Status Reports
Link Definition: Reports are provided by both Shovel and Truck maintenance. Reports are generated by IMMPOWER for shovels and maintenance monitor for trucks.




## REPORT FOR DIAGRAM: A1134, MAINTENANCE ADJUSTMENTS

Activity Name: Maintenance Resource Sharing
Activity Definition: occurs at 0830 meeting. Based on the detailed plan sharing arrangements are made to ensure each business maintenance unit has sufficient manpower.

Activity Name: Shovel Maintenance Adjustments

Link Name: Detailed daily Plan

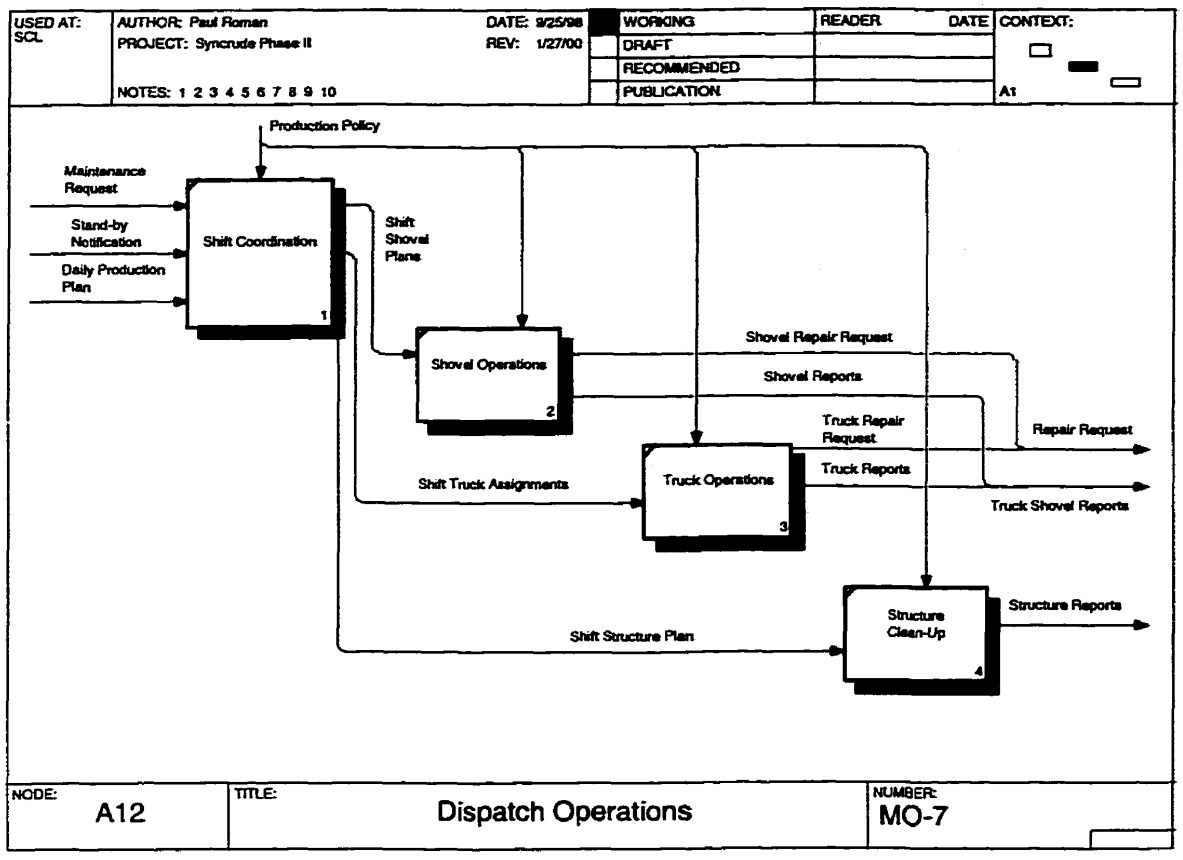
Link Name: 24 hr Maintenance Plan

Link Name: Manpower Sharing Agreements
Link Definition: These informal arrangements result in maintenance personnel getting assigned where they are most needed. Generally, occurs within business units.

Link Name: Daily Shovel maintenance Priorities

Link Name: Equipment Status Reports

Link Definition: Reports are provided by both Shovel and Truck maintenance. Reports are generated by IMMPOWER for shovels and maintenance monitor for trucks.




## REPORT FOR DIAGRAM: A12, DISPATCH OPERATIONS

Activity Name: Shift Coordination

Activity Name: Shovel Operations

Activity Name: Truck Operations

Activity Name: Structure Clean Up

Link Name: Repair Request
Link Definition: Radio call from dispatch to field mechanic.

Link Name: Stand-by Notification
Link Definition: Contact person or field mechanic to notify operations that the truck is ready to return to service. This can be achieved with a phone call as well as WENCO update code 99

Link Name: Maintenance Request

Link Definition: Includes: 7 day window from HD trucks. 21-day plan from shovels for trucks, telephone call to dispatch for opportune ans. P1-5 services.

Link Name: Production Policy

Link Name: Truck Shovel Reports

Link Name: Daily Production Plan
Link Definition: Several documents are used to convey the daily plan and the shift plan. One key document is the shovel/truck daily plan.

