OPEN PIT MINE PLANNING: ANALYSIS AND SYSTEM MODELING OF CONVENTIONAL AND OIL SANDS APPLICATIONS

by

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Abstract

In the last decade mineable oil sands production in Canada has grown rapidly. Constraints on the planning and design processes employed by surface mining oil sands operations vary in distinct ways from other commodities mined by both hard and soft rock open pit methods. The unique waste handling needs, including tailings disposal, of contemporary oil sands mining requires specific planning considerations.

It is the purpose of this research to analyze and document a conventional hard rock, metal mine planning system, and contrast this with the unconventional mine planning system used by oil sands mines. Systems activity models of both the conventional and unconventional systems are developed in support of documenting and contrasting the two systems.

Constraints unique to oil sands mine planning are identified and their impact on the oil sands mine planning system are documented. The impacts of challenging waste handling and storage requirements and a uniquely prescriptive regulatory environment defining mineable ore are identified as key constraints.

The research concludes with a proposal for a new planning system to better support the planning of oil sands mines. The proposed system respects the unique waste management considerations in oil sands planning and revisits the current regulatory approach to ensuring resource recovery. The proposed system is compatible with traditional approaches to economic analysis in open pit planning, and with emerging best practices to manage technical and economic uncertainty, improve project optimization, and develop robust mine plans.
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To my former Syncrude colleagues Eric, Jim, Geoff, Lynne, Dave, Steve and Steve, Pat, Cliff, Wayne, Bob, and Barbara, thank you for making tailings planning a joy.

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List of Acronyms

ARO  Asset retirement obligation
bbl  Oil barrel. An oil barrel has a volume of 42 US gallons or 158.9 litres.
CADD  Computer aided drafting and design
CNRL  Canadian Natural Resources Limited
COS  Canadian Oil Sands Limited. Also Canadian Oil Sands Trust.
CT  Consolidated tailings. Also Composite tailings.
DDA  Dedicated disposal area
EPEA  Environmental Protection and Enhancement Act (Alberta)
EPSF  Environmental Protection Security Fund
ERCB  Energy Resources Conservation Board
EUB  Energy and Utilities Board
FFT  Fluid fine tailings
GAAP  Generally Accepted Accounting Principles of Canada
GMP  General mine planning
IB  Interburden
IFRS  International Financial Reporting Standards
LG  Lerchs-Grossman algorithm
LOM  Life of mine
LRP  Long range planning
MFSP  Mine Financial Security Program
MFT    Mature Fine Tailings.
MIGP   Mixed integer goal programming
NIR    Not-in-reserve
NPV    Net present value
NST    Non-segregating tailings
OB     Overburden
OSCA   Oil Sands Conservation Act (Alberta)
PAG    Potentially acid generating
PAN    Potentially acid neutralizing
SMU    Selective Mining Unit. Also Smallest Mining Unit.
SP     Strategic planning
SRP    Short range planning
TFT    Thin fine tailings
tpd    tonnes per day
TV: BIP Total volume to bitumen in-place ratio
UML    Unified Modeling Language
Chapter 1

Introduction

Surface mining accounts for the vast majority of mined material in Canada, producing approximately 95% by mass of all ore mined in Canada, including aggregates (Chapter 3). In the last decade mineable oil sands production has grown rapidly. Approaches for the planning and design processes employed by surface mining oil sands operations vary in distinct ways from other commodities mined by both hard and soft rock open pit methods. Despite the important role of the oil sands industry in Canadian mining, scant literature exists describing the contemporary oil sands surface mine planning system.

Traditional open pit mine planning literature has largely focused on economic optimization based on a block model representation of the mine, i.e. pit limit analysis, mine sequencing, cut-off grade determination, and production rate selection, etc. While oil sands mines use block models as their design and planning basis, the economic considerations and planning constraints in oil sands mine planning vary significantly from other commodities, resulting in the use of different planning parameters and methodologies. There are similarities in some of the issues faced by the surface mined oil sands industry to other sectors of the mining industry, such as those encountered in traditional strip mining operations of coal, bauxite, and phosphate. However, the unique waste handling needs, including tailings disposal, of present-day oil sands mining does involve sector specific, unconventional planning considerations.

The following issues in particular differentiate oil sands mining:

- the Government of Alberta prescribes the definition of ore-grade material, i.e. fixed criteria for mining and processing which may include uneconomic material;
• mines are relatively shallow but cover large areas of land;
• as a result of challenging fluid tailings characteristics, tailings storage requirements are the major influence on mine sequencing;
• the operational scale of oil sands mines and their tailings dyke construction requirements may limit the ability to adjust mine plans in the short to intermediate horizon (up to 5 years); and,
• treatment and reclamation technologies for oil sands fine tailings are largely unproven, increasing planning uncertainty with respect to waste handling.

For these reasons, and due to the often restricted nature of mine planning software generally, oil sands mine design and planning is accomplished using a mixture of:

• a variety of mine planning software;
• computer-assisted drafting and design (CADD) and other commercial software packages;
• in-house computerized tools; and,
• manual and semi-automated processes.

Duplication of data, repetition of work, and sluggish responses to changing economic conditions are the result.

1.1 Purpose, Goals, and Objectives

It is the purpose of this research to understand and document the unconventional mine planning and design methodologies used by Canadian oil sands surface mining operations. The research goal is a proposal for a new planning system to support economic optimization of oil sands mines within constraints such as practicable mining, government objectives for resource
conservation, tailings disposal, etc. This is accomplished by developing and analyzing a formal model of the existing design and planning process using a systems analysis approach, with a focus on the system’s planning activities. A comparison is provided with a conventional open pit planning system used in hard rock, metal mine planning.

The objectives of the research are to:

- analyze and document the conventional open pit hard rock metal mine planning system;
- analyze and document the unconventional open pit oil sands mine design and planning process;
- produce formal system models of planning activities for both the conventional and unconventional case;
- identify key parameters and factors affecting the oil sands mine planning process and document the relationships between them;
- provide a comparison of unconventional oil sands planning to a conventional open pit, hard rock mine planning system; and,
- make recommendations for a new oil sands planning system.

This thesis provides a description of the contemporary oil sands mine planning process which is currently absent from the literature, and identifies and documents planning approaches where traditionally focused open pit algorithms and theories are not directly applicable. This is considered a particularly important contribution. The rapid expansion of the oil sands industry over the last decade, when coupled with the industry’s demographic trends, has resulted in a critical shortage of experienced mine planners and a resulting loss of knowledge within the industry.
It is expected that portions of the work will be relevant to mine planning in non-market driven or heavily regulated economies where government mandated restrictions may impede the ability to use, or restrict the relevance of, traditional profit motivated planning approaches.

1.2 Methodology

The research formally models a conventional approach to mine planning and design typical to hard-rock, metal open pit mines, followed by the unconventional mine planning methodologies used in surface oil sands operations. These models will be created using the Unified Modeling Language (UML).

UML is a widely utilized graphical modeling language that provides a standardized basis for creating pictorial representations of systems, such as object-oriented software systems. A reverse-engineered ‘blueprint’ for both systems under study (hard rock and oil sands) is created, documenting the activities that form the mine planning system. The use of UML enables a graphical representation of the systems under study using a standardized notation.

The processes are analyzed and modeled based on literature review, the author’s experience, and the advice of experienced practitioners. In the case of oil sands planning the latter two approaches are critical, as very little published information exists on the planning approaches employed by the oil sands industry.

1.3 Thesis Organization

The following structure is used to organize the research thesis: Chapter Two introduces the systems modeling approach and language used in the thesis. Chapters Three and Four present a review of a generic hard rock, metal mine planning system and a case study into an unconventional planning system used in the oil sands. The system descriptions in Chapters 3 and
4 are supported by formal models of the two systems’ activities. The full models are presented in Appendix A and B respectively. Based on a comparative analysis of the conventional and unconventional systems presented, Chapters Five and Six consider the impact of the unique constraints in oil sands mining on the planning system and present a proposal for a new system for oil sands planning. A system’s activity model for the proposal is presented in Appendix C. The final chapter provides conclusions based on the research and modeling work and provides recommendations for future work.

An extensive literature review was conducted. The breadth of topics presented challenges a traditional approach to presenting the literature review; therefore a separate literature review chapter is not presented. The research and resources relevant to the topic discussed are presented throughout Chapters Two through Five.

Chapter One – Introduction. This chapter provides an overview of the problem and discusses the purpose and goals of the research and the methodology employed.

Chapter Two – Introduction to Systems Modeling. This chapter presents a brief introduction to systems analysis and modeling and introduces aspects of UML relevant to the thesis.

Chapter Three – Systems Analysis and Modeling of a Conventional Open Pit Mine Planning System. This chapter presents a detailed review of the activities that comprise a generic hard rock, metal open pit mine planning system. The review is complemented by
a formal model of the system’s activities developed by the author. Contemporary research in open pit mine planning is introduced in this chapter.

Chapter Four – Unconventional Open Pit Mining: A Case Study into Oil Sands Mine Planning. This chapter presents a review of oil sands mine planning activities, with an emphasis on the differences between this system and the conventional system described in Chapter Three. The key constraints on oil sands mine planning are introduced. Preliminary research into the cost of reclamation in oil sands mining, an important aspect of oil sands mine evaluation and planning, is presented at the end of this chapter.

Chapter Five – Impact of Constraints on the Oil Sands Mine Planning System. This chapter explores the impact of constraints unique to the oil sands on the mine planning process.

Chapter Six – Proposal for a New Oil Sands Mine Planning System. This chapter presents a proposal for a new oil sands mine planning system. Government and corporate objectives are reviewed and the new system is introduced. A formal model is presented in support of the system description. The impact of the new system on planning activities is discussed.

Chapter Seven – This chapter presents the conclusions reached in the current research and identifies the original contributions of the thesis. The chapter provides recommendations for future work related to the research.
Chapter 2

Introduction to Systems Modeling

The *Oxford English Reference Dictionary* (2002) defines a system as “a complex whole; a set of connected things or parts; an organized body of material or immaterial things.” Mine design and planning can be thought of as a system. The mine plan is composed of a set of connected designs and policies. The designs and policies are created by executing an organized series of activities, many of which are interrelated. The policies and designs, and the activities that create them, form the planning system.

System analysis is defined by the *Oxford English Reference Dictionary* (2002) as “the analysis of a complex process or operation in order to improve its efficiency.” System analysis enables the understanding and description of the ways in which individual components in a system affect the behavior or performance of the system as a whole. A systems approach to analysis promotes a reasoned and integrated consideration of a system, rather than a fragmented understanding (Ramo & St. Clair, 1998).

Business process modeling employs a systems approach to model how business processes function. Business process models are often used in support of business process improvement. A business process model identifies the set of tasks, and their sequence, that achieves a business goal. System analysis is a critical part of business process modeling and business process improvement (Noran, 2000).

In this thesis a systems approach is employed to develop models of three open-pit mine planning systems: a conventional system, an unconventional system, and a proposed new system for unconventional mine planning. The unconventional and conventional models are compared.
and contrasted to identify potential system shortcomings and improvements to the unconventional system. The focus of the analysis is on the activities that are conducted to develop and implement a mine plan.

2.1 The Unified Modeling Language

The Unified Modeling Language (UML) is a formal language originally developed to model object-oriented software systems. UML is used to create abstract representations of complex systems through structured diagrams. UML is defined and maintained by the Object Management Group, Inc. UML consists of a set of graphical notations (symbols) which have defined meanings. A meta-model specifies the rules that govern the use of these symbols. Since initial development in the 1990s, the UML standard has undergone a number of revisions. This thesis uses UML standard 2.3, released in 2010.

UML is a modeling language, not a modeling methodology. It provides a means of expressing a model but the standard does not prescribe a specific model development process (i.e. the activities that are undertaken to develop a system’s model or the specific form of the model). As a consequence UML is highly flexible in its application.

There are 14 diagram types available in UML 2.3. The diagrams fall into two broad categories: structure diagrams and behavior diagrams (see Figure 2-1). Behavior diagrams describe the behavior or activities of a system. They enable the use of UML to capture time-ordered constraints as well as process entry and exit conditions. This is of benefit in modeling business processes (Noran, 2000; Miles & Hamilton, 2006). It is expected that this will be particularly beneficial in modeling the mine design and planning process, where there is a high
degree of iterative analysis and where activities are often dependent on the results of other activities.

Figure 2-1: UML diagram type classification (Object Management Group, 2010)

2.1.1 UML Activity Diagrams

Activity diagrams describe system workflows by illustrating the sequence of actions that comprise the activity. According to Miles and Hamilton (2006), activity diagrams are normally
used to model high-level actions. The degree of decomposition of the activity state is dependent on the requirements of the modeler or model.

The primary notational elements employed in this thesis are shown in Figure 2-2 and are described in the following pages.

**Figure 2-2: UML activity diagram notation**
- An activity start node represents the launch of an activity, and an activity end node is used to denote the end of an activity.

- An action represents a step in an activity. The degree of decomposition in the model (the degree of detail in describing the system) may result in an action on one diagram becoming its own activity. An action with its own sub-actions is represented with a two-pronged rake icon.

- The flow or sequence of activities is represented by a directional arrow. The work flow proceeds in the direction of the arrowhead. In this thesis a dashed line has been used in some cases to indicate important activities related to the mine plan but falling outside of the mine planning system.

- Forks and joins are used to model parallel actions. The actions after the fork are independent and may be executed at different times, but all actions must be completed or terminated before the activity can proceed forward from the join.

- Partitions are used on some activity diagrams to identify which business unit is responsible for a particular set of actions. Partitions were referred to as swim lanes in UML 1.x. In this thesis partitions will be bounded by a light grey box to aid distinction from flow arrows.

- Decision and merge nodes are used to show when multiple exclusive flow paths may trigger or result from an action. Only one incoming flow is required to initiate flow from a merge node. Flow paths exiting a decision node must be mutually exclusive.
• Notes can be added to activity diagrams, or connected to specific actions.

• Constraints can be generally indicated on activity diagrams or connected to specific actions.

2.2 UML and Mine Planning System Models

The purpose of the modeling undertaken in this thesis is to understand the activity structure of conventional and unconventional mine planning systems. The holistic examination of the two planning systems is used to critique the unconventional planning system and provide guidance for improvements to the system.

A well-established generic hard rock, metal mine planning system is modeled to represent conventional planning (Chapter 3 and Appendix A), and a generic oil sands mine planning system is modeled as a case study into an unconventional mine planning system (Chapter 4 and Appendix B). A descriptive or reverse-engineered approach was employed in the development of these models. That is, the models represent current planning systems as determined by experience and research.

The focus of the modeling is on the activities that constitute the mine planning system. UML activity diagrams therefore form the bulk of graphical modeling performed. Descriptions of key data inputs and constraints are provided in the appendices in conjunction with the UML diagrams.

A proposal for a new oil sands mine planning system is developed. The proposed system is intended to better support the mine planning objectives of corporations while respecting the resource conservation (i.e. efficient resource use) objectives of governments. The new system activities are presented in Chapter 6 and Appendix C.
Chapter 3

Systems Analysis and Modeling of a Conventional Open Pit Mine Planning System

The exploitation of large, low-grade ore deposits via open pit mining methods began in earnest at the start of the twentieth century, pioneered in the large copper porphyry deposits of the American Southwest. Lower costs as compared to underground mining, better safety conditions, and improved mining and processing technologies enabling the exploitation of low grade ore deposits have resulted in the widespread adoption of surface mining techniques. The *Canadian Minerals Yearbook 2007* (2009) identifies that surface mining represents nearly 80% (by mass) of traditional metal and non-metal mining activity in Canada. When sand, gravel, and quarried stone are included approximately 90% of ore production is from surface mines. The addition of bitumen ore extracted by surface mining methods increases the proportion of ore sourced from surface mining to 95% (Table 3-1). Although 2006 is the last year for which Natural Resources Canada published mine production by mine type data, the nearly 50% growth in bitumen production from oil sands mining since that time has likely increased the dominance of surface mining production in Canada.

### 3.1 Scope and Intention of the Analysis

The rapid proliferation of computer technology in the second half of the twentieth century has further spurred the growth of the open pit mining industry. The use of computers to aid in the analysis, design, and operation of open pit mines has been critical in the safe and profitable exploitation of increasingly lower grade and deeper deposits via surface mining.
methods. Maximizing the net present value of a project is the usual objective of mine planning. Achieving this objective through the optimization of the planning process has been the subject of significant research and development over the last fifty years, and new developments continue in the field.

Despite advances in the available algorithms, procedures, and software in surface mine planning, the role of the human planner is still paramount. It is particularly important for the mine planner to have a holistic understanding of mine planning as the different planning activities are highly interdependent. A decision at any stage of activity will not only influence future work, but may also demand revisiting and revising earlier evaluations. For example, the bench height in mining is typically the same as the block height used for the block model. The bench height is a key constraint in the selection of loading equipment, but anticipated loading equipment, based on deposit size, may be a constraint in the selection of block height. Thus one of the first decisions made in the planning process, the block size, is dependent on a loader size constraint that is itself constrained by the original decision of the block size. Nearly every decision in the planning process involves a similar ‘chicken or egg’ dilemma. This requires that the planners have a comprehensive understanding of the potential implications of their decisions on later stages of the project, as well as understanding of whether their decisions at any given stage of planning require revisiting earlier analysis.