Link Name: Shovel Repair Request

Link Name: Truck Repair Request

Link Name: Shovel Reports

Link Name: Truck Reports

Link Name: Shift Truck Assignments

Link Name: Shift Structure Plan

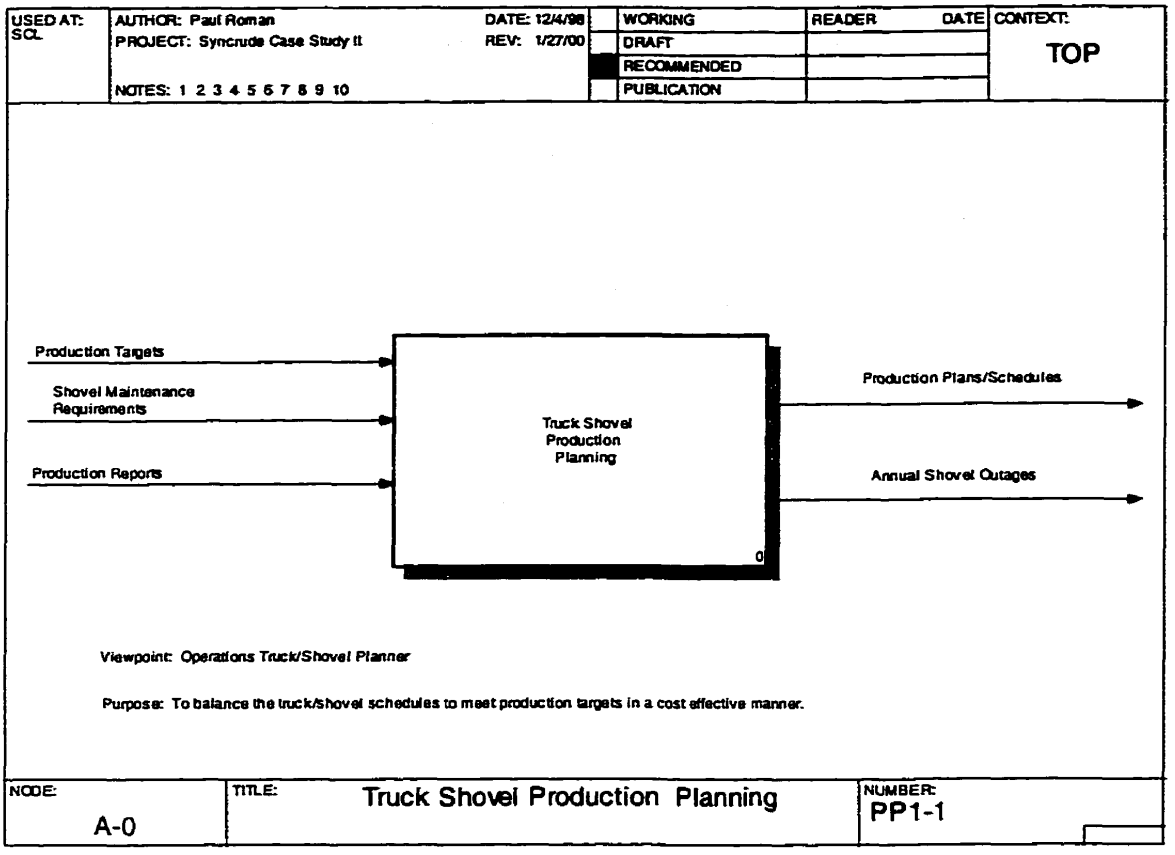
Link Name: Shift Shovel Plans

Link Name: Structure Reports

# APPENDIX D

## PRODUCTION PLANNING (AS-IS): PRODUCTION PLANNER'S VIEWPOINT

## (PP1-1 TO PP1-4)




## REPORT FOR DIAGRAM: A-0, TRUCK SHOVEL PRODUCTION PLANNING

Activity Name: Truck Shovel Production Planning

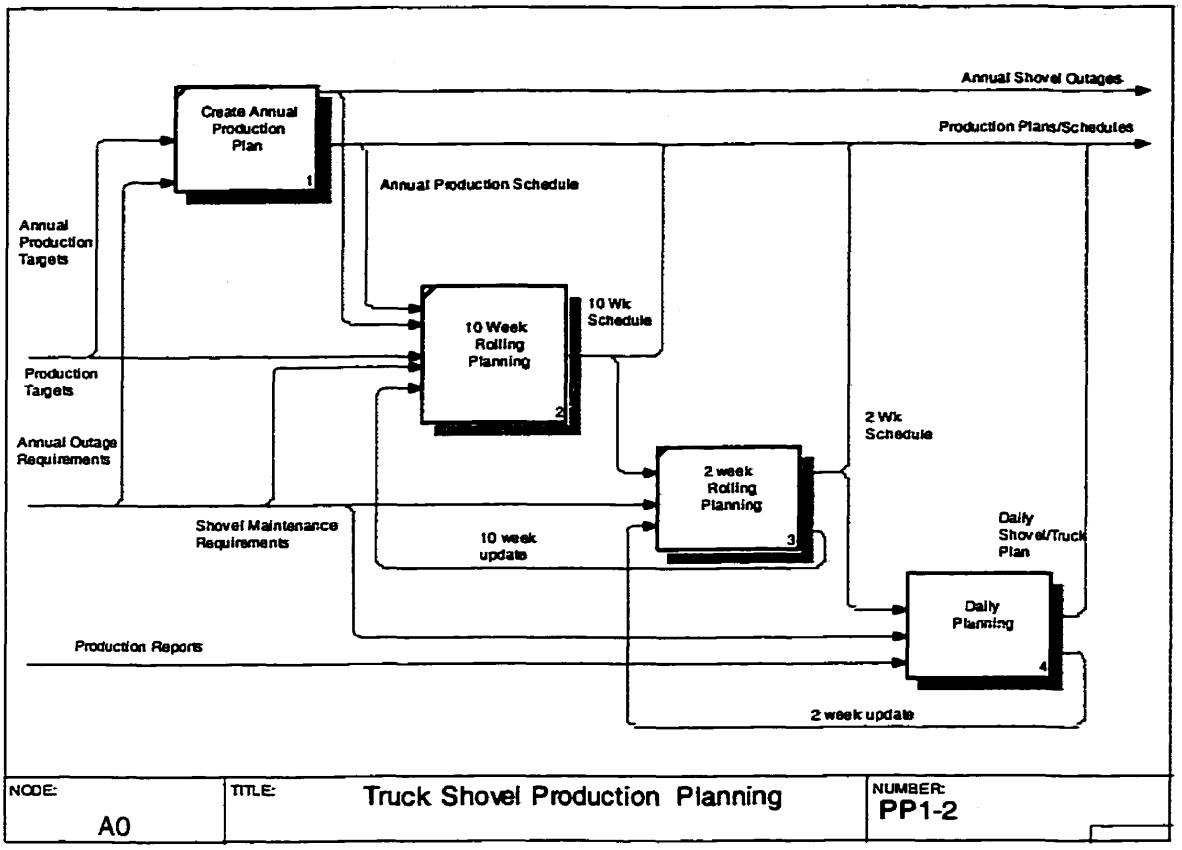
Link Name: Annual Shovel Outages
Link Definition: In November/December of each year, shovel maintenance negotiates annual shovel outages with operations. Required downtime per shovel (normally between 21 and 18 days) is submitted to mine planning. Mine planning then proposes the dates during the coming year that each shovel will be down. These outages form the basis of the annual PM schedule for shovels.

Link Name: Production Targets
Link Definition: Represents all production targets generated. Annual targets are set in December for the coming year. These may be adjusted throughout the year. There may be monthly, weekly even shift targets required from time to time.

Link Name: Production Plans/Schedules
Link Definition: Represents all production schedules generated by planning. These include the initial schedule created in December for the coming year, the 8-wk rolling schedule, the 2-week rolling schedule and the daily production plan.

Link Name: Shovel Maintenance Requirements
Link Definition: Represents all requests from shovel maintenance for shovel downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Production Reports
Link Definition: Represents all reports describing actual production.




## REPORT FOR DIAGRAM: A0, TRUCK SHOVEL PRODUCTION PLANNING

Activity Name: Create Annual Production Plan
Activity Definition: Represents work completed in November/December to turn next year's production targets into an annual plan.

Activity Name: 10-Week Rolling Planning

Activity Name: 2 week Rolling Planning
Activity Definition: 2-Week Planning

Activity Name: Daily Planning

Link Name: Annual Shovel Outages
Link Definition: In November/December of each year, shovel maintenance negotiates annual shovel outages with operations. Required downtime per shovel (normally between 21 and 18 days) is submitted to mine planning. Mine planning then proposes the dates during the coming year that each shovel will be down. These outages form the basis of the annual PM schedule for shovels.

Link Name: Annual Production Schedule
Link Definition: Represents the draft production plan for the coming year. Breaks production targets into 8 wk rolling schedule including planned shovel outages.

Link Name: Production Targets
Link Definition: Represents all production targets generated. Annual targets are set in December for the coming year. These may be adjusted throughout the year. There may be monthly, weekly even shift targets required from time to time.

Link Name: 10 Wk Schedule
Link Definition: This is a rolling schedule that is updated weekly to reflect the next 8 weeks. It includes planned production (overburden and oil sand), shovel outages, planned shovel moves and services.

Link Name: 2 Wk Schedule
Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: Production Plans/Schedules
Link Definition: Represents all production schedules generated by planning. These include the initial schedule created in December for the coming year, the 8-wk rolling schedule, the 2-week rolling schedule and the daily production plan.

Link Name: Shovel Maintenance Requirements
Link Definition: Represents all requests from shovel maintenance for shovel downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Daily Shovel/Truck Plan
Link Definition: Represents daily allocation of shovels to production tasks and trucks to shovels. Currently trucks are identified only in terms of how many are required, not by type of truck.

Link Name: Annual Production Targets

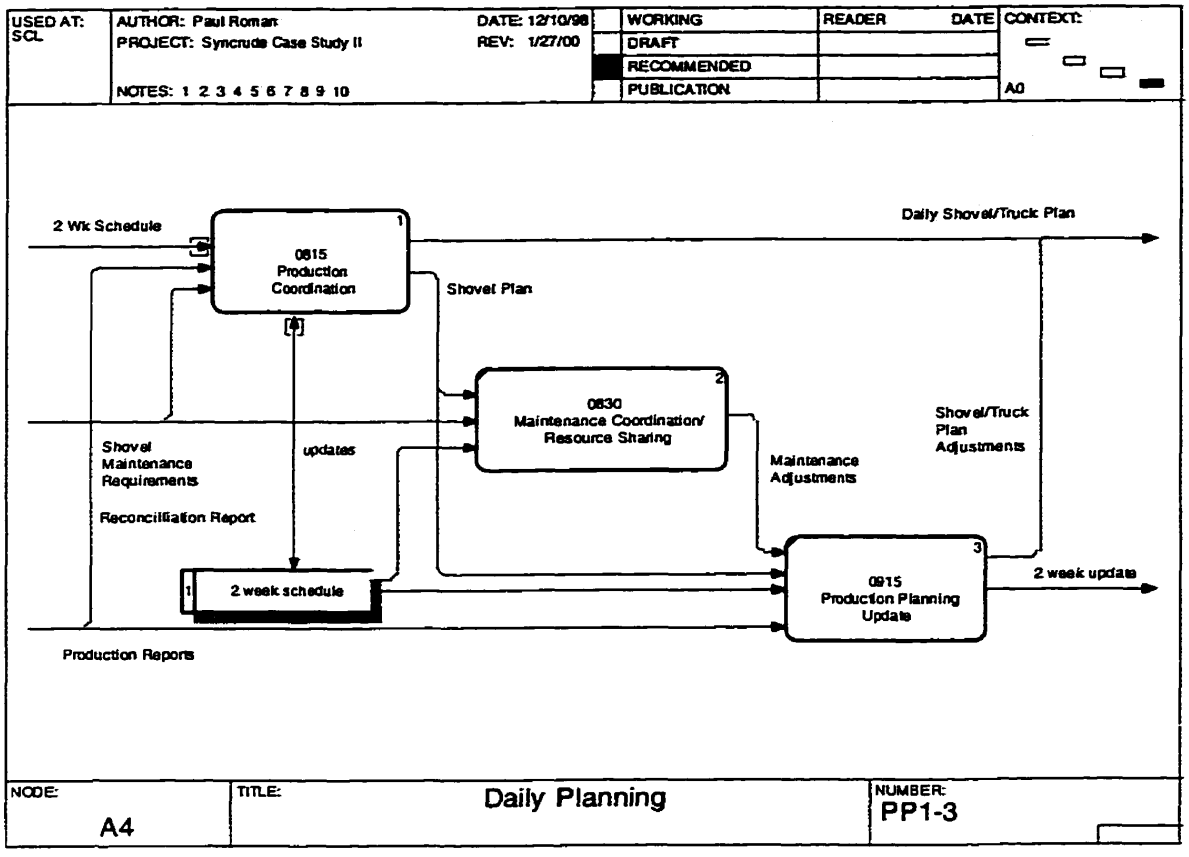
Link Name: Annual Outage Requirements

Link Name: 2-week update
Link Definition: Represents any changes to shovel outages due planned or unplanned maintenance as well as any revisions to the service outage schedule. Includes shovel walks.

Link Name: Production Reports

Link Definition: Represents all reports describing actual production.

Link Name: 10-week update




## REPORT FOR DIAGRAM: A4, DAILY PLANNING

Activity Name: 0815 Production Coordination

Activity Name: 0830 Maintenance Coordination/ Resource Sharing

Activity Name: 0915 Production Planning Update

Link Name: 2-week Schedule
Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: Shovel Maintenance Requirements
Link Definition: Represents all requests from shovel maintenance for shovel downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Daily Shovel/Truck Plan
Link Definition: Represents daily allocation of shovels to production tasks and trucks to shovels. Currently trucks are identified only in terms of how many are required, not by type of truck.

Link Name: 2-week update
Link Definition: Represents any changes to shovel outages due planned or unplanned maintenance as well as any revisions to the service outage schedule. Includes shovel walks.

Link Name: Shovel Plan
Link Definition: This represents the detailed maintenance plan for each shovel for the next 24-hr period.

Link Name: Shovel/Truck Plan Adjustments
Link Definition: Represents any agreed to changes discussed at the 0915 meeting.

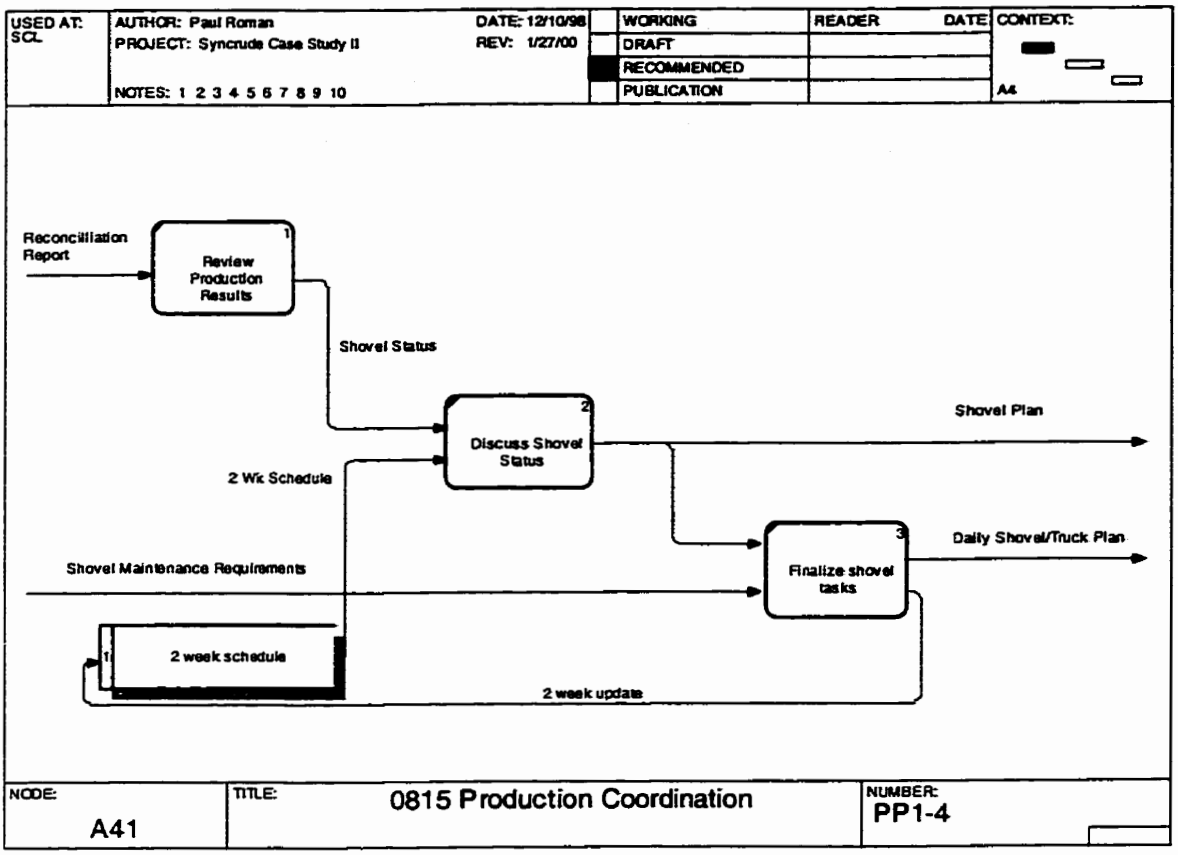
Link Name: Maintenance Adjustments
Link Definition: These are adjustments from the 0830 maintenance coordination and resource sharing meeting that are reported to the 0915 on an exception basis. Generally, the shovel maintenance plan is agreed to at the 0815, however, should it become apparent that it will prove difficult to implement that plan, this fact would be presented at the 0915.