A consequence of not having an understanding of the interdependencies in the planning system may be a plan that achieves a local goal at the expense of the broader plan objectives (Whittle, 2011). Hence, the application of experience and judgment in selecting planning inputs is considered to be as important to producing improved results as the software or optimization algorithms themselves (King B. , 2011; Kear, 2006).
Table 3-1: Canadian mine production by mine type (2006)

<table>
<thead>
<tr>
<th>Commodity Class</th>
<th>Underground Ore</th>
<th>Open Pit Ore</th>
<th>Underground Waste</th>
<th>Open Pit Overburden &amp; Waste Rock</th>
<th>Open Pit Tailings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>37 424</td>
<td>211 855</td>
<td>5098</td>
<td>209 876</td>
<td>229 856</td>
</tr>
<tr>
<td>Non-metals</td>
<td>44 007</td>
<td>21 614</td>
<td>2374</td>
<td>52 478</td>
<td>13 568</td>
</tr>
<tr>
<td>Coal</td>
<td>1 670</td>
<td>79 408</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Structural materials</td>
<td>0</td>
<td>421 247</td>
<td>0</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Oil sands*</td>
<td>0</td>
<td>480 000</td>
<td>0</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>83 101</strong></td>
<td><strong>1 214 124</strong></td>
<td><strong>&lt;1%</strong></td>
<td><strong>&gt;99%</strong></td>
<td></td>
</tr>
</tbody>
</table>

Proportion of production

<table>
<thead>
<tr>
<th></th>
<th>Underground Ore</th>
<th>Open Pit Ore</th>
<th>Underground Waste</th>
<th>Open Pit Overburden &amp; Waste Rock</th>
<th>Open Pit Tailings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metals</strong></td>
<td><strong>6%</strong></td>
<td><strong>94%</strong></td>
<td><strong>&lt;1%</strong></td>
<td><strong>&gt;99%</strong></td>
<td></td>
</tr>
</tbody>
</table>

* 2006 bitumen production of 240Mbbl synthetic crude oil was converted to an approximate production of 480Mt of oil sands.

The results of optimization activities undertaken during planning are limited by the quality of the inputs to the optimization study. In mining, uncertainty exists due to limited geologic sampling that results in an imperfect understanding of the ore body under consideration, the need to forecast future commodity prices and currency exchange rates, and the need to make assumptions regarding capital and operating costs, amongst other inputs. Often planning and design decisions are made on the basis of limited study, and there is still a strong reliance on simple approaches, and in some cases heavy reliance on rules of thumb, in some critical planning activities (King B., 2011; Smith, 1997; McCarthy, 2002; Hall, 2006; Grobler, Elkington, & Rendu, 2011).

No global optimizer exists for open pit mining; this will be discussed in greater detail in Section 3.9. Instead, sub-activities within the planning system are optimized in isolation, or co-optimized with one or two other activities. ‘Optimization’ activities often involve the use of heuristic approaches, including ‘rules of thumb’ and metaheuristic methods. This is due in part to the computer processing time demanded by the large size of mining models (both the number of blocks and number of block attributes), and the complexity of the problem (the number of decision variables and constraints). It is critical that the mine planner understand that optimizing a series of activities individually is not likely to produce a globally optimum solution. A local optimization which imposes constraints on other planning activities may significantly harm the potential value of the project.

This chapter will present a review of a generic open pit mine planning process as it proceeds from strategic planning through short range operational planning (Figure 3-1). To support a system level understanding of the process UML activity diagrams are used in the description. The full set of diagrams is included in Appendix A, diagrams A-1 through A-20. The
review is of typical industry practice with respect to the decision-making process. The system presented will be used as a basis for comparison with a case study of oil sands mine planning (presented in Chapter 4) in order to identify possible limitations or areas for process improvement in oil sands planning.

Figure 3-1: The open pit planning process

To facilitate the later comparison study between conventional and unconventional planning systems (presented in Chapter 5), the review in this chapter presents a description of typical planning practices. The review should not be considered to represent ‘best practices’ for all undertakings. For some activities the fact that currently available best practices are not commonly used by mine planners is highlighted.
The planning process described is directly relevant to open pit hard-rock, metal mines using truck and shovel mining methods, although portions, or all, of the activities and methods are employed by other sectors of the surface mining industry. To enable a relevant comparison with the unconventional oil sands planning methods discussed in Chapter 4, a single commodity metal mine with no stockpiling is assumed. The decision process between open pit and underground mining methods is not relevant to the case study and is not explored, nor is related analytical work that provides inputs to the planning exercise, such as the development of the reserve model, metal price forecasts, or geotechnical parameters.

A summary of research and development activities relating to mine planning, and specifically mine optimization, is presented at the end of this chapter.

### 3.2 Conventional Approaches in Open Pit Mine Planning

Typically the objective of mine planning is to produce a feasible mine plan that maximizes the net present value (NPV) of the deposit under study. In some cases the objective may differ, and could be to maximize short term cash flow from the operation, to maximize employment (e.g. a government-owned mine), or to maximize resource recovery (e.g. regulatory control). A feasible mine plan means that the plan satisfies all constraints. In open pit mining, constraints include societal and regulatory constraints (variable by jurisdiction), technologic constraints (required equipment and processes exist), geometric constraints (mining precedence, minimum working areas), and economic constraints in the form of available capital.

The mine plan is developed by mine planners. The mine planners are a class of technical employees. Mine planners are typically, although not exclusively, trained mining engineers and technologists. Mine planning interacts with a variety of other planning areas, and is influenced by corporate objectives and constrained by regulatory requirements. Some aspects of the business
planning system employed by mining companies are presented in Figure 3-2, with an emphasis on the role of the mine planner and the main stages of the mine planning system.

Figure 3-2: Select aspects of the mine business planning system
3.2.1 Strategic Planning

Strategic mine planning seeks to answer how best to develop an ore body in support of the objective of maximizing NPV. Development of a strategic plan may represent the totality of planning at the conceptual or scoping stage of mine planning. Strategic planning should continue throughout a mining project’s life, from scoping studies through active mining to the cessation of mining.

Strategic planning establishes the potential project value on the basis of:

1) identifying what material is to be mined through pit limit analysis (deciding the shape and extent of the final pit);

2) defining the optimal mining sequence (determining the order in which to mine the material);

3) defining the destination for each parcel of rock mined (identifying if material is waste or ore, and the process stream if ore); and,

4) establishing the rate at which the deposit should be mined and processed (selecting the production rate or mine life).

Strategic planning should also consider the environmental and waste handling impacts associated with mine development to ensure that adequate baseline and technical studies are initiated to support future planning work and regulatory approval.

Strategic mine planning requires, at a minimum, a definition of the objective(s) of the study, a block model containing information on block characteristics (grade(s), density, process recovery, etc.), an understanding of geotechnical constraints (allowable pit slopes), and estimates of commodity sale prices, mining and process operating costs, and capital costs.
3.2.2 Long Range Planning

Long range mine planning (LRP), or long term production planning, begins with pre-feasibility studies and is ongoing throughout the mine’s life. The objective of LRP is still to maximize the NPV of the project, but practical mining constraints now begin to be examined in more detail. LRP incorporates and advances the activities of strategic planning, identifying and evaluating in greater detail alternative planning scenarios for the mine’s development. The quantity and quality of data relating to the ore body’s characteristics, expected costs, and other planning inputs increases with more detailed pre-production studies and with experience gained after a project is brought into production, reducing uncertainty as planning progresses.

Unfortunately, key decisions related to mining sequence, processing rates, and cut-off grades, must be made on the basis of limited information and analysis during early conceptual and pre-feasibility studies. These decisions are often accepted as robust and not reexamined for suitability as planning progresses and more information becomes available. These are key inputs and the planning activities associated with their optimization should be revisited as plans are refined and additional information about the project becomes available.

The long range plan produces a life of mine (LOM) plan. Tactical decision making begins during LRP. Decisions related to the type of equipment used and the size and number of units are one of the outputs of LRP. Long range production planning (scheduling, equipment and labour forecasts, etc.) is done on the basis of annual time periods, although in the near term (0 to 5 years) quarterly planning should be conducted, and in the far-term (beyond 20 or 30 years) planning may employ up to a 5 year time period. A new LOM is normally generated on an annual basis for a producing mine.
3.2.3 Short Range Planning

Short range mine planning (SRP), or production planning, further develops and implements the specific tactics or means by which the long-term plan will be achieved. The short range plan is limited in terms of the degree of influence it has in establishing a project’s value, and SRP receives very little attention in mine planning literature. However, the tactical decisions made during SRP activities can cause significant damage to a project’s value if they are not consistent with the LRP (Hall, 2006).

The objective of SRP is normally to meet the mill’s demand forecast (i.e. produce a specific number of tonnes with specific characteristics) while respecting the long term plan. The objective is not normally to maximize production or profit for the budget month or quarter, although performance metrics sometimes emphasize production quantity over quality. Short range planners must resist the urge to make isolated strategic decisions which may negatively impact the overall value of the project. High-grading to meet production targets at the cost of long-term ore production, and the habitual deferral of waste stripping to avoid short term mill restrictions, are two examples of valid tactical approaches which may increase profit in the short term but be at odds with the LRP and strategic planning goals.

SRP involves detailed operations planning for a rolling twelve to eighteen month period, normally on a daily, weekly or bi-weekly, monthly, and quarterly basis. The plans specify the production targets, maintenance activities, what equipment is to be used, where it will be located, the production rate expected of each piece of loading equipment, and where the material mined is to be routed. Key considerations include blending for the process plant, planning the dump advance, ensuring the correct handling of potentially acid generating rock (PAG), maintaining
waste stripping in support of the LRP, and ensuring adequate ore inventories (ore which can be mined without further waste stripping).

3.2.4 The Planning Process

In practice, the process of planning an open pit mine is typically iterative. As planning progresses and key decisions such as production rate and mining sequence are made, the ability to influence cost diminishes. So, too, does the ability to positively impact value (assuming no new identification of reserves).

As mine planning progresses, initial planning assumptions are refined. This may trigger a review and potential revision of earlier analysis. Improvements in the quality and quantity of available data may help to reduce the uncertainty associated with the mine plan, but do not completely eliminate it. At all stages of the process, from early conceptual and pre-feasibility work through feasibility and detailed long and short range planning, the evaluation of multiple planning scenarios and the sensitivity analysis of input parameters is critical to successful mine planning. The end product should be a plan that is robust enough to remain economically attractive under a range of variations from initial planning assumptions.

3.3 The Block Model

The block model, or for stratified, layered deposits the gridded seam model (Gemcom Minex FAQ, 2012), is the basis of modern open pit mine planning. A block model is a regularized, three dimensional array of blocks (or voxels) used to represent the properties and characteristics of the ore body (Figure 3-3). The raster representation of the ore body is beneficial to analysis using computerized techniques and has resulted in the development of a
variety of algorithms and software packages that use the discretization of the ore body into a block model as their basis.

The block size is determined to a large extent by the deposit type. For mine planning purposes the block size should correspond to a reasonable mining increment, such as a shift or day’s production for a piece of loading equipment. This is termed the selective mining unit (SMU). The height of the block normally corresponds to the mining bench height.

The need for greater selectivity during mining (the ability to mine waste separate from ore) typically indicates a smaller bench height and smaller or more selective equipment to reduce dilution and mining loss. In deposits where selectivity is not an issue, a larger mining bench may be used. Smaller block sizes are to be avoided as they significantly increase model size and processing time for deposit analysis, as well as increasing the block estimation error.

Figure 3-3: A block model constrained by mineralization and coloured by block attribute
Any number of attributes may be associated with the blocks. Properties such as rock type, density, material grade (% metal for most base metal and g/t for precious metal deposits), and deleterious element concentration (typically ppm) are populated to the blocks. Other properties such as the ore type, resource classification, expected process recovery, classification of the block as potentially acid generating (PAG) or potentially acid neutralizing (PAN), etc. may be assigned to the blocks during mine planning on the basis of other studies. The properties of the deposit at each block location are populated from the geologic model and by geostatistical (e.g. kriging, simulation) or conventional (e.g. inverse distance weighting, polygonal) estimation methods.

Estimation of block properties represents one of the largest sources of technical risk in mine planning. Uncertainty with respect to ore grade and tonnes can have a critical, and often negative, impact on the economic success of a mine. Although the values vary with deposit and mine type, the literature suggests that between 20% and 73% of mines which failed to meet economic performance expectations identify problems with reserve estimates as a key contributor to failure (King, McMahon, & Bujtor, 1982; Vallee, 2000; Sinclair & Blackwell, 2002).

3.4 Pit Geometry

Geotechnical constraints define pit geometry, establishing what the shape, and, to the extent that the constraints influence waste stripping requirements, the size of the ultimate pit will be. A discussion of the development of pit wall criteria is beyond the scope of this thesis. Rock Slope Engineering by Wylie and Mah (2004), and Practical Rock Engineering by Hoek (2007) provide good coverage of the subject.
3.4.1 Pit Wall Criteria

Determination of the stable bench face height and slope, catch bench or safety bench width, the inter-ramp slope angle (slope angle between roads) and the overall slope angle (average pit slope angle) are important design considerations and can have a significant influence on the mine plan.

In determining pit slope geometry consideration is given to the rock type, including its friction angle and cohesive strength, the orientation of the pit wall relative to any discontinuities in the rock mass, and groundwater conditions. The final slope height and potential groundwater drawdown via dewatering wells are also considered.

Pit geometry will be impacted by the addition of haul ramps during detailed design (see Figure 3-4and Section 3.7.2.3). The pit wall criteria may guide the placement of haul ramps, especially in mines where one wall or portion of the pit has a much shallower maximum allowable slope; the introduction of the ramp to that wall may help achieve the shallower slope while reducing the impact of increased waste stripping associated with ramp incorporation elsewhere. It is prudent to ensure that locating the mine ramp on a wall with a shallow allowable slope does not place the ramp in jeopardy due to expected poor stability conditions.
3.5 Economic Forecasting

In order to perform pit limit analysis the value of each block in the model must be calculated, creating an economic block model. The value of the individual blocks is a function of cost to mine and process the block, the block grade, block tonnage, expected metallurgical recovery, expected commodity price, and expected sale costs (including smelter charges, transportation, marketing, etc.). The block value is determined by the following equation:

**Equation 1: Block value calculation**

\[
Block\ Value = (block\ tonnes \times block\ grade \times recovery \times metal\ price - block\ tonnes \times ore\ costs) - block\ tonnes \times waste\ mining\ cost
\]

where: block tonnes are the tonnes of rock in the block,
block grade expresses the block’s metal content as % or units of metal per tonne,
recovery is the percent of metal recovered by processing the block as ore,
metal price is the sale price of the metal in $/kg or $.g, minus any charges (smelter, transport, etc.).
ore costs are the additional costs associated with processing the block as ore rather than treating it as waste and expressed in $/t, and waste mining cost is the cost of mining a tonne of waste.

If the value realized from mining and processing the block as ore exceeds the cost of mining and treating the block as waste it will have a positive value. Marginal blocks have low metal content, but will generate sufficient value such that treating the block as ore produces a smaller loss than treating the block as waste. They will have a negative value (a cost), but it will be a lower cost than if the block was treated as waste. Waste blocks are blocks that do not have sufficient mineral content to offset the additional costs associated with processing the block.

3.5.1 Commodity Price Forecasting

In determining the pit size and shape that will produce the maximum NPV, future commodity prices are an unknown variable that must be forecast.

In strategic planning a single forecast commodity price is used and should be representative of the expected commodity price over the life of the mine. In LRP, particularly once a mine enters development, a near term price forecast (0 to 2 or 0 to 5 years) and a long term price forecast are often used. The expected price should be neither optimistic nor pessimistic. That is, an unlikely ‘high’ forecast should not be used to force an otherwise marginal or uneconomic project into production, nor should a pessimistic ‘low’ price be used to introduce conservatism to the project. A sensitivity analysis should be performed to analyze the performance of the project over the range of expected metal prices, as well as for other economic parameters including discount rate and exchange rate. The anticipated best and worst case scenarios will help to indicate the upside and downside potential of a mine.
The commodity price is not specific to a project, but rather should be a common assumption across all projects within a company. Price forecasting is a specialized task which may involve econometric modeling (Hustrulid & Kuchta, 2006). Price forecasting is not normally done by the mine planning team.

Related to commodity price forecasting is the forecast of the expected costs associated with the sale of the concentrate produced by the mine. These may include smelter costs, transportation costs, and marketing costs. A concentrate may be subject to penalty if it contains high amounts of undesirable metals (e.g. bismuth or arsenic in copper concentrates). In some cases the available smelters which will accept a concentrate may be limited due to deleterious materials. The actual payment to the mine for producing a unit of metal (the net smelter return) may be significantly lower than the commodity price. Hustrulid and Kuchta (2006) indicate that payment to the mine for base metal concentrates range from 50% to 95% of the contained metal value. Calculation of the net smelter return is described by Lewis and Streets (1978).

3.5.2 Mining and Process Cost Estimation

Mining and processing operating costs represent a second class of variables that must be estimated in order to carry out a pit limit analysis. Unlike commodity price forecasts the estimation of these costs does typically fall to the planning team.

There are a variety of methods that can be used in the estimation of operating costs. In the early stages of the planning process, when little is known about the ultimate size, scale, and depth of the potential pit, a high degree of engineering judgment must be applied to select an appropriate set of costs for initial evaluation. As planning progresses and the scale of the mine is better understood these costs are re-evaluated. The ultimate size of the mine and the production rate are dependent on the operating costs, and the operating costs are dependent on the production
rate and size (particularly depth) of the mine; cost estimation is part of the iterative and circular analysis that defines mine planning.