Link Name: updates

Link Name: Production Reports
Link Definition: Represents all reports describing actual production.

Link Name: Reconciliation Report
Link Definition: This report is prepared daily by the night shift using WENCO data. A hard copy report listing planned and actual production results by shovel is handed to the production planner who attends the 0815 meeting.

Data store Name: 2-week schedule
Data store Definition: Represents the information stored on the electronic whiteboard in the production planning conference room. Includes all shovel maintenance outages and shovel walks, as well as any unscheduled downtime.




## REPORT FOR DIAGRAM: A41, 0815 PRODUCTION COORDINATION

Activity Name: Review Production Results
Activity Definition: Reconciliation report is reviewed. Planned versus actuals are reviewed by shovel.

Activity Name: Discuss Shovel Status
Activity Definition: Any failures that have occurred over the last 24 hour period are described, including estimates on any further downtime.

Activity Name: Finalise shovel tasks
Activity Definition: Shovel status for next 24-hr period is finalised.

Link Name: 2-week Schedule
Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: Shovel Maintenance Requirements
Link Definition: Represents all requests from shovel maintenance for shovel downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Daily Shovel/Truck Plan
Link Definition: Represents daily allocation of shovels to production tasks and trucks to shovels. Currently trucks are identified only in terms of how many are required, not by type of truck.

Link Name: 2-week update
Link Definition: Represents any changes to shovel outages due planned or unplanned maintenance as well as any revisions to the service outage schedule. Includes shovel walks.

Link Name: Shovel Plan
Link Definition: This represents the detailed maintenance plan for each shovel for the next 24-hr period.

Link Name: Reconciliation Report
Link Definition: This report is prepared daily by the night shift using WENCO data. A hard copy report listing planned and actual production results by shovel is handed to the production planner who attends the 0815 meeting.

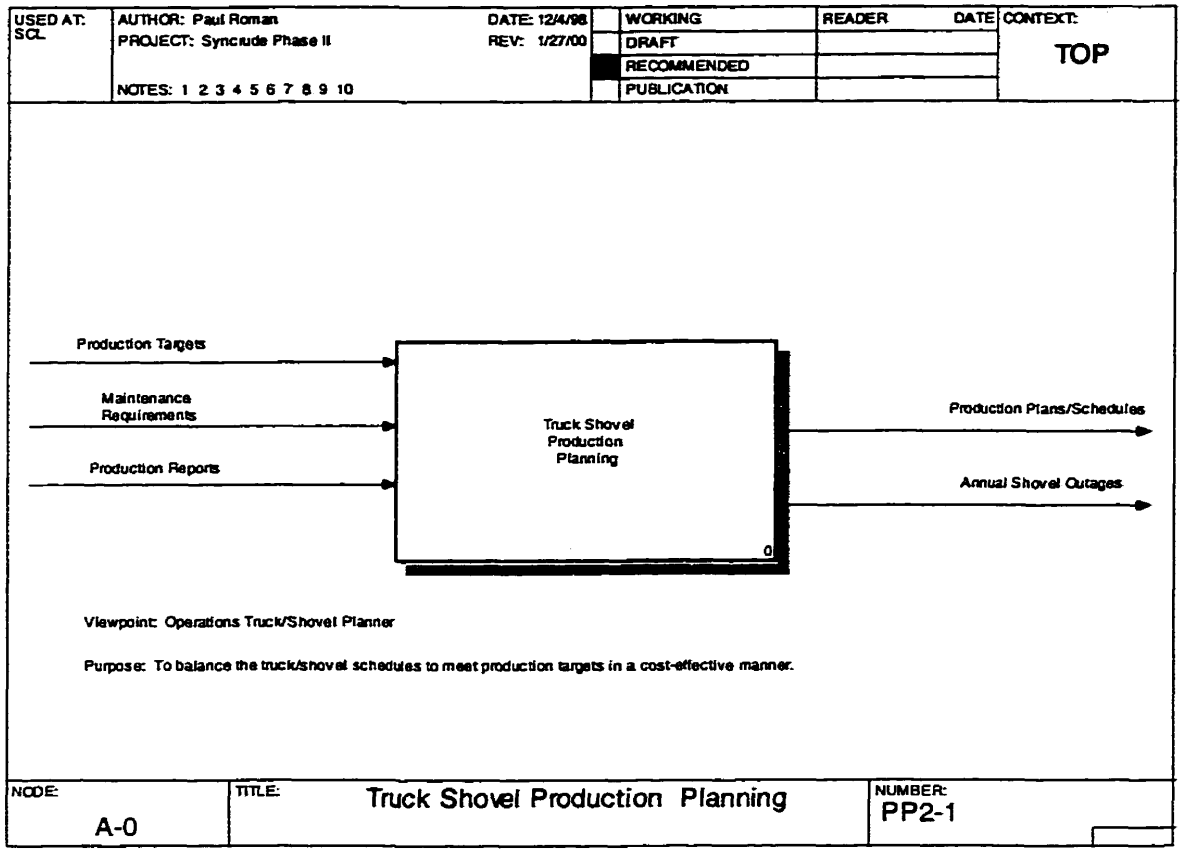
Link Name: Shovel Status
Link Definition: represents maintenance and operations information affecting each shovel based on what has occurred during the last 24 hrs.

Data store Name: 2-week schedule
Data store Definition: Represents the information stored on the electronic whiteboard in the production planning conference room. Includes all shovel maintenance outages and shovel walks, as well as any unscheduled downtime.