Operating costs may be estimated on the basis of cost models, by benchmarking similar operations, by developing costs from first principles, or in the case of short range planning and LRP for an active mine on the basis of historic costs. Cost models include those developed by the United States Bureau of Mines (1987a,b), O’Hara and Suboleski (1992), Camm (1991), and Singer, Menzie, and Long (1998). These models provide a very general approach to cost estimation and are not appropriate for planning. The Mining Cost Service and the Mine and Mill Equipment Costs Estimator’s Guide are potential sources of cost estimating data. Commercial software-based models exist which provide detailed engineering estimates of operating costs. Mining companies and consulting firms often develop their own cost models in-house on the basis of experience and detailed cost databases. Whatever the model used, it is important that the planner be able to apply sound engineering judgment in the selection and adjustment of costs to reflect the unique conditions at the mine under study.

Benchmarking may be used when costs are available for similar mining operations. It is important that the mines used for benchmarking are analogous to the mine under consideration, otherwise their costs will not be relevant. This approach is particularly relevant for mining companies that might operate multiple mines exploiting similar ores by similar methods within the same regulatory jurisdiction. Care is still required in adapting these costs for the mine under study.

Detailed cost estimates are developed during the later stages of planning. Historic or past costs are typically used in LRP by active mines.
3.5.3 Process Recoveries

Expected process recoveries are determined on the basis of bench-scale and, as a project progresses, pilot plant testing. Process recovery should be determined for each ore type in the deposit as well as for each potential process path.

3.6 Strategic Planning

As described, strategic planning seeks to identify a feasible mine plan that maximizes the NPV of the project. The primary activities that generate the strategic plan are shown in Figure 3.5 and described in greater detail in Sections 3.6.1 through 3.6.6. Modeling of the sub activities indicated is presented in detail in Appendix A, Figures A-2 through A-8.

The strategic plan should establish the method and technologies to be employed in developing the deposit and answer the questions:

1. what blocks should be mined (pit limit analysis)?
2. what order the blocks should be mined in (mine sequencing or phasing)?
3. what destination the block should be routed to (cut-off grade analysis)?; and,
4. at what mining and processing rate should the deposit be mined (production rate determination)?

The strategic plan should also identify the planned end use or closure state for the project. Jurisdictional requirements and the unique properties of each ore body mean that reclamation costs vary widely from mine to mine. High anticipated reclamation costs, and societal and jurisdictional attitudes towards mining are important considerations in project evaluation.

Finally the plan should provide a high-level mining schedule.
3.6.1 Pit Analysis

The activities in pit analysis are presented in detail in Appendix A, Figures A-3 and A-4.

3.6.1.1 Pit Limit Analysis

The location of the ultimate pit limit or the final wall is the first activity of mine planning and is an important determinant of mine value. The objective of pit limit analysis is normally to maximize the undiscounted value of the ore deposit; optimizing the pit to maximize the NPV based on a discounted valuation follows in later stages of planning. The undiscounted value is used to determine the pit limit as the timing of material extraction cannot be known until the material to be removed has been identified, a production rate established, and the order of mining or mining sequence established.

The Lerchs-Grossman (LG) algorithm (Lerchs & Grossman, 1968) is the most commonly applied optimization algorithm in determining the pit limit. The LG algorithm provides a mathematically optimum solution to the problem of maximizing the pit value. Non-optimizing heuristic approaches, including the floating cone algorithm, may also be employed and in many cases will provide a reasonable result.

Commercial software is normally used to perform a pit limit analysis. Specialized strategic planning software packages include Gemcom’s Whittle which employs the LG algorithm, Datamine’s NPV Scheduler which employs the LG algorithm, Minemax’s Scheduler which employs a push-relabel algorithm, and ThreeDify’s FlowPit which is based on the LG algorithm. Most general mine planning software packages (GMP) will also perform pit limit analysis including Mintec’s MineSight and Maptek’s Vulcan, both of which allow the user the choice of either the LG or floating cone algorithm.
Strategic Planning (SP)

1. Perform PIT ANALYSIS A - 3
2. Evaluate CUT-OFF GRADE A - 6
3. Schedule MINING A - 8
4. Develop RECLAMATION PRINCIPLES A - 7

- Assume production capacities on basis of modeled resource
- Costs consistent with pit analysis
- Costs inconsistent with PIT ANALYSIS
- Schedule not viable/attractive
- Financial evaluation
- Project attractive
  Proceed to detailed long range planning
- Schedule satisfactory
- Project not attractive
  Shelve.

Figure 3-5: Conventional planning activity diagram-strategic planning
Pit limit analysis requires an economic block model, discussed in Section 3.3, and is constrained by the maximum allowable pit slopes. Although the algorithm used may vary, the objective is usually the same: to maximize the undiscounted value of the pit. Each operates under the same fundamental principle: a block is mined if, and only if, it pays for its own mining and processing, as well as for the mining of any overlying sub-economic blocks that must be mined in order to access the block under consideration. Marginal blocks (see Section 3.5) will have a negative value, but it will be less than the cost of treating the block as waste (Figure 3-6).

**Figure 3-6: A simplified 2-D pit limit example**
3.6.1.2 Nested Pit Generation

In addition to identifying the optimum pit limit, pit limit analysis is also used to identify a series of sub-pits or nested pits within the final pit limit. The purpose of these nested pits is to establish the transition from the most profitable material (highest value per unit mined) in the pit to the least profitable or break-even material, which occurs at the pit limit. This understanding will aid the planner in selecting where to begin mining, and in what sequence to mine the pit out in order to produce the highest NPV from the material within the final pit limit.

The nested pits are generated at the same time as the pit limit using the same algorithm and methods; the difference is that one input (commodity sale price or processing cost) is varied (Figure 3-7). Most software uses the commodity price approach although the specifics of the implementations vary. The pit limit optimizing algorithm may be run for a series of fifty or more metal prices, with the final pit limit being the pit created at the ‘expected’ long-term commodity price forecast. Some prices may not produce a nested pit, and some pits will be small. The focus of such analysis is on pits created at commodity prices below the long-term expected price, and even below the worst-case price. These pits help the planner to identify the highest value per tonne portions of the ore body and thus guide the mining sequence. A limited number of pits may be created for prices up to the ‘best’ price forecast in order to assess potential expansions of the pit and to guide in the future location of infrastructure and waste storage facilities.
3.6.1.3 Determining Pushback Parameters

Most open pits are mined in a series of phases or pushbacks. An initial mining pit is established within the bounds of the final pit. The initial pit is then expanded in phases or pushbacks (i.e. pushing back the wall towards the final pit limit). The order in which the pit expands is the mining sequence. The specific time at which a given block is mined will be determined by the schedule, established during later planning. The initial pit contains high value material (higher than average grade and/or lower than average stripping requirements). Mining a smaller, high value pit first normally reduces the amount of waste that must be mined to access ore. If the grade of the material is higher than the pit average, a higher value per tonne of ore will result in the initial mill feed. These two factors combine to increase NPV by realizing larger profits earlier in the mine life.

Figure 3-7: A cross section showing nested pit progression
An illustration of the impact of using pushbacks is presented by Whittle (1990) and is commonly reproduced in the literature. For the section shown in Figure 3-8 a pit limit analysis is undertaken. Eight pit shells are generated. The mine can be developed to the pit 5 wall using two extreme approaches: the ‘best case’ or highest NPV sequence, and the ‘worst case’ or lowest NPV sequence.

The best case sequence requires mining of the nested pits sequentially. First pit 1, the highest value per tonne nested pit, is mined in its entirety, followed by the mining of pit 2, and so forth until the last pit (or pushback) is mined, achieving the final pit limit. Mining proceeds within each nested pit from the top elevation, or bench, to the bottom bench. Only when the first pit is exhausted does mining begin in the next pit or pushback. In this way waste stripping at the beginning of the mine plan is minimized, minimizing or deferring the costs incurred. The strip ratio increases with each successive pushback, as the waste mining demands increase.

The worst case schedule requires mining from all nested pits concurrently. Mining of the entire first bench, to the final pit limit, is completed before mining of the second bench is initiated and completed to the final pit limit, and so forth until the lowest bench in the mine is exhausted. In this way maximum waste stripping (and associated cost) is incurred early in the mine life, declining over time. The advance or deferral of the costs associated with waste mining mean the NPV impact of using the best versus worst case mining scenario would be significant.
Figure 3-8: Pushbacks and mine sequencing (Whittle, 1990)

Unfortunately, the generation of a pit outline in the process of creating nested pits does not mean the indicated pits can be mined independently. This is evident in the 4 pit shells immediately preceding the ‘expected’ case pit in Figure 3-7, which are too small to support equipment placement. While all of the material within the final limit will be mined, not all nested pits will be used to define the locations of interim walls. Instead multiple nested pits will be coalesced into pushbacks. A schedule which seeks to balance ore and waste mining was developed for the pit shells in Figure 3-8, and discounting was applied to the block values. As indicated by the tonnes-value curve in Figure 3-8, pit five is the highest value pit given the assumed cost and price inputs.

The size and number of pushbacks will be determined by factors which include the size of equipment and its minimum working requirements, the size and characteristics of the ore body, the number of working faces required, and management/planning preference. Selection of pushback size and width are determined largely based on experience, preference, and conventional wisdom. The typical activity flow in establishing pushback parameters is presented in Appendix A, on diagram A-4.
The one constant factor in determining pushback size is the minimum mining width. Loading equipment and haul trucks require a minimum width to operate in. Efficient mining requires the use of a width greater than the minimum mining width. Conventional wisdom suggests that pushback width should be at least 2 to 3 times the minimum mining width. A discussion of minimum mining width calculation and mining face advance can be found in Hustrulid and Kuchta (2006). Although it is commonly accepted that wider pushbacks result in lower operating costs, no studies were found quantifying the relationship between pushback width and productivity or cost.

The NPV impact of using pushbacks will be lower in deposits that have relatively constant stripping ratios (waste tonnes: ore tonnes) and a fairly even distribution of ore grade. In such mines a pushback may contain 4 or 5 years’ worth of production. In mines with high variability in the stripping ratio between pushbacks (such as in Figure 3-8), and/or grade distribution, the impact can be significant. In these mines the tonnage of the pushbacks will be lower in order to maximize NPV. This will be described in more detail in Section 3.6.1.4.

3.6.1.4 Pushback Selection/Mining Sequence

Once the pushback design parameters have been established the pushbacks to be used can be determined. Although traditional pit limit optimization identifies the pit outline that produces the highest undiscounted value the goal of planning is to maximize the NPV of the project; discounted values matter. As introduced in Sections 3.6.1.2 and 3.6.1.3, the practical implication is that it is more desirable to mine higher value material early in the mine life. Mining of low value material should be deferred as long as possible; a series of nested pits is generated to guide this. The nested pits may or may not represent desirable or even feasible mining geometries.
Instead, a limited number of the nested pits are selected, and their pit walls represent the pushback advance.

It is obvious that the best-case sequence in Figure 3-8, mining each nested pit to completion sequentially, is likely not feasible. In Figure 3-7, some or all of the nested pits may contain sections that are too narrow to mine, would require numerous equipment moves into new working faces resulting in lower equipment productivity and higher per tonne costs, or, because of limited tonnages available on the benches, require rapid sinking of the pit. These issues are potentially solved by specifying a minimum width for each pushback discussed in Section 3.6.1.3. In specifying a minimum pushback width, a geometric constraint is introduced that will result in the final mining sequence’s NPV being lower than that indicated by the best case.

Perhaps more importantly, the mining of a pushback is not instantaneous. The best case sequence in Figure 3-8 would almost certainly result in periods of exclusively waste mining and exclusively ore mining. Regular mill shutdowns are not a practical plan, would challenge staffing, would almost certainly result in increased operating costs, and would require a larger mill (with attendant increased capital costs) in order to achieve the same commodity production (the mill would process the same tonnes of ore over the life of the mine but would require increased capacity as it would not operate during periods of exclusive waste stripping). The actual mining sequence will lie somewhere between these two extremes and will be defined by the initial pit and the selection of a series of pushbacks.

A variety of techniques exist to try to provide an optimal pit outline that accounts for discounted cash flow, but most are marred by simplified assumptions regarding mining rates. Gemcom’s Whittle software offers a discounted pit shell technique (DPS) that produces improved results, but is not an optimization. Training documentation for Gemcom’s Whittle software
indicates that the conventional method to seek a maximum NPV is still in wide use and has
delivered acceptably good results (Gemcom Software International, 2008). This method can be
implemented by a mine planner in any of the specialized or GMP packages available for pit limit
analysis. The method requires production of a pit limit and nested pits as described in Section
3.6.1. From the pit limit analysis the planner proceeds to run a number of different sequences for
different final pit limits for which the NPVs are generated. This activity can be done manually,
semi-automated, or automated and is presented in Figure 3-9. Practical pushback constraints, such
as minimum mining width or maximum number of concurrent working benches, can be imposed
by the planner to eliminate infeasible scenarios, reducing the number of sequences to analyze.
This is illustrated by the activity diagrams on diagram A-4 of Appendix A. The pit which
produces the highest NPV can then be identified; it is likely not the optimal undiscounted pit.

Selection of the nested pits or pushbacks that form the mining sequence follows from the
above analysis. Just as practical constraints can be introduced to reduce the number of scenarios
required, judicious elimination of nested pits from consideration will also reduce the number of
scenarios to analyze. Two graphs should be examined: the tonnage-value graph (Figure 3-10)
and the pit-by-pit tonnage-value graph (Figure 3-11).
Select Pushbacks

[Insufficient pits. Revise pit analysis. Increase number of pits]

[Sufficient pits for selection of appropriate pushbacks]

Select pushbacks that meet criteria

Rough check of stripping ratio and total tonnes per pushback selected

[Tonnages and/or ratios require adjustment]

[Output pushback sequence]

Figure 3-9: Conventional planning activity diagram - pushback selection
Best and worst case scenarios produce identical values; no scheduling risk.

Best and worst case scenario values deviate; increasing scheduling risk as deviation increases.

Scheduling has the capacity to add over 200% to the pit value at 350 Mt.

Figure 3-10: Cumulative tonnage-value graph
Figure 3-11: Cumulative tonnage and value graph by pit
The tonnage-value graph illustrates the increase in pit value as a function of pit tonnage. The curve will be different for each ore body but the general characteristics will be the same. In particular an increase or decrease in tonnes around the tonnage which produces the highest value pit will have a smaller effect on pit value than an increase or decrease in tonnage of similar magnitude for a smaller (lower tonnage) pit. Intuitively this makes sense. The tonnes added to the pit at the peak of the curve, or at the final pit limit, are the tonnes that required higher commodity prices to be economically attractive to mine. They have a lower value per tonne than those added near the start of the curve. This means that significant value can be added to or lost from a project when dealing with even small changes in the highest value nested pits, whereas small changes to the lower-valued pits will have essentially no impact on project value. Scenarios should therefore be focused on the sequencing of these highest value pits in order to maximize NPV and reduce project risk. The behavior on this graph is also an important consideration during LRP and the generation of mine access ramps.

The pit-by-pit tonnage-value graph, with best- and worst-case sequence NPVs calculated, can also be used to guide pushback sequence analysis. The value curve in Figure 3-11 indicates large changes in value and tonnage with the addition of certain nested pits or pushbacks. Certain pushbacks also mark increases in the deviation of the worst case NPV from the best case NPV. Where the two NPV lines are close (or identical), the impact of the sequence and schedule on the NPV is minimal; as they diverge the impact of poor planning on NPV becomes greater. The selection of pushbacks that precede a sudden increase in distance between the two curves will generally provide better NPV results.
3.6.2 The Production Rate Decision

Identification of the optimal pit limit will provide a resource estimate and in turn allow a preliminary production rate to be established, although the determination of an appropriate cut-off grade may cause a change in the resource estimate and trigger a revisiting of the production rate decision. The application of rules-of-thumb is most often used to establish an initial production rate. Once this base rate has been established it is important that scenarios are analyzed in which the production rate is both increased and decreased to examine the impact on NPV. The operating and capital costs should be adjusted accordingly for each scenario. The activity diagram for determination of the production rate is presented in Appendix A, on page A-5.

The most commonly identified production rate rule of thumb is Taylor’s Rule (Taylor, 1986), presented in Equation 2, although Smith (1997) identifies some other commonly used rules of thumb.

**Equation 2: Expressions of Taylor’s rule**

\[
\text{Mine life} = 0.2 \times \text{expected reserve}^{0.25}
\]

or,

\[
\text{Production rate} = 5 \times \text{expected reserve}^{0.75}
\]

where: mine life is in years,

expected reserve is in tonnes, and,

production rate is in millions of tonnes per year (Mt/a).

Taylor’s Rule can be implemented to produce either a suggested ore production rate or a mine life.

It is important to stress that Taylor’s Rule is an empirical relationship. It is not a predictive tool and does not provide an optimized production rate, despite sometimes being
described as Taylor’s Law. The rule is based on a study comparing the reserves to production rate (or mine life) at a small number of open pit mines. There is some debate about the performance of Taylor’s Rule and some have proposed different constants (Singer, Menzie, & Long, 1998; McSpadden & Schaap, 1984; Long, 2009).

Smith (1997), McCarthy (2002), and Long (2009) identify Taylor’s Rule as a good starting point for further analysis but stress the need for scenario analysis to define an appropriate production rate. The apparent lack of this analysis in practice is recognized (Smith, 1997; McCarthy, 2002; Hall, 2006). Such analysis is facilitated by strategic planning packages and can be conducted in a short period of time. Grobler et al (2011) present an approach to selecting a production rate in the face of commodity price uncertainty, and Whittle (2011) describes the use of commercial software to optimize mine and mill capacities over the life of the mine.

The production rate may be constrained by the capital requirements of the project. It will also be limited by the available working space. Detailed simulation studies should take place during LRP. In some cases the production rate decision will be the result of regulatory intervention or stipulations (Allen, n.d.; Gibson, 2006).

Taylor’s Rule has been widely accepted as a means of determining a mine’s production rate. The author believes that the observation that the production rates at existing mines generally correspond to Taylor’s Rule (Long, 2009) may be explained at least in part by the fact that its use in determining the production rate is widespread. This is identified in Chapter 7 as a crucial area for future research.
3.6.3 Cut-off Grade Policy

In pit limit analysis, “ore” is mined if it will pay for its own removal and processing as well as the removal of any overlying waste. Once a pit limit has been identified the discrimination between ore and waste changes. All blocks within the limit will be mined and presumably hauled to surface. Since the cost to mine any individual block will be incurred whether or not it is to be processed (waste must be mined to expose ore) only the incremental cost of mining and treating a block as ore should be considered in evaluating cut-off.

A detailed discussion of cut-off grade policy is beyond the scope of this work. The classic approach to the cut-off question is provided by Lane (1964, 1988), and Rendu (2008) provides a good treatment of the topic. Hall (2006) describes an approach to the co-optimization of cut-off grade and production rate. Although sophisticated approaches to establishing an improved cut-off policy exist it is the both author’s experience and reported in the literature that a simple breakeven cut-off grade is often used in practice (Dagdelen, 2001; Hall, 2006). In diagram A-6 presented in Appendix A, a breakeven approach to cut-off grade selection is assumed. The breakeven cut-off is calculated using Equation 3:

**Equation 3: The breakeven cut-off grade**

\[
G = \frac{m}{(p - s) \times r}
\]

where:  
- \( G \) is the cut-off grade (kg/t),  
- \( m \) is the milling cost ($/t),  
- \( p \) is the sale price of the commodity ($/kg),  
- \( s \) is the sales cost (i.e. refining, marketing; $/kg), and  
- \( r \) is the process recovery (%).
3.6.4 Developing Reclamation Principles

The consideration accorded to waste handling and reclamation planning during strategic planning is normally limited. Although some high strip ratio mines may be challenged to physically locate their waste within their property boundaries, most metal mining plans are not waste-bound. At the early stages of planning, the assumption that adequate waste dump and tailings impoundment space will be available is often made. Although detailed planning may not take place it is prudent at this stage to identify:

- the site closure objectives;
- any materials of concern within the ore body from an environmental perspective for further study;
- preliminary structure designs or construction methods, including locations of tailings and mined waste storage facilities so site investigations can commence.

A valid estimate of the costs associated with both mining and tailings waste handling should be developed. These costs may have a significant impact on the economic and political attractiveness of a project.

A high-level activity diagram illustrating the key activities related to waste and reclamation planning is presented in Figure 3-12. Mining projects located in environmentally or culturally sensitive areas, which involve evaluation of a deposit containing potentially harmful materials from a health or environmental perspective, or which are located in jurisdictions that are not supportive of mining from a regulatory or societal standpoint, will devote more time to closure planning at the strategic stage.
Reclamation principles

Identify regulatory requirements

Define and prioritize corporate requirements

Develop site closure objectives

Develop waste structure design objectives

Develop dump and tailings design guiding principles

Identify waste material types

Identify materials of concern

Determine material balance

Identify & assess design alternatives

Preliminary waste structure design and cost estimates

Further geochemical testing prior to LRP

Detailed geotechnical site investigation prior to LRP

Figure 3-12: Conventional planning activity diagram - reclamation principles
3.6.5 Developing a Mining Schedule

Once the decisions on the limits of mining, the rate of mining, the demarcation of ore, and the sequence of mining have been made, the mine can be scheduled. In sequencing the mine we identify the preferred order of mining on the basis of net block value. In reality it is unlikely that mining of the initial pit, followed by the first pushback, then the second, and so on to the final pit limit would result in a desirable ore mining schedule. Instead we must identify at what point in the mining of the initial pit the mining of the first pushback should commence, at what point in time mining of the second pushback should commence, etc. The pushbacks themselves may be divided into subsets of material based on pit sector in order to minimize redevelopment of haul roads or moving of infrastructure such as an in-pit crusher.

Schedule development is an iterative process and if done poorly has the potential to have a significant negative influence on the NPV of the project. This is illustrated in Figure 3-11, where the difference in NPV between the best and worst case mining scenarios was $600 million, or approximately 1/3 of the value of the project.

Most software offers semi-and fully-automated routines to identify an optimal mining schedule. The planner, however, must make decisions regarding the minimum allowable mining width, the number of phases or pushbacks that can be mined concurrently, the degree of advance in one phase before mining can begin in subsequent phases, and the maximum allowable mining rate. The activity flow is presented in Figure 3-13. Although most of the actions are accomplished using software, the planner may intervene to accept or reject scenarios that do not meet their requirements.
Schedule mining

Determine scheduling goal

Assign ore tonnes from model until period production met

Determine waste stripping required to uncover ore; Assign waste to 1: Current period, then 2. Previous period (current -1), etc.

Calculate properties of scheduled ore production

[Properties acceptable (grade, deleterious content, etc.)]

Determine waste stripping required to uncover ore; Assign waste to 1: Current period, then 2. Previous period (current -1), etc.

[Waste mining exceeds capacity]

[Waste can be scheduled]

[Excess capacity in earlier period Waste can be scheduled]

Assign waste tonnes to earlier period

[All ore within pit limit scheduled]

Calculate NPV

[Properties do not meet process requirements]

[Waste can be scheduled]

[Excess capacity in earlier period Waste can be scheduled]

Assign waste tonnes to earlier period

[Ore remaining in ultimate pit limit]

[Alternative scheduling scenario possible]

[Waste can be scheduled]

[Insufficient unused capacity Waste cannot be scheduled]

[Revise ore scheduling and refine sequence/timing]

[Revise pit limit analysis, pushback parameters & selection]

[Insufficient unused capacity Waste cannot be scheduled]

[Revise ore scheduling and refine sequence/timing]

[Calculates properties of scheduled ore production]

[Properties do not meet process requirements]

[Properties acceptable (grade, deleterious content, etc.)]

[Properties do not meet process requirements]

[Insufficient unused capacity Waste cannot be scheduled]

[Revise pit limit analysis, pushback parameters & selection]

[NPV deviation from best case too great]
Scheduling should begin with the use of the indicated highest value pit from pit analysis as the final pit limit. A variety of scenarios should be run, varying the decisions listed. Scenarios should also be run for a few pits immediately preceding the indicated final pit; these may yield a higher NPV. The planner should be able to identify and focus additional scenario analysis on the pit that offers the highest NPV option.

Although automated scheduling is designed to maximize NPV subject to the constraints input by the planner (e.g. Whittle, MineSight Strategic Planner) the results may not be consistent with the desired mine production profile. In particular, attempts to maximize NPV at this stage often result in highly erratic rates of waste mining. These may require manual adjustment by the planner and may result in the use of semi-automated methods. Some planning packages are capable of applying production smoothing constraints to their automated scheduling routines.

Despite the increasing flexibility of automated methods in strategic planning software semi-automated methods are often favored by experienced planners. The time associated with schedule analysis is part of the reason; optimizing a schedule will take significantly more processing time than the original pit optimization, often hours versus minutes. Since many scheduling scenarios are run it is desirable to add intelligent constraints to the optimizer to reduce the number of possible schedules to be enumerated. The analysis of the curves presented in Section 3.6.1.4 may aid in this. For example, understanding that commencing mining in a subsequent pushback at the earliest, rather than latest, opportunity will negatively impact NPV should result in the planner selecting a large fixed lead (the number of benches in pit 1 that have to be mined before mining begins in pit 2).
3.6.6 Finalizing the Strategic Plan

Once the final schedule is decided on, the NPV for the project is identified. Sensitivity analysis should then be conducted on the proposed plan to develop a better understanding of the influence of various project inputs on the project’s value. These may include commodity prices, capital costs, operating costs, exchange rate, discount rate, recovery, reserve grade and tonnage, and mining dilution and loss. The sensitivity analysis not only indicates the key risk factors in the mine plan but may also help to guide trade-off decisions and studies towards more detailed planning and ultimate production. A base metal mine with gold by-product, for example, may want to conduct optimization studies on the mill flow sheet. As a high value metal there might be temptation (or pressure) to focus efforts on improving gold recovery. If the gold is present in small quantities the benefit realized from additional recovery may be marginal; from a value perspective the resources for the study (time, money and people) might be better spent on improving the recovery of the base metal.

The final product of strategic open pit mine planning should include decisions on:

- the suggested ultimate pit limit;
- the suggested production rate;
- the suggested cut-off grade policy;
- the proposed approach to reclamation; and,
- the proposed mine schedule.

The underlying assumptions regarding commodity price, capital costs, mining and process recoveries, etc. and their bases should be clearly presented.
The expected project NPV should be presented, as well as a best and worst case NPV generated under optimistic and pessimistic metal price forecasts. The mineable reserve should be identified.

Strategic planning should also identify key areas on which to focus analysis during long range planning. In particular it should provide guidance to later planners on the sensitivity of the project to scheduling decisions, and which decisions (number/size of pushbacks, fixed lead, number of concurrent pushbacks, etc.) are most influential. This will help to focus the analysis at later stages of planning.

There is no substitute for a thorough understanding of the impacts of the various planning decisions on NPV. Manual scheduling scenarios should be executed by new planners to allow them to develop their knowledge base by observing the impacts of a variety of criteria on project NPV. Training in planning software, an understanding of its limitations and the limitations of the underlying algorithms, an understanding of the limitations (or degree of accuracy) of the inputs to the planning process, an understanding of the interdependency of many of the planning activities, and an understanding of the objectives of the planning exercise, are all critical to developing a good planner. Time and experience are an important part of this development and sufficient planning resources should be allocated to allow new planners to develop under the mentorship of experienced practitioners.
3.7 Long Range Planning

Long range planning activities involve greater analysis in the development of assumptions, more emphasis on scenario analysis to identify preferred design choices and planning decisions, and greater detail in the scheduling of the mine than strategic planning. Tactical decisions about plan execution, including equipment selection, are part of the long range planning activities. The activities and subactivities that formulate the long term plan are presented in Appendix A, on diagrams A-9 through A-15.

As indicated in Figure 3-14, a number of the activities carried out during strategic planning are repeated by long range planning. The key difference in these activities is that the quality of assumptions made with respect to key planning inputs is greatly improved and the analysis is focused on further refining these assumptions and conducting thorough scenario analysis. The long range plan uses the strategic plan as its basis and produces a plan that contains both strategic and tactical decisions. More rigor is demanded in the planning activities, and the plan should move away from rules-of-thumb and simplified decision making towards engineering decisions made on the basis of detailed planning and analysis.

This section will focus on the generation of a detailed mine plan and its sub activities. Activities common to strategic and long range planning will not be revisited. The objectives, sub-activities, methods, decision-making processes, and outputs are the same.
Select PUSHBACKS
A - 4
[Pushback decision possible]

Determine CUT-OFF GRADE
A - 6

Generate DETAILED MINE PLAN
A - 10

Set production capacities

Determine production costs

Perform PIT ANALYSIS
A - 3

Define PUSHBACK PARAMETERS
A - 4

Select PUSHBACKS
A - 4
[Pushback decision possible]
[Cut-off cooptimized with production rate Increase/ decrease production rate]
[New scenario indicated Increase/ decrease production rate]
[Pushback selection indicates change in costs]
[More nested pits required]
[Mine plan indicates change in pushbacks]
[Mine plan indicates change in costs]
[Mine plan indicates different cut-off strategy possible]
[Mine plan indicates improved cut-off strategy possible]
[Mine plan indicates different pushback design]
[Mine plan indicates over/under utilization of capacity]

Determine production costs

Produce budget

[Detailed plan economics satisfactory]

[More scenario analysis required]

[Sufficient scenario analysis]

Subactivities follow SP flow and methodologies

Figure 3-14: Conventional planning activity diagram – long range planning
3.7.1 Production Capacity

In the pre-production stages the LRP normally begins with the production rate identified by the strategic plan. This production rate should not be considered to be finalized; normally only limited analysis is conducted to determine the production rate during scoping studies.

The assumption of a production rate does aid the long range planner in beginning LRP with a better estimate of the mining and processing operating costs, and in identifying some of the constraints that will govern pushback selection.

LRP should examine potential improvements to the NPV from a change in production capacity. The generation of a number of high-level plans using different mining and processing rates, with appropriate adjustments to the cost estimates, will allow the planner to focus more detailed LRP on the production capacities that generate the highest NPV. If more detailed planning indicates that these identified capacities are not feasible then the production rate decision is revisited.

3.7.2 The Detailed Mine Plan

Unlike strategic planning, LRP involves detailed mine planning. The proposed mining schedule is examined in detail to ensure it is feasible. This includes ensuring that mill feed grade and other blend considerations can be met under the proposed schedule, and that the material balance required by the waste plans is met. Equipment selection and forecasting are completed. While a GMP may not be used in generating the strategic plan one will almost certainly be used during LRP to generate ramp and haul road layouts, dump designs and other details of the plan.

The activity flow in detailed mine planning is presented in Figure 3-15. Sub-activity models are found in Appendix A, diagrams A-11 through A-15.
Detailed mine planning

- **LAYOUT SITE**
  - A - 11

- **SELECT EQUIPMENT**
  - A - 12

- **Create FUNCTIONAL MINE DESIGN**
  - A - 13

- **SCHEDULE MINING**
  - A - 14

- **Forecast EQUIPMENT REQUIREMENTS**
  - A - 15

  - Simulation study: equipment interaction (as required)

  - Economic analysis

  - [Insufficient scheduling scenarios]

  - [Costs inconsistent. Revise pit analysis]

  - [Design not feasible]

  - [Scheduling not feasible]

  - [Scheduling exhausted. Revisit pit analysis, prod. rate, cutoff]

  - [Equipment interactions impair productivity. Revise selection.]

  - [Plan does not meet expectations. Mine uneconomic.]

  - [Plan meets economic expectations. Proceed with investment decision/continue mining.]

Figures 3-15: Conventional planning activity diagram – detailed mine planning
3.7.2.1 Site Layout

Mine planners will not be the only group involved in site layout but mine planning will play a defining role. Site layout begins with detailed topographic maps (see diagram A-11). The property boundary is mapped. Existing infrastructure and right-of-ways (roads and highways, power lines, pipelines, etc.) are identified as are constraints relating to cultural resources, surface and ground water, and final land use requirements. In some cases it might be financially attractive to pay for the relocation of roadways or other infrastructure to accommodate mining. If relevant this should be assessed.

Once the site constraints are identified the initial pit, pushbacks, and final pit should be mapped. The pit outlines will guide infrastructure placement.

The location of the ramp entry/exit point is normally the starting point in locating mining-related infrastructure and features. In a typical metal mine uphill travel by haul trucks will represent the greatest portion of fuel used. A review of equipment performance curves shows the speed of ultra-class haul trucks travelling up 8 to 10% ramp slopes experiencing rolling resistances of 2-4% travel at a maximum of 15 km/h (Komatsu Ltd., 2009; Caterpillar, Inc., 2010). Under normal circumstances the uphill haul will represent the longest time component of the truck’s cycle time (the load-haul-dump-return time). It is therefore desirable to minimize the uphill haul out of the pit. The more significant the topographic relief in the area of the mine, the more desirable it is likely to be to locate the ramp exits from the pit at the lowest elevations possible (this should, of course, be subject to analysis once the layout is complete).

Once the pit access point is established the location of the crusher and mill, waste dumps, and tailings impoundments may be determined (this is important as in the later pushbacks of a large open pit multiple access points and ramps may be planned). Elevation is an important
consideration here too, and in mines with high stripping ratios waste dump location should be considered more important than the location of the crusher and mill. Uphill hauls on the dumps are no more desirable than in the mining pit. The use of a shallower slope, or larger flatter dumps versus smaller, steeper dumps, should be assessed. In some cases the increase in haul distance may be more than offset by an increase in the maximum speed attained by the truck.

Sufficient drilling to eliminate the possibility of ore should exist in the areas of proposed waste storage facilities. If sufficient drilling does not exist a campaign should be commenced to ensure facility placement does not result in the sterilization of ore. The best-case pit limit should also be considered at this stage. A desire for short haul distances may result in waste dumps or other infrastructure being located outside of the final pit wall but inside the best-case pit. In the event that future conditions were favorable to mining of the best case pit a decision may need to be made regarding moving the infrastructure. The trade-off between reduced haul distances and expenses in the short term should be evaluated against the potential loss of value in the long term by quantifying the potential for future ore sterilization.

Once the key mining infrastructure is located ancillary facilities such as the maintenance shops, truck muster points, offices, etc. can be located. Mine access roads, light vehicle roads, dewatering ditches and pipe networks, and tailings pipeline routes, should be laid out.