# APPENDIX E

## PRODUCTION PLANNING (TO-BE): PRODUCTION PLANNER'S VIEWPOINT

## (PP2-1 TO PP2-7)




## REPORT FOR DIAGRAM: A-0, TRUCK SHOVEL PRODUCTION PLANNING

Activity Name: Truck Shovel Production Planning

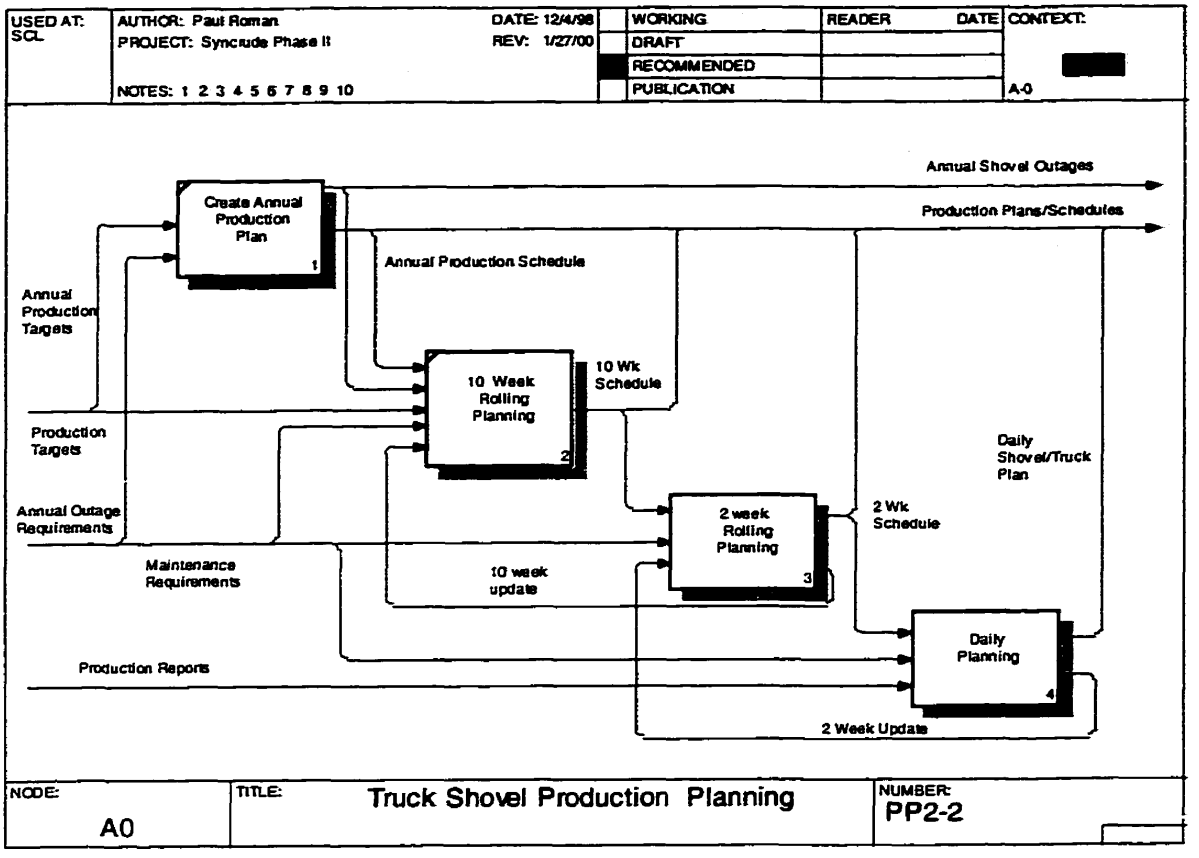
Link Name: Annual Shovel Outages
Link Definition: In November/December of each year, shovel maintenance negotiates annual shovel outages with operations. Required downtime per shovel (normally between 21 and 18 days) is submitted to mine planning. Mine planning then proposes the dates during the coming year that each shovel will be down. These outages form the basis of the annual PM schedule for shovels.

Link Name: Production Targets
Link Definition: Represents all production targets generated. Annual targets are set in December for the coming year. These may be adjusted throughout the year. There may be monthly, weekly even shift targets required from time to time.

Link Name: Production Plans/Schedules
Link Definition: Represents all production schedules generated by planning. These include the initial schedule created in December for the coming year, the 8-wk rolling schedule, the 2-week rolling schedule and the daily production plan.

Link Name: Maintenance Requirements
Link Definition: Represents all requests from shovel and truck maintenance for planned downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Production Reports
Link Definition: Represents all reports describing actual production.




## REPORT FOR DIAGRAM: A0, TRUCK SHOVEL PRODUCTION PLANNING

Activity Name: Create Annual Production Plan
Activity Definition: Represents work completed in November/December to turn next year's production targets into an annual plan.

Activity Name: 10-week Rolling Planning

Activity Name: 2-week Rolling Planning
Activity Definition: 2-week Planning

Activity Name: Daily Planning

Link Name: Annual Shovel Outages
Link Definition: In November/December of each year, shovel maintenance negotiates annual shovel outages with operations. Required downtime per shovel (normally between 21 and 18 days) is submitted to mine planning. Mine planning then proposes the dates during the coming year that each shovel will be down. These outages form the basis of the annual PM schedule for shovels.

Link Name: Annual Production Schedule
Link Definition: Represents the draft production plan for the coming year. Breaks production targets into 8 wk rolling schedule including planned shovel outages.

Link Name: Production Targets
Link Definition: Represents all production targets generated. Annual targets are set in December for the coming year. These may be adjusted throughout the year. There may be monthly, weekly even shift targets required from time to time.

Link Name: 2-week Schedule
Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: Production Plans/Schedules
Link Definition: Represents all production schedules generated by planning. These include the initial schedule created in December for the coming year, the 8-wk rolling schedule, the 2-week rolling schedule and the daily production plan.

Link Name: Maintenance Requirements
Link Definition: Represents all requests from shovel and truck maintenance for planned downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Daily Shovel/Truck Plan
Link Definition: Represents daily allocation of shovels to production tasks and trucks to shovels. Currently trucks are identified only in terms of how many are required, not by type of truck.