The final site design should be subject to a hydrologic or watershed analysis. Understanding the impact of changes to the topography on surface water flow is important, especially in areas of high rainfall where erosion may be a concern.

3.7.2.2 Equipment Selection

Two criteria normally govern equipment selection:
excavation equipment must provide selectivity and mobility suitable to the ore body; and,

haulage equipment should be selected with a focus on reducing the total cost per tonne of material moved.

The activity diagram for equipment selection is found on diagram A-12.

3.7.2.2.1 Loader Selection and Sizing

The loader is normally the first piece of equipment specified in detailed planning. It is normally advantageous to have more than one loader so that ore and waste mining activities can take place concurrently and that production does not cease when one loader is unavailable due to maintenance or breakdown. The loader type should be selected first: front-end rubber tired (wheel) loader, hydraulic excavator, or electric (rope) shovel.

Factors considered in loader selection and sizing include: the bench or muck pile height, the degree of selectivity required in mining, the degree of mobility required from the excavators, the expected mine life, the capacity required to meet the production rate, the availability of electric power vs. diesel fuel, the operating cost of the equipment, etc. Humphrey and Wagner (2011) provide a summary of the some of the considerations in loader selection. Surface Mining (Kennedy B., 1990) also provides a good description of the considerations in equipment selection and sizing.

Bench height should be a limiting factor in loader selection. From a safety perspective, if not from a regulatory perspective, the height of the bench or muck pile should be limited to a height that will allow the safe operation of the loader without risk to the operator in the case of rock fall from the face. In Ontario, the regulations prescribe a maximum vertical height of the
working face of no more than 1.5m above the maximum reach of the equipment where earth, clay, sand, or gravel is being removed. In the surface mining of rock the vertical bench height is limited to 25m, but the regulations do not prescribe a maximum height above the loader’s height (Occupational Health and Safety Act (Ontario), R.R.O. 1990, Regulation 854 Mines and Mining Plants, s. 88, 89, 2011). In British Columbia, the mining face is limited to no more than 2m above the maximum reach of the loader (point sheave height for rope shovels). Exceptions are made in cases where multiple-benching is conducted under authorization by the chief mine inspector or in free running material where the slope is limited to 60° or 30m in length (Health, Safety and Reclamation Code for Mines in B.C., Part 6.23, Mines Act [RSBS 1996] Chapter 23, 2008).

In high production mines it is normal to have a mixed loading fleet and rope, hydraulic, and wheel loaders may all be employed. It is common to see large capacity, lower operating cost rope shovels used in waste stripping with more selective and mobile hydraulic shovels used in ore mining. In some cases a different bench height may be used in ore and waste mining to further aid ore selectivity and reduce mining loss and mill feed dilution.

The number of loaders required is determined once the mining schedule has been finalized.

3.7.2.2.2 Haul Truck Selection

Haul trucks may represent up to 50% of the operating cost associated with mining (Humphrey & Wagner, 2011). Selection of haul trucks should therefore be considered with an objective of minimizing operating cost.

The haul truck is matched to the selected loader(s). Loading geometry (dump height) will limit available options. It is good practice to select a truck that requires between three and
five passes (or loaded buckets) of the excavator to reach capacity. Current truck capacities range from under 100t to 360t.

3.7.2.2.3 Ancillary Equipment

A wide range of equipment is needed to support a load-haul operation. This includes but is not limited to:

- drilling equipment to prepare patterns for blasting;
- blast hole loading equipment;
- bulldozers for shovel pit cleanup, dump support and maintenance, slope trimming, stockpile maintenance, establishing temporary access ramps, etc.;
- motor graders for ramp construction and maintenance, snow removal, etc.;
- backhoes for ditching and miscellaneous tasks;
- lube and refueling trucks; and,
- service vehicles for in-pit maintenance activities including welder’s trucks, boom trucks, etc.

Just as the selection of haul trucks follows from the selection of the loading equipment, ancillary equipment is dependent on the loaders and trucks selected. Bulldozers must be appropriately sized to be able to handle the volumes of waste delivered to the dump, drilling equipment must be sized to the anticipated blast hole length and diameter, motor graders should be sufficiently large to work haul roads with a minimum number of passes, etc.

The *SME Mining Engineering Handbook, 2nd and 3rd Editions* (eds. Hartman and Darling), *Surface Mining, 2nd Edition* (ed. Kennedy), and equipment application and specification
handbooks from manufacturers such as Komatsu, Caterpillar, etc. provide details on productivity calculations and other considerations in ancillary equipment selection.

3.7.2.4 Cost Estimation

Once the type of equipment to be used in the mining fleet is identified, operating and capital costs should be estimated. Capital costs may be determined from direct vendor quotes. Most equipment manufacturers will also provide guidance on maintenance and operating costs, although it is prudent to perform independent analysis on any values provided by the potential vendor and to adjust for the expected mine conditions. As a project moves into production experience in operating costs incurred by the operation will be gained and may be used as the basis for cost estimation.

If the anticipated operating costs vary significantly from the assumptions used in pit limit optimization different equipment may be considered or the pit limit analysis may have to be revisited with updated cost assumptions. Some mines elect to enter maintenance service agreements with their equipment vendors as a way of reducing risk associated with cost estimation errors.

3.7.2.3 Creating Functional Mine Designs

Pit analysis provides an indication of the location of the final pit wall, and the progression of mining through pushbacks to achieve that wall. Pit analysis identifies the blocks to be mined; it does not provide a mine design.

The pits identified by pit analysis must be transformed into mineable designs by the planning team. The tasks involved in this are:

- smoothing the pit limit to a mineable geometry;
• imposing bench design on the pit limit; and,
• developing ramps with which to enter/exit the pit.

Creating a functional mine design is a task for the human planner and is accomplished using a GMP program. In most cases creating a functional design and the introduction of ramps will have a small impact on the overall pit slope, resulting in a shallower wall. With experience or calculation it is possible to modify the wall slope constraints used during pit analysis to account for the presence of ramps and if the variation from the maximum allowable slope is more than a few degrees the pit limit analysis should be rerun.

The mine design is constrained by geotechnical criteria for the pit walls. The criteria normally specified for a given bench height are: maximum bench face angle, maximum interramp slope, maximum overall slope, and minimum catch bench width (Figure 3-16 and Figure 3-4).

3.7.2.3.1 Catch bench design

In a normal pit each bench in the vertical direction is accompanied by a horizontal catch or safety bench. The purpose of the catch bench is to prevent falling rocks and small bench-scale failures from continuing down the pit wall to working areas where people and equipment are located and would be at risk. In double-benching a catch bench is left with every second bench in the vertical direction. Catch bench design is described by Hoek (2007).
3.7.2.3.2 Ramp design

In conjunction with introducing bench geometry the planner drafts the haul ramps. The haul ramp normally consists of the running surface, a safety berm on the outside edge of the ramp, and often a ditch on the inside edge. Allowance may also be made for running dewatering pipe or electric cables on the inside edge although in some mines the safety berm may provide double duty and be used for these.

Ramp grades in hard rock open pits are normally in the 8-10% range. Most operators are comfortable operating downgrade over this range. The other limiting consideration in ramp grade is the upgrade speed attainable by the haul truck. Although a steeper ramp shortens the haul distance of the ramp and has less impact on slope geometry, the distance savings may not be outweighed by the loss in speed. An analysis should be conducted to guide ramp grade selection.
A ramp running surface width of 3.5 times the width of the widest haul truck is suggested for two-way traffic (Mine Safety and Health Administration, 1999). This factor provides for one-half the truck width’s clearance on either side of the haul truck. In British Columbia a minimum of 3 times the truck width is specified in the regulations (Health, Safety and Reclamation Code for Mines in B.C., Part 6.23, Mines Act [RSBS 1996] Chapter 23, 2008). If a future increase in the size of equipment is planned, adequate width to support the increased truck size should be considered for any long-life ramps. In addition to the width of the running surface, allowance should be made for required berms and ditches when designing the pit.

The safety berm on the outside edge of the ramp is only intended to deflect a haul truck that has strayed too far to the edge of the ramp. The size of berm required to stop an out of control haul truck from going over the ramp edge is prohibitive. The height of the berm should be at least equal to the axle height of the largest haul truck. Best practice and regulatory guidelines vary from ½ (Mine Safety and Health Administration, 1999) to ¾ (Health, Safety and Reclamation Code for Mines in B.C., Part 6.23, Mines Act [RSBS 1996] Chapter 23, 2008) of the diameter of the largest truck tire. The safety berm should be continuous, with allowances or cut-outs made for drainage of the ramp and removal of debris. Particular attention should be paid to the berm at corners and intersections; the height of the berm may block the view of light vehicle occupants and hide light vehicles from the truck operator’s view.

Median berms are used in some locations, particularly the US Southwest and Australia. A ramp design should allow additional width for median berms if they are to be used. A median berm is a series of discontinuous berms that run down the middle of the haul road. Median berms are intended to be used by haul trucks that have lost braking capacity to slow or arrest their motion. The berm is made of loose unconsolidated material (e.g. sand, gravel). At a break in the
berm the driver can maneuver the truck into the middle of the ramp and center the truck over top of the median berm. At the entry to the berm (the up-ramp portion) the berm is lower than the axle height of the haul truck. As the berm extends down-ramp the height of the berm increases so that it is higher than the axle of the truck, slowing or stopping the truck driving over the top. There are no hard guidelines for the width of the berm other than it should be narrower than the distance between the inside edges of the rear haul truck tires.

Median berms are not a practical alternative in areas with cold or wet climates. Freezing conditions in the winter would result in freezing of the median berm and likely result in injury to a driver attempting to use one and significant damage to the truck. In areas with regular or high rainfall the fine material in the berms is washed out resulting in the need for frequent maintenance of both the berm and the ramp.

Ramps may be of two types: a spiral ramp or a switchback ramp. A spiral ramp progresses downwards following the pit wall over the full 360° of the pit. A switchback ramp progresses downwards but does not use the full 360° of the pit. Instead it turns back on itself, possibly multiple times in a deeper pit. The switchback itself should be designed at a flat grade, not at the grade of the ramp, so that the inside wheel is not subjected to greater forces than the outside wheel. The need to provide flattened corners increases the total ramp length, and the impact of the ramp on the overall pit slope. Truck speeds, already below 15 km/h for ultra-class haul trucks under regular ramp conditions, are reduced in the corner.
3.7.2.3.3 Smoothing the pit limit

The output of pit analysis identifies the blocks to be mined. These adhere to mining precedence rules (in order to mine a block the blocks above must be mined) and the pit slope constraints. For each pushback or pit the perimeter blocks on each bench represent the pit limit. The shape of the pit limit from pit analysis is an artifact of the block model. To produce a practical mining geometry the planner simply generates a new pit limit from the limit indicated by the analysis (Figure 3-17). It should be noted that the blocky pit limit outline produced by pit limit analysis is simply an artifact of the use of a block model and not representative of the deposit’s geometry. The new smoothed limit will form the basis for development of the mining benches and ramp systems.

Figure 3-17: Generating a smoothed pit limit

The small impact of smoothing on the pit wall is accepted as part of the design process. With a smoothed pit limit and ramps introduced, a base metal mine may accept a variance of up to 10% between the total tonnage indicated by the pit analysis and the tonnage resulting from final pit design (Soderman, 2010). As discussed with the aid of Figure 3-18, the planner will attempt to balance the change in wall geometry to minimize the impact on pit tonnes and value. However, normally a decision must be made to ensure all ore identified in the optimum pit limit is mined, or to accept a loss in ore recovery resulting from less stripping. Full ore recovery is
accomplished by stepping the pit wall outwards, but comes at the expense of additional waste stripping. It is important to remember that the ore at the pit limit is marginal; stepping the wall out will result in the mining of uneconomic material. This will be examined in more detail.

![Diagram showing impact of ramp on pit slope and pit tonnage]

**Figure 3-18: Impact of ramp on pit slope and pit tonnage**

Most software vendors train users in a bottom-up ramping method. That is, the user generates a smoothed outline for the lowest bench in the indicated pit and develops the ramp and pit wall up from this point. It is also common to instruct software users to draw the smoothed wall so that it completely encompasses the blocks indicated for mining. As the mine wall is expanded upwards, it can be stepped-out at any level where the indicated pit wall expands more than the pit wall generated by the bench development. The reasoning is that in this way no ore will be lost.

Two concerns exist with this approach to bottom-up benching. The first is that control of the ramps’ entry/exit point to the pit is extremely important. An elevation difference of 20m may not seem significant, but in medium to large pits several hundred million to well over one billion
tonnes of rock may need to be hauled up that additional difference. By beginning ramping at the top bench, the user has exact control of where the ramps enter/exit the pit. Ramping bottom-up usually requires several iterations and additional time to arrive at the correct exit point.

The second concern with bottom-up ramp development relates to the idea that it is better to step the limit outside of the indicated mining extents to avoid “missing” ore when the wall is smoothed and ramps are introduced. This approach will capture all ore. However, it will also result in an increased mine tonnage, and a reduced mine value, as no additionally mined material outside the final pit limit is economic. Conversely, if the pit wall is stepped in as a result of adding the ramp, ramp development results in the loss of some ore the total mine tonnage will be reduced. This is also at the expense of net mine value. However, because the total tonnage is lower an equivalent loss in value due to not mining some ore will result in a smaller loss in NPV due to mining all ore with more stripping (Figure 3-19). The impact of reducing the total pit tonnage may result in an increase in NPV; this will be discussed in Section 3.9.

Examining the tonnage-value curve of Figure 3-19, it is clear that at the “optimum” final pit limit the impact of moving the pit wall on undiscounted value is small when moving in either direction (best case schedule line), although the impact on NPV should also be considered as it may be considerable (worst case line).

Normally a number of ramp configurations may be planned, especially in managing the transition from one pushback to another. As physical ramp development is a slow and expensive process (compared to mining in the face) the pushback walls and/or sequence may be altered to support reduced ramp redevelopment. The impact of the ramp design on the tonnage and grade of the pit versus the mineable reserve indicated by the pit limit analysis should be undertaken for each pit design to aid in identifying the best design.
3.7.2.4 Scheduling Mining

Once the mine design is finalized, mining should be scheduled using the mining pits and pushbacks designed. The general activity flow is the same as in strategic planning, but there is an emphasis on ensuring that the ore blend for the mill and material balance for waste planning is met (see Appendix A, diagram A-14).

For planning purposes mining volumes should be identified by quarter in the 0-5 year timeframe and annually beyond the fifth year. The expected production in each quarter or year should be checked to ensure that the average ore properties meet the mill’s blend requirements. The waste mined should be checked to ensure that material is available for tailings dam development (where rockfill dams are used), that the PAG/PAN ratios are appropriate to the dump design where acid rock drainage is an issue, etc. Metal mines are not normally waste-constricted.

The NPV for the final schedule should be calculated. For each production rate a number of different mining schedules should be developed to allow for selection of the most valuable mining sequence while ensuring that material balances, minimum lead times on waste stripping, etc. are adhered to. These schedules may vary the number of concurrent mining faces and benches, the lead time on ore exposure, the point at which pushbacks are started, etc.

A number of commercial tools offer scheduling routines, and most GMPs include a scheduling module. While these are useful for identifying the exact sequence of mining polygons and meeting blend considerations they do require informed user input regarding minimum lead times, concurrent benches, etc.
Figure 3-19: Potential impact of ramp placement on NPV

Although the difference in value for the best schedule is small, as realism is added to the mining schedule the impact of ramp placement will increase.
3.7.2.5 Calculating Equipment Requirements

With detailed mine design and a defined mining schedule, equipment requirements can be forecast. Even with a fixed production rate equipment requirements will change over the life of the mine as haul distances increase and possibly as mining faces become separated by greater distances, making the relocation of loading equipment to address short-term outages less viable. The activity diagram for forecasting equipment requirements is presented on diagram A-15 of Appendix A.

Haul distances for all scheduled material should be determined. This should be done on a period-by-period basis and involves determining the haulage profile from the center of mass of each ore and waste mining polygon to the crusher location or center of mass of each dump advance (the centroid-to-centroid approach). The use of a single ore and waste haul profile when there are multiple pieces of loading equipment, or where the mass of ore or waste mined is not continuous is discouraged. A failure to adequately account for increases in haul distance and haul time will result in production losses during mining. A failure to account for reduced haulage demands (transition from the lowest elevation of one pushback to higher elevations in the subsequent pushback) may result in increased capital and per tonne operating costs due to an excess of trucks. It is generally desirable to have a mining schedule that supports smooth equipment profiles. The number of pieces of equipment may increase or decrease over time, but they should not fluctuate erratically from period to period.

Equipment productivity calculations and equipment specifications are presented by manufacturers in their equipment handbooks. Komatsu’s Haulage Analysis Tool (HAT) and Caterpillar’s Fleet Production and Cost Analysis (FPC) software may be used to aid in determining equipment requirements based on haul profiles and loading conditions. Several
GMP programs now include at least a haulage analysis tool and third-party solutions, such as Runge’s *Talpac* are also available.

A simulation study should be carried out once the long range plan is finalized. The study is used to confirm that the proposed equipment fleet is capable of meeting the required production level. The study should model fleet productivity for the proposed mining schedule. Haul road congestion, bottlenecks at the crushers or dumps, and other equipment interactions may result in a lower level of productivity than anticipated. These studies are important in mines with large equipment fleets, where haul profiles vary over the short or long term, or where the plan calls for a concentration of mining activity in a small area. Identification of any issues that may impact production should help ensure they are proactively addressed, and that the project produces the expected returns when it is brought into production.