Link Name: Annual Production Targets

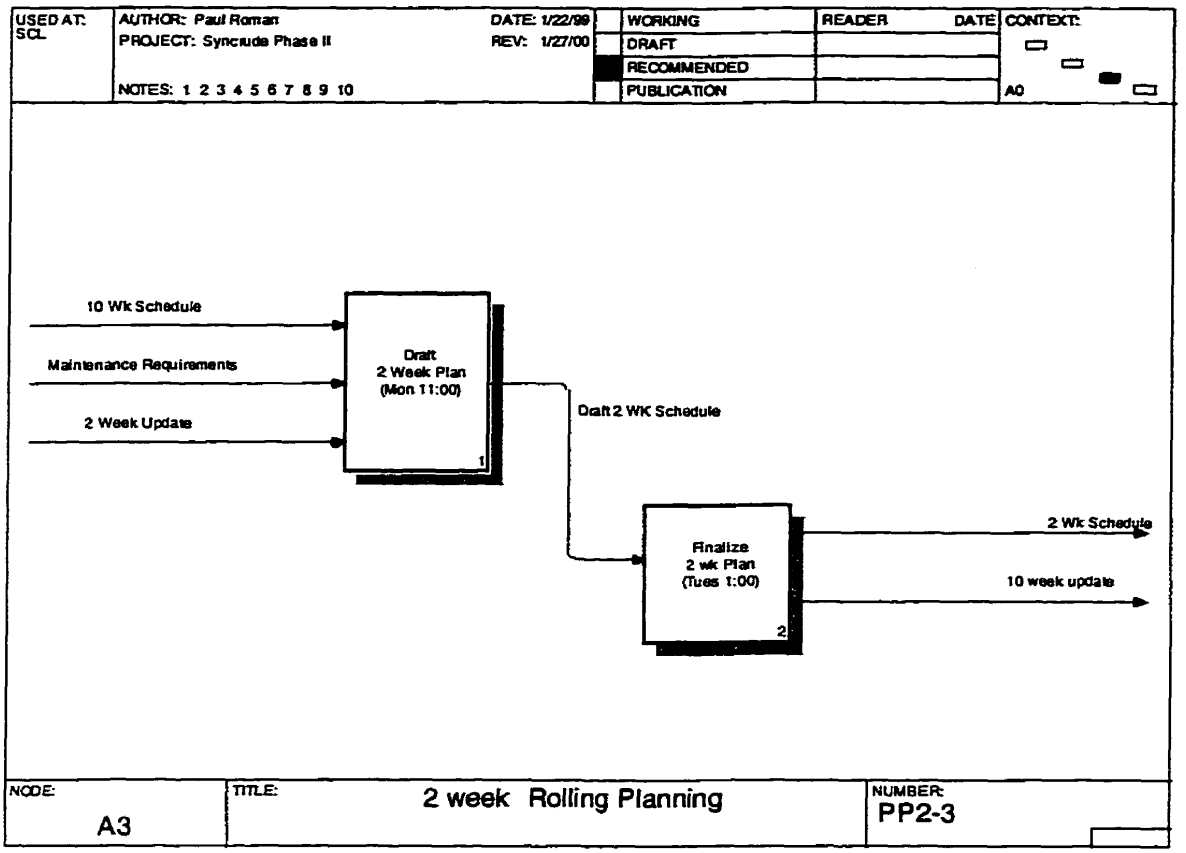
Link Name: Annual Outage Requirements

Link Name: 2-week Update
Link Definition: Represents any changes to shovel outages due planned or unplanned maintenance as well as any revisions to the service outage schedule. Includes shovel walks.

Link Name: Production Reports
Link Definition: Represents all reports describing actual production.

Link Name: 10-week Schedule

Link Name: 10-week update




## REPORT FOR DIAGRAM: A3, 2-WEEK ROLLING PLANNING

Activity Name: Draft 2-week Plan (Mon. 11:00)

Activity Name: Finalise 2-week Plan (Tues. 1:00)

Link Name: 2-week Schedule
Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: Maintenance Requirements
Link Definition: Represents all requests from shovel and truck maintenance for planned downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

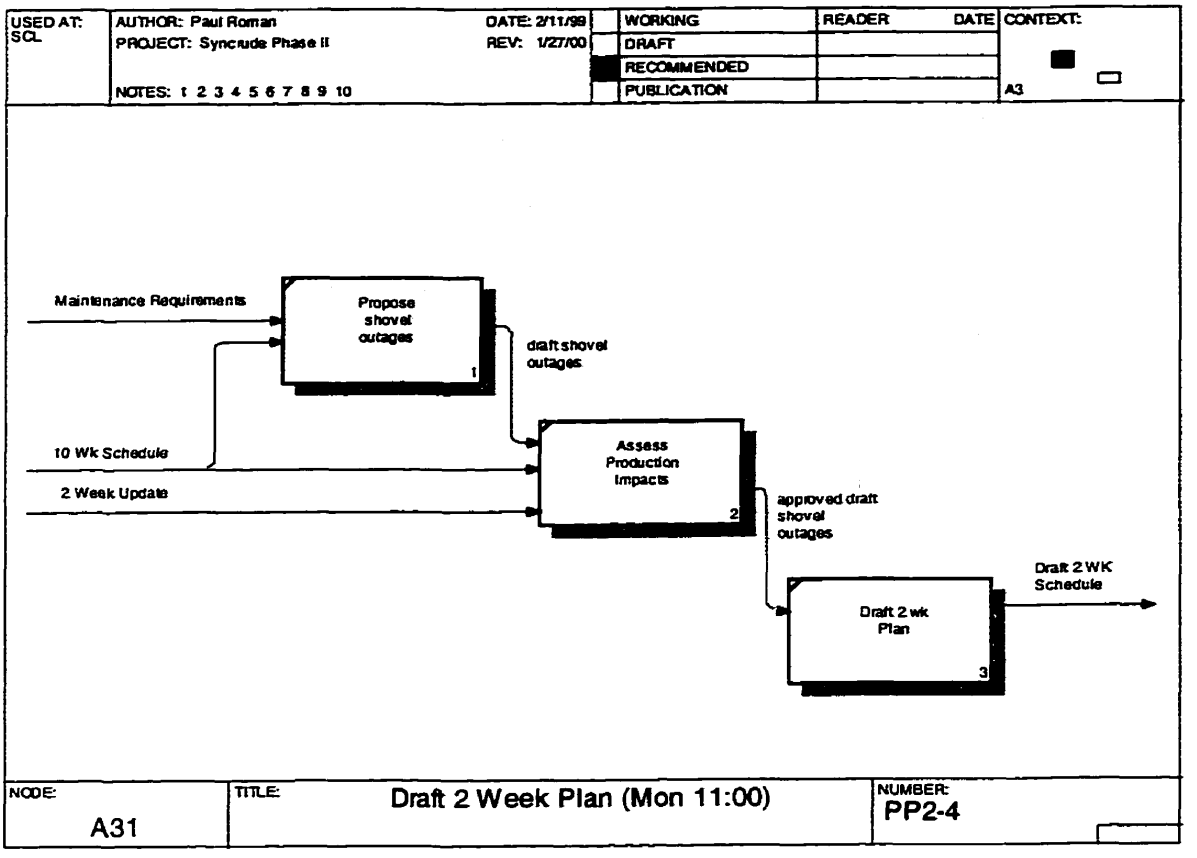
Link Name: 2-week Update

Link Definition: Represents any changes to shovel outages due planned or unplanned maintenance as well as any revisions to the service outage schedule. Includes shovel walks.

Link Name: 10-week Schedule

Link Name: 10-week Update

Link Name: Draft 2-week Schedule




## REPORT FOR DIAGRAM: A31, DRAFT 2-WEEK PLAN (MON 11:00)

Activity Name: Propose shovel outages

Activity Name: Assess Production Impacts

Activity Name: Draft 2-week Plan

Link Name: Maintenance Requirements
Link Definition: Represents all requests from shovel and truck maintenance for planned downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