Equipment productivity calculations and factors are available in both the *SME Mining Engineering Handbook* (2011) and *Surface Mining* (1990). Similar to the concern in cost estimation, expected equipment productivities must be critically reviewed and adjusted to reflect the specific mine site conditions (altitude, climate, diggability, operator skill, etc.).

3.7.2.6 Economic Analysis

With a detailed pit design, mining schedule, and equipment profile economic analysis for the proposed plan can be carried out. The introduction of more mining constraints in the detailed plan is unlikely to yield a NPV as high as indicated by less detailed planning, but the difference should not be great. The relative sensitivity of the project to the impact of scheduling (the difference between best and worst case planning scenarios) provides a guide to how much variation may be acceptable.
A number of detailed long-range planning scenarios should be analyzed to assess the impact of changes in production rate, change in pushback sequence, etc. Only after detailed scenario analysis is complete should the long range plan be finalized and a budget produced. Sensitivity analysis should also be performed to understand how variances in different economic and technical assumptions will impact project value.

3.8 Short Range Planning

The objective of short range planning is to ensure that mill demand is met (tonnes and blend) while stewarding to the long range plan. Just as LRP extends the strategic plan, SRP develops the detailed plans required to implement the LRP. Poor long range plans are unlikely to be overcome by SRP, but poorly executed SRP can have significant negative implications for a project’s success.

SRP determines the execution of the LRP set forth in the annual mine plan or budget. SRP is less iterative than LRP and strategic planning, particularly in the plans from daily to monthly resolution. The SRP function exists in producing mines and in mines about to enter production. SRP is sometimes referred to as production planning or operations planning.

Short range planning progresses from a twelve to eighteen month annual plan through to daily plans (see Appendix A, A-16 through A-20). As the stages progress a greater degree of certainty regarding equipment maintenance schedules and availability, muck pile properties, mill demand, digging advance on the benches, and dump advances, and to ensure that in-pit ramp and bench access is always available.
Short-range planning is a constant activity during the production stage of a mining project’s life. Large mines will have planners on site seven days a week to respond to changes as they occur. The relationship between the different planning stages is shown in Figure 3-20.

![Short-range planning activity diagram](image)

**Figure 3-20: Conventional planning activity diagram – short range planning**
3.8.1 Developing the Budget and Annual Plan

The annual plan begins with the 0-1 year portion of the long range plan. The LRP may provide quarterly or monthly detail on planned mine face advances and dump development. If LRP employs a quarterly basis the SRP will transform the plan to a monthly basis. The annual plan is developed once a year, with quarterly forecasts and monthly updated plans reacting to unanticipated conditions. An eighteen month plan is often generated at the mid-point of the budget year to ensure that mining activities transition smoothly from one year to the next.

SRP involves close communication and plan integration with the mill and with mine maintenance. Functions such as dewatering, mine electrical, and drilling and blasting, will be coordinated by the plan.

The activities and key constraints of the annual plan are shown in Figure 3-21. The plan identifies shovel production by bench, and by specific location(s) on the bench. The anticipated or required tonnes and quality of the production are determined using data available or modified from the resource model. As drilling progresses additional sampling data is obtained and the modeled properties of ore and waste are refined.

As part of identifying shovel advances, ramp development, bench access, and shovel pit configurations are determined. Most mines employ back up loading. In back up loading the truck reverses into a position for loading (spots) that is perpendicular or near perpendicular to the mining face. A double back up configuration, where a truck may spot on either side of the shovel, is preferred. A double back up configuration is more productive than a single back-up configuration. Double back up reduces or eliminates the shovel wait time between the completion of loading one truck and the start of loading the next. The primary disadvantage of double back up is that it requires a wider working face, as there must be room for a truck to spot
Twelve month planning

Identify annual ore advance (tonnes and location)

{Meet mill demand forecast (tonnes and blend) by month
Minimize loader moves
Minimize ramp redevelopment/temporary ramps,
Do not exceed water table drawdown, etc.}

Identify waste advance

{Maintain LRP stripping ratio (quarterly)
Minimize loader relocation
Meet dump construction needs
(PAG-PAN balance, etc.)
Meet reclamation requirements
Minimize ramp redevelopment/temporary ramps, etc.}

Calculate equipment hours and numbers

[Schedule change possible]

[Insufficient equipment in one or more quarters]

Assess ore and/or waste schedule change

{Schedule change possible
Schedule change not possible}

Assess rental/contractor fleet

[Rental/contractor available within budget.]

[Rental/contractor not feasible.]

Pursue changes outages & plant demand forecast.

[Changes accommodated]

Forecast availability and utilization. Forecast decommissionings & purchases.

(PAG/PAN requirements, reclamation requirements, etc.)

Plan dump development

[Changes not accommodated.
Continue planning exercise.
Trigger impact assessment & quantify impacts.
Notify management.]

Prepare budget

Figure 3-21 Conventional planning activity diagram – twelve month planning
for loading on both sides of the shovel. When cable shovels are used, double back up also requires that trucks spotting on one side of the shovel cross the cable. This is done by suspending the cable overhead on cable stands, and having the trucks pass under the cable. In mines with wide pushbacks multiple shovels may be assigned to work the same face advance. Drive-by loading, where the truck drives forward into a loading position parallel to the pit wall and then forward out, is very efficient from the standpoint of truck spotting, but requires a greater swing angle for the loader to dig and discharge a bucket of muck. Details of mining pit configurations and face advance, and minimum work-area calculations are found in *Open Pit Mine Planning and Design* (Hustrulid & Kuchta, 2006).

Once the planned advances are identified and quantified loading capacity is assigned. Shovel production capacity is assigned to each dig location on the basis of priority (e.g. ore mining vs. waste stripping), and adjustments to production rates for each piece of equipment are made on the basis of anticipated conditions including face height, working area, digging conditions, and, if relevant, season. The mine maintenance forecast is accounted for in assigning shovel capacity and the mill maintenance forecast is also considered in assigning ore mining capacity. If possible, major maintenance outages on ore shovels will be timed to correspond to forecast mill or crusher outages.

When waste material types and quantities are known the dump development plan is created. This will ensure that requirements for support equipment such as bulldozers are met. A detailed dump development plan will also identify if required material balances (e.g. potentially acid generating and acid neutralizing materials) are being met. Finally the detailed dump plan will enable determination of haul route profiles.
Haulage profiles are normally calculated on a centroid-to-centroid basis, as in LRP, but the centroids are now calculated on a monthly basis for each forecast mining polygon, and the centroid of the dump is based on the monthly dump advance planned. If haul profiles are averaged over longer time periods (i.e. quarterly or annually) there is a risk of production shortfalls when longer hauls are experienced and of lower truck productivity when shorter hauls are experienced. It is important to provide sufficient definition to haul distance by period to ensure such situations are not inadvertently created.

Haul profiles are then used to determine the number of trucks required to meet shovel production demand. If there is insufficient truck capacity in one or more periods the mining advances may be revisited and the schedule reexamined. If the capacity shortfall cannot be addressed by a schedule change it may be possible to rent equipment to make up the shortfall, if budget and the location of the mine allow. If this is not possible changes in the mill forecast can be requested, to align reductions in mill demand with periods of longer haul times. If none of these alternatives is possible planning continues, and the planner notifies management of the potential shortfall. Normally waste stripping is sacrificed to maintain ore production but if this becomes common it can have significant impacts in the mining of ore in future pushbacks. Feedback should be provided to the long range planners so the new forecast advances are incorporated in their planning activities for the next year.

Excess truck and/or loader capacity may allow maintenance to be scheduled at an opportune time to reduce production impacts. The mine and maintenance teams should work to coordinate this.
3.8.2 Quarterly Forecasting

The quarterly forecast is similar in concept to the annual plan but is updated on a quarterly basis. A monthly time period is normally used, and the production budget variances are summarized. As the year progresses the quarterly forecast will be updated based on monthly plans. The forecast will provide a higher level of certainty with respect to planned outages than the annual plan, and will respond to changing conditions. At this stage of planning specific loaders may be assigned to specific dig faces. This will allow for shovel moves and any related infrastructure changes to be identified and planned for in advance.

3.8.3 Monthly Planning

The monthly plan updates the work of the annual plan on an ongoing basis and will form the basis of quarterly forecasts. The activity flow is presented in Figure 3-22. The upcoming two to three months are normally scheduled in two week periods, with the remaining months scheduled monthly.

The monthly plan will identify specific timeframes for planned maintenance activities for the loading and haulage fleet. In assigning specific equipment to specific working faces these outages are taken into consideration. Any forecast variances from budgeted production or expenses should be identified. Monthly plans are used to generate and update the quarterly forecast.
**Monthly planning**

- **Schedule major outages**
  - [Equipment hours, maintenance personnel available, etc.]

- **Select production polygons weekly**

- **Calculate equipment hours and numbers**
  - [Insufficient equipment in one or more weeks]
  - [Sufficient equipment]

- **Assess ore and/or waste schedule change, investigate main’t schedule change, mill demand change**
  - [Schedule change possible]
  - [Schedule change not possible]

- **Plan dump development**
  - [Reduction can be accommodated]
  - [Reduction not advisable]
  - [Rental/contractor possible]

- **Identify budget variances**
  - [Continue planning by reducing waste lead time then restricting mill]
  - [Assess LRP alternatives/consequences]

- **Assess rental/contractor fleet**

- **Quantify impacts/notify management**

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**Figure 3-22: Conventional planning activity diagram – monthly planning**
3.8.4 The One or Two Week Plan

The two week plan provides detail for all mining and support activities for a two-week period (see Figure 3-23). It is normally updated weekly. Mine production and advance is forecast by loader by shift. If loading capacity is needed in different mining faces the moves should be identified in this plan so they can be properly executed; shovel moves should not be introduced in the daily plan except under special circumstances (Section 3.8.5).

The two week plan will lock-in the timing of planned maintenance activities for the loader fleet. These will be changed only in the event of plan upset. Specific drilling and blasting activities will also be identified to help mine-support services in scheduling their resources and to ensure that any area preparation is carried out.
Weekly planning

- Forecast available mining capacity (tonnes per loader per shift)
- Assign loaders to production polygons
  - [Can meet mill demand]
  - [Cannot meet mill demand]
    - Evaluate moving ore or waste loader(s)
    - [Can meet mill tonnage demand]
    - [Cannot meet blend requirements]
      - Notify mill
      - Reduce tonnage
  - [Can meet mill blend requirements]
    - Determine waste shovel priority to maintain lead time
      - Notify Maintenance of any opportune equipment availabilities
    - Determine trucks required
      - [Insufficient trucks]
        - Evaluate ore and waste priorities
          - Adjust waste plan
            - [Waste restriction preferable]
            - [Ore restriction preferable Reduced tonnes and/or change blend]
          - Identify drill patterns to maintain inventory
          - Identify blast patterns to maintain inventory
          - Identify support activities

Figure 3-23: Conventional planning activity diagram – weekly planning
3.8.5 Daily Planning

The activities in daily planning involve responding to variations from the two-week plan (see Figure 3-24). Planning activities follow the same work-flow as the two week plan and the location of specific equipment and planned production from specific locations should not vary from the two week plan. Unplanned maintenance, unexpected changes in ore or waste quality, etc. will require reaction from the short range planning team. One or more meetings are normally held with the maintenance and operations teams, as well as with support function supervisors such as drilling, blasting, mine electrical, and dewatering, to ensure that any issues are identified and reacted to appropriately. Reactions to short-term upsets should be evaluated carefully.

It is important that SRP should direct the operation; the operation should advise, but not direct, SRP. If SRP does not guide the development of the mine, decisions may be made in the field which cause production and feed issues later. Just as mine operations should adhere to the short range plan, the short range plan should adhere to the long range plan.
Daily planning

Calculate available mining capacity (tonnes per loader per shift)

Calculate available mining inventory by open mining face (tonnes and properties)

Determine ore loader priority by shift to meet mill demand (tonnes and blend)

[Cannot meet mill demand]  Evaluate moving ore or waste loader(s)

[Can meet mill tonnage demand]

[Can meet blend requirements]  [Cannot meet blend requirements]

Notify mill

Determine waste shovel priority to maintain lead time

[If excess shovel capacity notify maintenance of 'opportune main't window]

Determine trucks required

[Insufficient trucks]  Evaluate ore and waste priorities

[Sufficient trucks] If excess notify maintenance of opportune window

Adjust waste plan

Notify mill

Identify drill patterns for drilling to steward to 2 week plan

Identify blast patterns for loading

Identify support activities

Figure 3-24: Conventional planning activity diagram – daily planning
3.9 Emerging Techniques in Mine Planning

This chapter presents an overview of the typical activity flow in contemporary open pit mine planning. Commercial software exists to aid the mine planner in developing the mine plan, including for pit limit analysis, production rate and cut-off grade decisions, and mine scheduling. These evaluations are interrelated, but are largely treated independently or optimized in conjunction with one other decision. Significant research has been devoted to the NPV optimization question as well as to the question of addressing project uncertainty due to risk. An overview of major research and development activity is presented here.

The absence of a global optimizer for the mine planning process was introduced at the start of this chapter. The complexity of the problem stems from both the number of decision variables and the size of the models under study. From a computational standpoint, the problem of global mine optimization is not solvable in a timeframe compatible with project evaluation or planning (Everett, 2008; Osanloo, Gholamnejad, & Karimi, 2008; King B., 2001; Askari-Nasab, Frimpong, & Szymanski, 2007). In practical terms the problem is solved by breaking it into a series of sub-problems (pit limit optimization, sequence optimization, etc.) and restricting the problem inputs, and/or employing heuristic and metaheuristic algorithms.

From a research and development perspective, advances in mine optimization and mine planning techniques to mitigate risk are limited by the requirement that simplified assumptions have to be made, or a limited subset of variables be analyzed, due to processing times. Nevertheless, the development and commercialization of these methods is likely to offer improvements in future generations of mine planning software.
3.9.1 Pit Limit Analysis

The Lerchs-Grossman (LG) algorithm remains the most widely used approach to the identification of the optimal final pit limits. The LG algorithm produces a mathematically optimum solution to the problem of identifying the most valuable, undiscounted, pit limit. Unfortunately the goal of mine planning is normally to generate the optimal NPV through the use of discounting techniques.

The optimal pit from an undiscounted value perspective is unlikely to correspond to the optimal pit from a NPV perspective. The waste associated with the mining of economic ore at the margins of the final pit must be removed to access the ore. The mine sequence is likely to result in this waste material being removed one year or more prior to the ore that is associated with it. This time delay means that the impact of discounting on the profit generated by the ore will be greater than the impact of discounting the cost of the waste. When the pit is sequenced and costs and profits are discounted, this formerly economic ore will reduce the NPV. The optimal pit from a NPV perspective will therefore be a subset of the optimal pit from an undiscounted value perspective.

Dagleden (2001) proposes a solution which involves generating a pit limit using the LG algorithm in the traditional way, scheduling the pit, and then assigning new discounted block values to the blocks in the model on the basis of the schedule. The pit limit analysis is then re-run, a new final pit limit identified, and the mine sequenced and planned in the normal fashion.

Advances in mine planning software enable similar approaches. The planner is able develop a series of schedules for the identified final pit limit (i.e., the undiscounted final pit limit at the expected metal price). The schedules may vary mining and processing rates, stockpiling strategies, the rate of mine advance, pushback size, etc. The generated schedules are then
analyzed to select the highest NPV case. The pit which yields the highest NPV becomes the final pit limit. In Figure 3-11, for example, pit 13 corresponds to the optimum pit at the forecast metal price identified by the LG algorithm. However, with mining and processing rates constrained, pit 12 generates the highest NPV assuming a best case schedule development (see 3.6.1.3) and pit 6 would generate the highest NPV using a worst case schedule.

The second limitation in the application of the LG or other pit limit determining algorithms is that they rely on single-point, deterministic estimates of block grade, metal price, mining and processing costs, etc. Pit limit analysis itself does not account for the uncertainties associated with mine planning.

3.9.2 Mine Scheduling

Mine scheduling is a major focus of mine optimization research. The research is focused primarily on incorporating geologic and economic uncertainty to develop mine schedules that improve NPV and/or minimize the risk associated with the plan (i.e. minimize the likelihood of the plan not meeting minimum economic expectations). The complexities of the mine scheduling problem and the resulting computing time required for solution have made the identification of efficient algorithms and techniques important.

A comprehensive review of deterministic and uncertainty-based open pit scheduling approaches in provided by Osanloo, Gholamnejad, and Karimi (2008). Deterministic solutions reviewed include: linear programming (LP), mixed integer programming (MIP), integer programming, dynamic programming (DP), and meta-heuristic solutions. Uncertainty-based algorithms reviewed include risk analysis (RA) using deterministic algorithms, RA using DP, LP, and meta-heuristics. A number of limitations were presented by Osanloo et al.
The inability to solve for the ultimate pit limit and mine schedule concurrently.

Limitations in the ability to consider uncertainty related to data input.

The exclusion of practical mining constraints in generating a proposed solution (equipment access, etc.).

Limitations in considering a dynamic cut-off grade policy in mine scheduling.

A failure to integrate short-term production scheduling with long-term production planning.

### 3.9.3 Production Rate and Cut-off Grade Decisions

Decision support for production capacity and cut-off grade strategies is another focus of research.