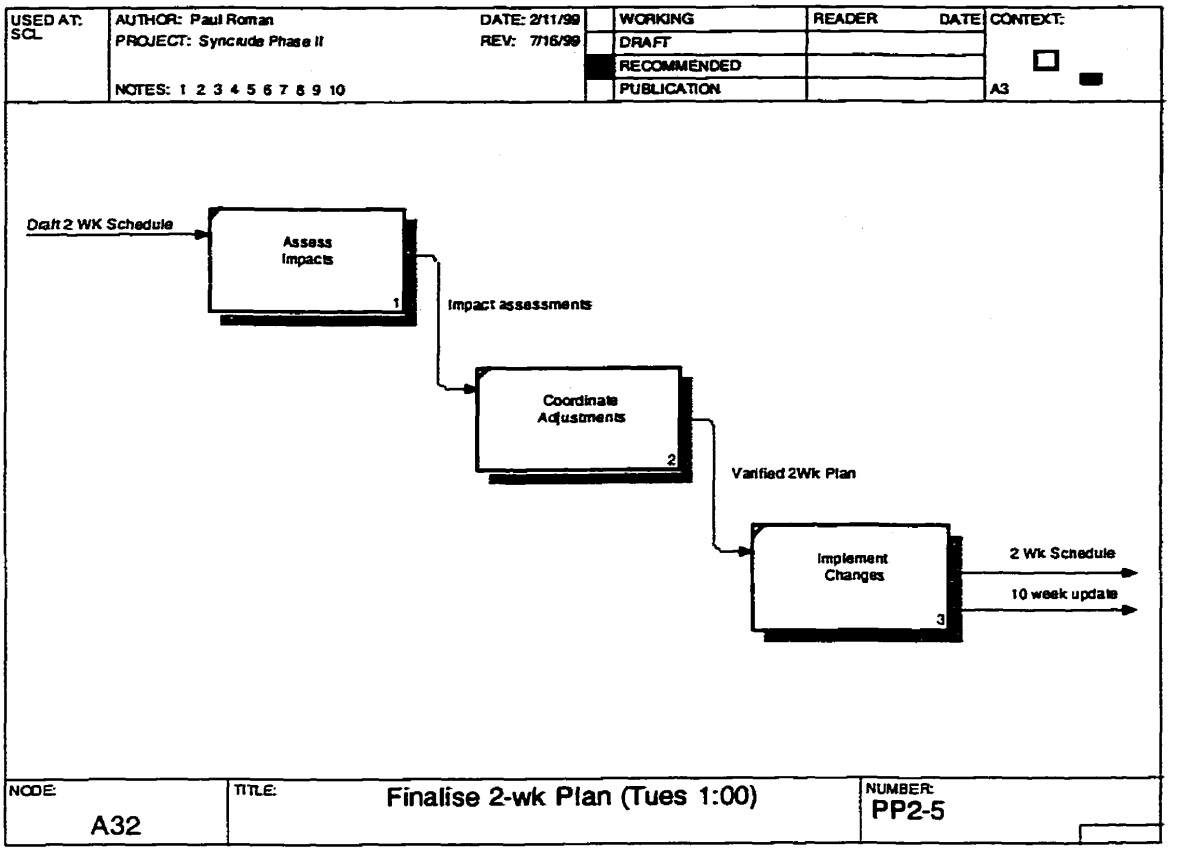
Link Name: 2-week Update
Link Definition: Represents any changes to shovel outages due planned or unplanned maintenance as well as any revisions to the service outage schedule. Includes shovel walks.

Link Name: 10-week Schedule

Link Name: Draft 2-week Schedule

Link Name: draft shovel outages

Link Name: approved draft shovel outages




## REPORT FOR DIAGRAM: A32, FINALISE 2-WK PLAN (TUES 1:00)

Activity Name: Assess Impacts

Activity Name: Coordinate Adjustments

Activity Name: Implement Changes

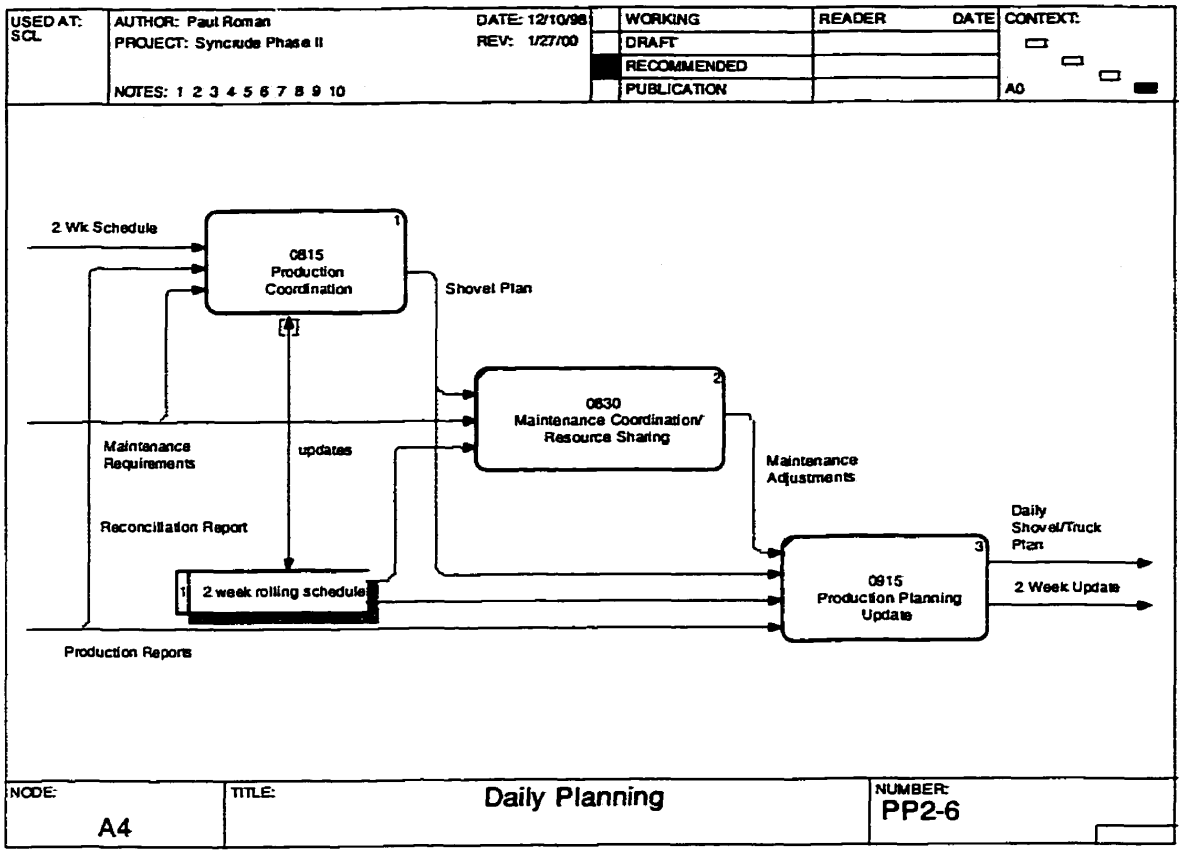
Link Name: 2-week Schedule
Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: 10-week Update

Link Name: Draft 2-week Schedule

Link Name: Impact assessments

Link Name: Verified 2-week Plan




## REPORT FOR DIAGRAM: A4, DAILY PLANNING

Activity Name: 0815 Production Coordination

Activity Name: 0830 Maintenance Coordination/ Resource Sharing
Activity Definition: All maintenance BUs discuss their priority work and arrange to share manpower in support of accomplishing higher priorities first.

Activity Name: 0915 Production Planning Update
Activity Definition: This production meeting breaks daily targets and allocates this to each shovel. Moves and relocation of shovels is finalised. Dumping plan is finalised. Based on haul distance the estimate the number of trucks required

Link Name: 2-week Schedule
Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: Maintenance Requirements

Link Definition: Represents all requests from shovel and truck maintenance for planned downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Daily Shovel/Truck Plan
Link Definition: Represents daily allocation of shovels to production tasks and trucks to shovels. Currently trucks are identified only in terms of how many are required, not by type of truck.

Link Name: 2-week Update
Link Definition: Represents any changes to shovel outages due planned or unplanned maintenance as well as any revisions to the service outage schedule. Includes shovel walks.

Link Name: Shovel Plan
Link Definition: This represents the detailed maintenance plan for each shovel for the next 24-hr period.

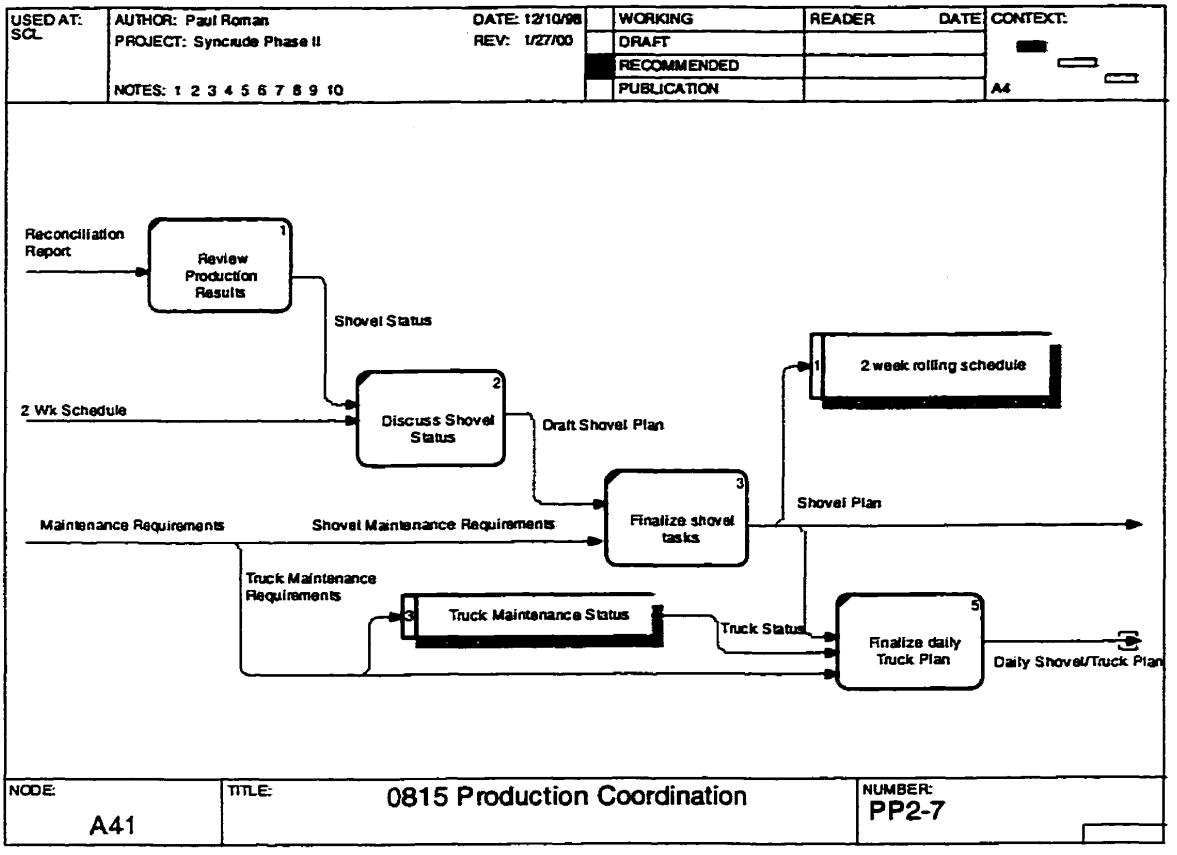
Link Name: Maintenance Adjustments
Link Definition: These are adjustments from the 0830 maintenance coordination and resource sharing meeting that are reported to the 0915 on an exception basis. Generally, the shovel maintenance plan is agreed to at the 0815, however, should it become apparent that it will prove difficult to implement that plan, this fact would be presented at the 0915.

Link Name: updates

Link Name: Production Reports
Link Definition: Represents all reports describing actual production.

Link Name: Reconciliation Report
Link Definition: This report is prepared daily by the night shift using WENCO data. A hard copy report listing planned and actual production results by shovel is handed to the production planner who attends the 0815 meeting.

Data store Name: 2-week rolling schedule
Data store Definition: Represents the information stored on the electronic whiteboard in the production planning conference room. Includes all shovel maintenance outages and shovel walks, as well as any unscheduled downtime.




## REPORT FOR DIAGRAM: A41, 0815 PRODUCTION COORDINATION

Activity Name: Review Production Results
Activity Definition: Reconciliation report is reviewed. Planned versus actuals are reviewed by shovel.

Activity Name: Discuss Shovel Status
Activity Definition: Any failures that have occurred over the last 24 hour period are described, including estimates on any further downtime.

Activity Name: Finalise shovel tasks
Activity Definition: Shovel status for next 24-hr period is finalised.

Activity Name: Finalise daily Truck Plan
Activity Definition: Taking into account shovel tasks estimate the trucks required to match the days shovel output. Determines the number of trucks available for maintenance work for that day.

Link Name: 2-week Schedule

Link Definition: This is also a rolling schedule based on a period of 2 weeks. It is coordinated at 2 meetings, the 11:00 AM Monday and the 1:15 PM on Tuesday. Planners meet with shovel maintenance to confirm the 8-week plan for the next two weeks. The schedule exists in hard copy on an electronic white board in the production planning conference room.

Link Name: Maintenance Requirements
Link Definition: Represents all requests from shovel and truck maintenance for planned downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Daily Shovel/Truck Plan
Link Definition: Represents daily allocation of shovels to production tasks and trucks to shovels. Currently trucks are identified only in terms of how many are required, not by type of truck.

Link Name: Shovel Plan
Link Definition: This represents the detailed maintenance plan for each shovel for the next 24-hr period.

Link Name: Reconciliation Report
Link Definition: This report is prepared daily by the night shift using WENCO data. A hard copy report listing planned and actual production results by shovel is handed to the production planner who attends the 0815 meeting.

Link Name: Shovel Status
Link Definition: represents maintenance and operations information affecting each shovel based on what has occurred during the last 24 hrs.

Link Name: Draft Shovel Plan
Link Definition: Represents the results of the negotiations between operations and shovel maintenance with respect to daily shovel assignments and maintenance activities.

Link Name: Truck Maintenance Requirements
Link Definition: Represents all requests from truck maintenance for truck downtime. These include both the planned requirements per truck as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a truck already be down due to failure.

Link Name: Shovel Maintenance Requirements
Link Definition: Represents all requests from shovel maintenance for shovel downtime. These include the annual outage requirements per shovel as well as unforeseen requests due to breakdowns. May for example include a request for opportune maintenance should a shovel already be down due to failure.

Link Name: Truck Status
Link Definition: For each fleet of trucks includes: Unit code for downed trucks including reason for downtime and anticipated uptime

Data store Name: 2-week rolling schedule
Data store Definition: Represents the information stored on the electronic whiteboard in the production planning conference room. Includes all shovel maintenance outages and shovel walks, as well as any unscheduled downtime.

Data store Name: Truck Maintenance Status
Data store Definition: This status board resides in the production planning conference room. It consists of the following information listed by truck fleet: Unit code for trucks that are down including reason for the downtime and anticipated uptime