Grobler et al (2011) present an enumerative price scenario-production capacity analysis that employs a combination of commercial software (identified as Whittle) and in-house software (identified as Snowden’s Evaluator) to incorporate risk analysis into the selection of an optimal production rate. Whittle (2011) presents cut-off grade and production rate optimization tools available in strategic planning software but notes that most users do not take advantage of the functionality.

The co-optimization or simultaneous optimization of one or more of the decision variables in planning is often undertaken. Although such exercises do not involve producing a truly optimal global NPV they can produce significant improvements in NPV and practical guidance for long and short range planners who may have to develop plans that react to changing metal prices or other conditions without having the opportunity to conduct full analysis. The return on time and resources involved in conducting such work is value added. Hill (2006) describes a process for co-optimizing production rate and cut-off grade and presents an analysis of the results. In 2010, Gemcom Software introduced the Simultaneous Optimization module to...
Whittle which enables the simultaneous optimization of cut-off grade, stockpiling policy, and mill blend.

3.9.4 Moving Research and Development into Commercial Applications

Available commercial tools for mine planning have advanced rapidly. Several programs offer production scheduling optimization functions, cut-off-grade optimization, and stockpile optimization. Nevertheless, as presented earlier in this chapter many mines still produce plans that are heavily reliant on rules of thumb and basic analysis. The industry is not making widespread use of already available tools and analysis techniques.

Whittle (2011) contends that mine optimization no longer faces a software challenge but rather faces a managerial challenge. He highlights that available tools in Gemcom’s Whittle, including cut-off and stockpile optimization, are rarely used in practice yet in the case study presented produced an increase in NPV of 17%. The simultaneous optimization of cut-off and stockpile grade yielded an additional 10% increase in NPV. He argues that mining companies should refocus on the profit question; organizational changes in attitudes and behaviors are the key to improving long term mine schedules.

King (2009, 2011) argues that time and budgetary limitations require important planning choices be made “without exhaustive optimization rigor (King B., 2011).” The expertise and judgment of those conducting the analysis becomes of paramount importance. King discusses the importance of scenario analysis when attempting to determine optimal policies without integrated optimization algorithms. King (2011) raises the following points in discussing mine optimization

- Optimizing problems sequentially does not guarantee an optimal solution for the integrated problem. The limitations of the partial optimizations must be understood for the limited optimizations to be of value.
• The realism of the results produced by the various algorithms should be given greater attention.

• Scenario analysis is often undervalued. Rapid scenario generation and analysis enables more policies to be optimized than is possible in a single optimization.

King discusses the need for highly trained and educated engineers to conduct analysis. King presents a similar concern to Whittle (2011), namely the focus on divisional objectives within mining companies may not support an integrated optimal strategy. King concludes that “people are more important than software and/or algorithms due to their capacity to add or destroy project value”.

3.10 Emerging Considerations in Mine Planning

3.10.1 Regulatory Intervention

The emergence of increased environmental awareness, an improved understanding of the rights and requirements of Aboriginal communities impacted by mining activities in their traditional territories, and in some cases social opposition to mining, are increasing in their influence over the mine planning process in Canada and in other jurisdictions.

The prospect of increased regulatory control over mining may have a profound impact on future generations of mine planners. In Canada most mines must address the concerns of First Nations in whose traditional territories they operate. In some cases a mining approval or license may be contingent upon a minimum mine life (Allen, n.d.). By introducing a mine life constraint the optimum NPV is reduced.

Gibson (2006) presents an overview of the environmental assessment for Inco’s Voisey’s Bay mine (now owned by Vale S.A.). The review panel for the Voisey’s Bay mine recommended that Inco plan for a minimum mine life of 20-25 years to provide stability and lasting benefit to
local aboriginal communities. Under Inco’s original mine plan ore production would begin in a high-grade open pit, and underground reserves would be identified prior to mine permitting that would allow the company to blend anticipated low-grade underground feed with the higher grade open pit feed. The review panel expressed concern that this plan may result in a high-grading or “scoop and run” scenario. In this scenario Inco would rapidly mine the high grade, low-cost open pit first and then abandon underground, low profit plans. Underground mineralization did not meet Inco’s original expectations and the regulators demanded Inco meet the review panel’s mine life recommendation. The final approved open pit mine plan had a mill production rate of less than one-third Inco’s originally planned rate (6000 tpd vs. 20,000 tpd.).

Resource conservation through the specification of minimum mining grades may also need to be considered in some jurisdictions. The impacts of regulatory intervention will be examined through a case study of oil sands mine planning presented in Chapter 4 and Chapter 5.
Chapter 4

Unconventional Open Pit Mining: A Case Study into Oil Sands Mine Planning

Large-scale open pit mines are complex systems subject to significant economic, spatial, technological, environmental, and societal constraints. The surface mines which develop Alberta’s oil sands are no exception. There are, however, significant regulatory controls and waste handling issues impacting the planning process for oil sands mines that merit understanding in order to achieve more logical and effective planning strategies.

This chapter will present an overview of Alberta’s oil sands. Planning challenges and considerations unique to oil sands mines will be presented. A systems model of the oil sands mine planning process is presented. A full set of UML diagrams in support of the modeling process are found in Appendix B.

4.1 An Overview of Alberta’s Oil Sands

Oil sands are a mixture of sand, silts, clays, bitumen and connate water. Alberta’s oil sands deposits contain trace salts, metals, and other hydrocarbons. Bitumen is naturally occurring, biodegraded heavy oil. Bitumen is recovered directly from oil sands using in-situ extraction methods or indirectly through surface mining of the oil sands and the extraction of bitumen using the Clark hot water process or similar processes (Chalaturnyk, Scott, & Ozum, 2002). Surface mine planning is the focus of this thesis.

Three oil sands deposits occur in Alberta: the Athabasca; the Cold Lake; and, the Peace River. The surface mineable oil sands are located within the Athabasca Basin. A combination of

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thick recoverable bitumen deposits and thin overburden cover make these sands amenable to surface mining. Approximately 20% of the 170 billion barrels of recoverable oil sands hosted reserves are amenable to surface mining, underlying approximately 5000 square kilometers of land. Overburden thicknesses typically range from 40-80m, with the ore bodies exhibiting thicknesses of up to approximately 60m. The remaining deposits do not currently support economic extraction via surface mining and must be exploited via in-situ methods. Currently surface mines account for 55% of Alberta’s bitumen production, with in-situ operations accounting for the remaining production (Oil Sands Information Portal, 2012)

The oil sands have seen tremendous growth in production and footprint over the last decade (see Figure 4-1). At the start of 2002 Suncor (Base Operations) and Syncrude (Mildred Lake and Aurora North) were the only companies with oil sands mines in production. At the start of 2012 Suncor and Syncrude have both significantly increased their production capacities, and Shell’s Muskeg River and Jackpine Mines and Canadian Natural Resource’s Horizon Mine have commenced production. Imperial Oil’s Kearl Mine is scheduled to commence production in 2012. Production capacity has risen from under 500,000 barrels of oil per day in 2002 to over 1,000,000 bpd in 2012. A number of other mining projects are planned with both Fort Hills (Suncor, Total E&P, and Teck) and Jocelyn North (Total, Suncor, Occidental Petroleum, Inpex Canada) having received regulatory approval. Growth in the sector has resulted in a sharp increase in demand for personnel, including mine and tailings planners. This growth has come at a time when many experienced oil sands mine planners are retiring, further exacerbating the human resources problem.

The region that hosts the surface mineable oil sands deposits is capped by a layer of Holocene soil, predominantly muskeg and peat. Underlying this soil is a layer of Pleistocene Era soil and till. The composition of the till ranges from fine sands, silts, and clays to coarse sands and gravels. These overlie the Clearwater Formation. The Clearwater Formation is comprised of clay shale interlaid with thin siltstone beds. It is subdivided into up to eight sub-units on the basis of density and clay content. Some Clearwater units are used in dyke construction by oil sands mines. The Wabiskaw member, a glauconitic siltstone, marks the boundary between the Clearwater and the bitumen-bearing McMurray Formation throughout most of the region (Figure 4-2).
The bitumen laden sands of the McMurray Formation overlie Devonian limestone bedrock. The McMurray Formation sediments were laid down in three depositional settings during the Cretaceous Period: fluvial (Lower McMurray); estuarine (Middle McMurray); and, estuarine/marine (Upper McMurray). A number of facies exist within each depositional environment. Suncor identifies 56 ore facies alone (Wilkinson Jr. & Heltke, 2005). The properties of the facies in these three settings vary widely, and influence bitumen recovery.

A review of the mine and tailings plans submitted by oil sands mine operators under Alberta Energy’s Directive 074, discussed in Section 4.2.4, indicates a range in the characteristics of ore amongst the operators. The surface mineable oil sands resources typically contain (weight %):

- 10-12% bitumen;
- 65-75% ‘sand’ greater than 44 microns;
- 10-25% ‘fines’ less than 44 microns; and,

- 5% water.

The mineral portion of the ore (sand and fines) is composed of approximately 95% quartz, 2-3% feldspar, and 2-3% mica and clay minerals. The fraction of the mineral portion that is greater than 44 microns is referred to as ‘sand’. The presence of quartz in this fraction makes the oil sands highly abrasive. The portion that is under 44 microns is comprised of silts and clays and is referred to as ‘fines’. It is recognized that the clay mineral fraction (less than 2 microns) of the ore, which may range from 20% to 80% of the total fines, is of greatest interest as it has a negative effect on the extraction process and is the primary cause of the formation of fine fluid tailings (Mossop, 1980; O’Carroll, 1999; Kasperski & Mikula, 2011; Gulf Canada Resources Ltd., 1993; Mikula, Kasperski, Burns, & MacKinnon, 1996). However, oil sands operators do not routinely measure clay content during exploration drilling, only fines content.

Bitumen and fines content varies among the facies. Generally facies deposited in low energy environments contain higher amounts of silt and clay. This reduces the permeability and porosity of these facies and results in lower bitumen grades. Facies deposited in higher-energy environments consist primarily of coarse-grained sands (the turbulent flow having kept clay and silt particles in suspension) which exhibit high permeability and porosity. Significant quantities of bitumen were able to flow into these sands. Bitumen content in oil sands varies from 0% to approximately 19% and fines content can vary from 3% to over 50%. On the basis of average bitumen grades and recoveries it takes approximately 2 tonnes of oil sands to produce 1 barrel of oil. Stripping ratios range from 0.8 to 1.4 tonnes of overburden to 1 tonne of ore.
Oil sands mining production is accomplished using truck-shovel methods, with the last dragline-bucketwheel reclaimer system for the mining of ore retired by Syncrude in 2007. The largest oil sands mine, Suncor’s Millennium Mine, operates at daily production rates approaching 1 million tonnes mined (ore and waste) with ore crushing and primary extraction capacity exceeding 500,000 tpd (Suncor Energy Inc., 2010a). Syncrude, the largest producer of bitumen, operates two mines which have a combined extraction plant capacity in excess of 650,000 tpd and well over 1M tpd mining (ore and waste) capacity (Syncrude Canada Ltd., 2010a; Syncrude Canada Ltd., 2010b). Including the tailings produced these largest oil sands mines handle approximately 1.5Mt of material per day. These production values place the oil sands mines operated by Syncrude and Suncor among the largest mines in the world and make their primary extraction facilities the largest processing plants in the world. The smallest oil sands projects have extraction plant capacities of over 200,000 tpd, and rank among the highest producing mines in the world.

Mining begins with clearing the land. These clearing activities are staged, and may begin up to five years before the mine advance. Clearing and grubbing of the future mining area is the first stage. Ditches are then dug to dewater the cleared muskeg for up to two years, dependent on soil depth. Once the muskeg cap is sufficiently dewatered for handling it is removed and stockpiled for later use in reclamation activities. Muskeg removal happens one year or more prior to overburden mining, and is scheduled for the winter months.

The overburden is mined in a series of benches in order to adhere to safe bench heights and to facilitate separation of overburden materials that meet construction specifications for tailings dykes, haul roads, and other projects. Overburden removal normally precedes ore mining by a period of weeks to months. Once the overburden is removed the ore is mined. Interburden,
oil sands below the cut-off grade, may need to be selectively mined. The ore is normally mined in a series of benches, with bench height being a function of the safe dig height for the shovels and geologic controls. Issues associated with mining are discussed in Section 4.2.

Mining project approvals under Alberta’s Environmental Protection and Enhancement Act (EPEA) cover over 135,000 ha (1,350 km²) of land. To date, mining activities have disturbed over 71,000 ha of the approved total (including plant site footprint and cleared land) of which 13,000 ha is occupied by tailings ponds (Oil Sands Information Portal, 2012). Reclamation activity is shown in Table 4-1.
Table 4-1: Regional disturbance and reclamation tracking

Regional Totals for Reclamation and Disturbance Tracking, by Year (ha)

<table>
<thead>
<tr>
<th>Year</th>
<th>EPEA Approved Footprint</th>
<th>Mine Site Footprint</th>
<th>Plant Site Footprint</th>
<th>Total Active Footprint</th>
<th>Cleared</th>
<th>Disturbed: Used for Mine or Plant Purposes</th>
<th>Ready for Reclamation: No Longer Used for Mine or Plant Purposes</th>
<th>Soils Placed (Terrestrial &amp; Wetlands &amp; Aquatics)</th>
<th>Permanent Reclamation (Terrestrial)</th>
<th>Permanent Reclamation (Wetlands &amp; Aquatics)</th>
<th>Temporary Reclamation (Terrestrial)</th>
<th>Certified</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>134,155</td>
<td>63,285</td>
<td>4,045</td>
<td>67,330</td>
<td>18,735</td>
<td>41,362</td>
<td>913</td>
<td>1,090</td>
<td>3,494</td>
<td>1,158</td>
<td>863</td>
<td>104</td>
</tr>
<tr>
<td>2010</td>
<td>135,157</td>
<td>67,970</td>
<td>3,527</td>
<td>71,497</td>
<td>17,055</td>
<td>46,899</td>
<td>394</td>
<td>1,534</td>
<td>3,643</td>
<td>1,192</td>
<td>780</td>
<td>104</td>
</tr>
</tbody>
</table>

(Oil Sands Information Portal, 2012)
Oil sands tailings present significant storage and reclamation challenges. Tailings are stored in a mix of external to pit, above grade, tailings impoundments and in-pit, below grade, tailings impoundments. With the exception of overburden used in construction of in-pit dykes, behind which tailings are stored as the mine progresses, nearly all pit space in the oil sands is earmarked for solid or fluid tailings storage. Of particular concern from a long-term liability and reclamation perspective is mature fine tailings (MFT). MFT is a fluid tailings consisting of fine silt and clay particles (i.e. < 44 micron) suspended in the process or tailings water. There is evidence that MFT consolidates to a fluid state with a maximum of 40-45% solids by weight under normal drainage and loading conditions (Wells, 2011). This means that MFT is expected to remain in a fluid state unless subject to additional treatment.

MFT has historically had a negative impact on the pace of reclamation, and its re-treatment increases the costs to reclaim oil sands mine sites. Tailings and reclamation concerns will be discussed further in Section 4.4 and Chapter 5. A review of oil sands tailings treatment technologies is beyond the scope of this thesis. Interested parties are referred to BGC Engineering’s 2010 *Oil Sands Tailings Technology Review*, prepared for the Oil Sands Research and Information Network (OSRIN). The review considers 34 tailings treatment technologies.

There are approximately 780Mm$^3$ of legacy oil sands fluid tailings requiring either treatment to form a solid landscape or permanent storage in end pit lakes (see Table 4-2). There are difficulties in defining and measuring fine and mature fluid tailings, evidenced by a reported MFT inventory of 186m$^3$ in 2010 at Suncor (Suncor Energy Inc., 2010a), versus a MFT inventory of 230Mm$^3$ at Suncor reported by Mamer (2010) and Suncor (2010b).
Table 4-2: Fluid fine tailings inventories reported under *Directive 074*

<table>
<thead>
<tr>
<th>Project</th>
<th>Fluid Fine Tailings Inventory (Mm$^3$)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizon*</td>
<td>20</td>
<td>(CNRL, 2010, p. 47)</td>
</tr>
<tr>
<td>Muskeg River</td>
<td>70</td>
<td>(Shell Canada Energy, 2010, p. 10)</td>
</tr>
<tr>
<td>Mildred Lake</td>
<td>426</td>
<td>(Syncrude Canada Ltd., 2010c, p. 24)</td>
</tr>
<tr>
<td>Aurora North</td>
<td>77</td>
<td>ibid</td>
</tr>
<tr>
<td>Suncor Base (incl. Steepbank/Millenium)</td>
<td>186</td>
<td>(Suncor Energy Inc., 2010a, p. 39)</td>
</tr>
<tr>
<td><strong>Regional Total</strong></td>
<td><strong>778</strong></td>
<td></td>
</tr>
</tbody>
</table>

* Inventory is mine plan estimate
Jackpine mine (Shell) had not deposited tailings at time of the baseline survey requirement. Plans submitted under *Directive 074* are available from the ERCB website.

4.2 Constraints and Challenges in Oil Sands Mine Planning

Modern, computer-based open pit mine planning and design techniques have largely focused on economic optimization based on a block model representation of the mine while respecting constraints, i.e. pit limit analysis, mine sequencing, cut-off grade determination, and production rate selection, etc. (see Chapter 3 and Appendix A).

Oil sands mines are classified as soft rock mines; they mine sedimentary rocks which may be free-dug, although blasting may be utilized. Although often identified as strip mines, oil sands mines defy the conventional definition of strip mining: not all overburden waste is rehandled to the previous mining panel in the pit, and overburden waste that does remain in-pit is usually hauled and placed for tailings dyke construction. Most oil sands mines have external to pit waste dumps.

While oil sands mines use block models as part of their design and planning basis, the economic considerations and regulatory constraints in oil sands mine planning are unique. The
nature of waste planning also differs in oil sands mining. In particular limited lease space for waste disposal and the issues associated with the characteristics and production rate of tailings demand industry- specific planning considerations.

The following noteworthy issues differentiate oil sands mining:

- mines are relatively shallow but have large areas;
- the nature of the ore in some cases requires seasonal planning;
- as a result of unique tailings characteristics, tailings storage requirements are the major influence on mine sequencing;
- the operational scale and tailings dyke construction requirements allow for little adjustment of mine plans in the short to intermediate horizon (up to 5 years);
- treatment and reclamation technologies for fluid oil sands tailings remain largely unproven, increasing planning uncertainty with respect to waste handling;
- oil sands tailings disposal is subject to the requirements of Alberta’s Energy Resources Conservation Board (ERCB) of Directive 074; and,
- the Government of Alberta, through Interim Directive 2001-7, prescribes a minimum recovery, a regulatory definition for ore-grade material, and minimum mining limits, i.e. fixed criteria for mining and processing which may include uneconomic material “Not in Reserve”\(^1\).

These issues may be broadly categorized as seasonal, waste planning, and regulatory issues.

\(^1\) Not in Reserve (NIR), originated as a South African gold mining term to describe sub economic mineralized material (Janisch, 1986). Such material could not be profitably mined in the future if left as waste by the first pass of mining activity. It was mined and blended with higher grade ore feeds during the first pass of mining to increase total gold recovery, albeit at a lower level of profit per ounce of gold. See Section 4.2.3.5 for further detail.
4.2.1 Seasonal Issues

Northern Alberta is subject to large variations in temperature. The Mildred Lake weather station, located at Syncrude’s Mildred Lake site, reports a 30 year average low temperature in January of -21°C and the average high in July of 24°C. The maximum recorded temperature is 36.2°C and the minimum recorded temperature is -44.5°C (The Weather Network, 2012).

Warm temperatures in the summer are problematic for mining. As the temperature rises the oil sands soften. This results in increased rolling resistance, increased fuel use, and generally poor ground conditions, including large ruts where trucks must travel over oil sands. According to Tannant and Regensburg (2001), VanWeiren and Anderson reported rolling resistance tests in compacted oil sands used in haul road subgrades to show a range in rolling resistance of 6-12% in the spring, summer and fall months vs. 4-6% in the winter. High-grade in-situ oil sands may be expected to show higher rolling resistances, and Singhal and Kolada (1987) cite rolling resistances in the summer months of up to 16%. Mobile equipment may become mired in soft underfoot conditions.

In the winter months freezing temperatures create different problems. The stiffening of the oil sands reduces rolling resistance but introduces the problem of frost in the digging face. Frost penetrates the top of exposed oil sands benches. The result is large, frozen lumps of material that must be worked out of the face. These large lumps cause jams if routed to the ore crushers. Singhal and Kolada(1987) identify frost penetration depths in the oil sands of up to 5m, while McKee (1992) indicates frost penetration of up to 4m depth has been experienced at the Syncrude site. Cyr (2004) calculated a probable frost penetration depth of up to approximately 2.1m. This penetration depth is based on a 14 day atmospheric exposure time, however, no measurements were done to calibrate and validate the model used in his calculation, which is at
odds with earlier reported frost depths. It is speculated that maintaining an insulating snow cover may minimize frost penetration.

4.2.2 Waste Planning Issues

Oil sands mines are waste restricted. The extent of the economic deposit on oil sands mining leases is such that there is not sufficient space to create storage for mined waste and tailings without significant ore sterilization. Waste planning is the most significant non-regulatory constraint to be considered in oil sands mine planning. The result is the creation of integrated mining-tailings plans whereby tailings are placed behind dykes in mined out portions of the active mine.

The creation of MFT was identified earlier as a key issue in waste management. Fundamentally issues in oil sands waste are related to 1) the increase in volume of processed oil sands when it becomes tailings and the permanent fluid state of a significant portion of the tailings if not treated; and 2) the mine sites being waste bound.

4.2.2.1 Tailings Issues

Oil sands tailings are deposited hydraulically. The presence of coarse sand in oil sands tailings, and the particle size distribution generally, makes it suitable for direct use in the construction of the upstream and centerline dykes used for oil sands tailings storage. As with tailings dams in other sectors of the mining industry, tailings material that is not required for construction (raising) of the embankment is deposited (beached) on the downstream face of the dam. This may be done using spigots or an open-ended pipe. List and Buckles (1993) and Morgenstern and Scott (1997) provide a summary of oil sands tailings deposition and construction methods. Shell (2012) provides a simple overview of the construction process.
Representative cross sections for an external settling basin and in-pit tailings impoundment are presented in Figure 4-3.

Figure 4-3: Representative cross sections, in and ex-pit tailings impoundments (Shell Canada Ltd., 2012)

When oil sands tailings are deposited hydraulically the tailings stream segregates. The quartz sand settles after discharge. This is advantageous in the construction of tailings impoundments from tailings material, and in the formation of downstream beaches in the dams. The beach forms approximate beach slopes of 1-2% above the pond surface and 4-6% below. Approximately 50% of the clay and silt fines are captured in the voids of tailings sand placed by conventional cell and beaching methods (List, Martens, & Meyer, 1999; Suncor Energy Inc., 2010a). The remaining fines and fluid flow to the pond where they form a fluid thin fine tails
TFT. TFT has a density of 5-15% solids by weight. TFT undergoes an initial, rapid, consolidation over approximately 2 years to form MFT at 30% solids (Jeeravipoolvarn, 2005). A MFT dewatering limit of approximately 40% fines/(fines + water), reached after approximately 25 years, is suggested by experience at Suncor (Wells, 2011). The failure of MFT to consolidate further than this 40% limit traps process water, removing it from potential use in the recycle circuit, and creates long-term fluid storage demands. The term fluid fine tails (FFT) is also used to refer to TFT and MFT.

The volume increase associated with oil sands tailings is presented in the literature. Estimates indicate that between 1.2 m$^3$ and 1.5 m$^3$ of tailings requiring long term storage are produced per 1 m$^3$ of ore processed (Kasperski & Mikula, 2011; Morgenstern & Scott, 1997). Morgenstern & Scott (1997), indicate that in the early stages of mining, before sufficient tailings consolidation has happened, a “bulking factor” of 3 is more appropriate. Jeeravipoolvarn (2005) estimates that 1 m$^3$ of in-situ oil sands will initially produce a tailings volume of 3.3 m$^3$ at 40% solids content and 1.9 m$^3$ at 60% solids content, which represents the normal range of tailings slurry densities. He indicates that in the transition from TFT to MFT approximately 65% of the water volume associated with the fines will be released, resulting in a permanent storage volume in line with earlier estimates and supporting Morgenstern’s suggestion of an early bulking factor of three. Figure 4-4, developed after BGC Engineering (2010), presents a schematic of the volumetric process inputs and outputs required to produce one cubic meter of bitumen.
Figure 4-4: Schematic of historical oil sands tailings management (after BGC Engineering Inc., 2010)
Oil sands mines operate under zero mine and process water discharge conditions. Large volumes of water are required for the process. As indicated by Figure 4-4, over 16% of water introduced to the process is lost from the recycle circuit in the form of MFT. A further 14% is lost to the void space in the tailings beaches. Removal of this water from the recycle circuit, and high rates of evaporation, result in oil sands operators withdrawing freshwater from the Athabasca River. The loss of water to MFT also creates the need for long-term fluid storage or for methods by which to treat or reduce the formation of MFT.

Composite or consolidated tailings (CT), or non-segregating tailing (NST), is one technology for treatment of MFT. In the CT process the fresh tailings stream is cycloned to produce a dense underflow that is mixed with MFT (dredged from the tailings pond) and a coagulant (normally gypsum). The result is a flocculated clay matrix which supports the coarse sand fraction of the tailings. The overflow is directed to the tailings pond, where it will form TFT and then MFT to support future CT production. The target ratio of sand:fines is 4:1. CT dewateres rapidly, addressing the consolidation issues associated with traditional tailings disposal and the production of MFT.

To reclaim CT as a solid landscape it requires a cap. The cap allows the deposit to be travelled on by equipment (trafficked). It should also ensure that any release water from the CT is kept separate from the root zone of reclamation plantings; the addition of gypsum causes the CT release water to be sodic. From a planning perspective deposition of CT and beaching of regular tailings are largely the same. CT is considered to be the only commercially demonstrated tailings treatment technology, although other methods have reached advanced stages of demonstration. Both Syncrude and Suncor have, however, struggled to meet their planned CT
production levels. Suncor is moving away from CT for future tailings treatment and towards thin lift drying (also called mud-farming).

The tailings planning system is described in Section 4.3.1.2 and Appendix B; regulatory reaction to tailings issues is discussed in Section 4.2.4.

4.2.2.2 Mined Waste Planning

When mining begins tailings are placed in an ex-pit impoundment. The starter dyke is constructed with overburden, and tailings are used to complete construction as mining and tailings production advance. The raised embankment tailings dams constructed by oil sands operators are by volume among the largest in the world and present design challenges on leases that have little ex-pit space available.

In addition to external to pit storage oil sands mine planning requires a series of overburden dykes be constructed within oil sands mining pits. Tailings are placed behind these dykes as mining continues on the downstream side. The volume demands created by tailings production mean that waste production and handling must be carefully planned and managed.

Overburden planning is a separate planning function within the mine planning group at most oil sands mines. The overburden planner is responsible for planning the removal of overburden and planning its placement in overburden-construction tailings dykes. Just as the ore planners must achieve a certain blend for the process the waste planners must ensure that the right overburden materials are available at the right time. Some construction activities are seasonal, and can only take place during the limited frost-free window in the summer months. The material balance is important to the design and construction of overburden dykes. Some Clearwater Formation facies are suitable for high-specification construction due to low clay content, and as
clay content increases the suitability for overburden dyke construction decreases. The relative tonnage of high, medium, and low specification materials varies from lease to lease. The overburden planning team must ensure that the tonnages of material indicated by the mining model meet the requirements for construction, and must monitor the operation to ensure that short-supply materials are not simply wasted to the dump.

Successful oil sands waste planning is dependent on the interaction between overburden planning, ore planning/ore control, tailings planning, and extraction planning. The medium to long term tailings plan must meet the forecast tailings containment requirements, ensure that there is sufficient recycle water available for use by the process plant, and meet the fluid transfer requirements of the long term plan. In the short term the plan must ensure sufficient recycle water is available, ensure that sufficient volume is available at the tailings discharge points, identify tailings pipeline moves, and coordinate feed requirements with the mine and extraction. High fines content in the tailings stream will tend to erode or ‘cut’ placed beach or cell sand and low fines streams may experience difficulties with pipeline flow. Mature oil sands operations may have five or more ponds under active management, with tailings feed going to more than one pond at a time. Fluid tailings are typically cascaded from one pond to the next as older ponds are infilled with coarse tailings or other tailings products, and recycle water is returned for use in the process.

4.2.3 Interim Directive 2001-7

The ERCB, formerly the Alberta Energy and Utilities Board (EUB), regulates the development of the oil sands in the province of Alberta. The ERCB is responsible for ensuring that the oil sands and other energy resources are developed in a safe, efficient and responsible manner. The Oil Sands Conservation Act was enacted to “…prevent waste of the oil sands
resources of Alberta… [and] ensure orderly, efficient and economical development in the public interest of the oil sands resources of Alberta.” (Oil Sands Conservation Act, RSA 2000, c O-7, 2011).

Interim Directive (ID) 2001-7, “Operating Criteria: Resource Recovery Requirements for Oil Sands Mine and Processing Plant Sites”, was developed by the EUB in conjunction with oil sands mine operators and came into effect in October 2001. The purpose of ID2001-7 was to establish a standard set of resource recovery criteria to assess future oil sands mining applications, thereby improving certainty in the regulatory environment and operational flexibility for mine operators.

The criteria established by ID2001-7 are intended to:

- reduce the need for an application for technical changes or modifications to approved mine or processing plant sites when the changes or modifications relate to resource recovery;
- reduce information relating to resource recovery that must be provided in an application;
- reduce the extent to which resource recovery aspects of an application will be subject to a detailed review;
- establish a clear basis for reporting on resource recovery;
- establish a clear basis for determining compliance with resource recovery requirements; and
- reduce the level of EUB involvement if compliance with resource recovery requirements has been demonstrated. (ID 2001-7).

Four criteria governing bitumen recovery requirements are specified by ID 2001-7. These criteria were developed based on “current [2001] technical, economic, and geological conditions … [to] aid in defining what the EUB believes is the minimum required level of resource recovery
for existing and greenfield operations and below which the EUB will take enforcement action”.

The four criteria govern:

- cut-off grade
- mining thickness
- ratio of total volume to bitumen in place (TV:BIP)
- processing plant recovery.

These criteria impose significant constraints on oil sands mine planners and severely limit the opportunities to improve NPV that are the focus of most mine planning studies. Production rate, and to a limited extent mining limit, become the only strategic parameters the planner has control over.

4.2.3.1 Cut-off Grade

_ID 2001-7 establishes a static cut-off grade for oil sands mines at 7% bitumen by weight._

No recognition is given to the processing characteristics of different facies, or the potential differences in tailings production due to differing fines content.

4.2.3.2 Mining Thickness

_A minimum mining thickness of 3m is defined by ID 2001-7. Ore grade material (i.e. greater than 7% bitumen by weight) must be processed if it occurs in a continuous height exceeding 3m. Isolated bands of ore grade material less than 3m may be wasted to the dump. Included bands of low grade oil sands material (interburden) less than 3m must be processed if the total bitumen content when considered in conjunction with surrounding ore meets the cut-off criteria of 7%._
This requirement has resulted in the development and use of block grade models in the oil sands industry with 1m high blocks to enable ore zone identification (see Figure 4-5). The ore reserve estimation techniques used in the oil sands, and the efficacy of this policy, will be discussed further in Sections 4.5 and 5.3.1.2.

Figure 4-5: Ore-waste classification scheme at Suncor (Wilkinson Jr. & Heltke, 2005)

4.2.3.3 Total Volume to Bitumen In-Place Ratio

The total volume to bitumen in-place ratio (TV:BIP) is used to define the pit limit or extent of mining required. The ratio compares the volume of bitumen contained within a mining block, defined using the 7% cut-off grade and 3m mining thickness, to the total volume mined to obtain the bitumen. The volumes of ore and waste are both considered in calculating the total volume value. This ratio is one of several methods that oil sands operators historically used to define recoverable bitumen reserves and favorable mining areas (O'Donnell & Ostrowski, 1992).
The ratio is calculated using Equation 4:

**Equation 4: Calculation of TV:BIP**

\[
\frac{(Ore + Interburden + Overburden), m^3}{(Volume of Bitumen in Place, m^3)}
\]

where: \( Volume\ of\ Bitumen\ in\ Place = \frac{(Ore\ volume\ x\ Density\ x\ %Grade)}{Bitumen\ Density} \).

Allowance is made for mining loss/dilution of a 0.5m thickness at the base of each ore and waste zone. Given similar grades of ore, a low TV:BIP will be more profitable as it requires less material movement than a higher TV:BIP.

4.2.3.4 Processing Plant Recovery

Minimum processing plant recoveries are mandated under *ID 2001-7*. For as-mined ore grade material with bitumen content equal to or greater than 11% (weight) bitumen, the minimum acceptable recovery is 90%. For as-mined ore grade material below 11% bitumen, the minimum acceptable recovery is governed by Equation 5:

**Equation 5: Minimum process recovery of bitumen requirements**

\[
Recovery = -202.7 + 54.1X - 2.5X^2
\]

where: \( X \) is the average weight percent bitumen content of the as-mined ore.

A 7% ore, for example, would be expected to yield a minimum bitumen recovery of 53%. The minimum recovery factor was based on historic experience.

Operators are subject to compliance checks to ensure they meet minimum recovery criteria. It is interesting to note that the understanding of a grade-recovery relationship in oil sands ores implied by the recovery calculation is not acknowledged in the TV:BIP ratio.
4.2.3.5 Precedence for ID 2001-7

Universal criteria governing mining limit and cut-off grade are unusual in the regulation of the mining industry. Most jurisdictions review individual mine plans to ensure responsible resource development as part of the mining approval and lease renewal process. Maximum resource extraction can be effectively controlled through this process. In Alberta plans are reviewed, but they are reviewed to ensure consistency with ID 2001-7 and do not consider the geological characteristics of the individual projects. The only reference to a regulatory regime similar to that in Alberta was found in the historic South African mining literature (Janisch, 1986).

As explained by Janisch, in South Africa, under the Mines Act of 1967, all mining lease applications were reviewed to ensure the resource was exploited in an optimal manner (optimal manner being open to interpretation). The normal result was a requirement to mine annually to the average in situ ore grade of the deposit. This would maximize total gold extracted and prevent high-grading (the preferential early mining of the richest parts of the ore body). Other regulatory controls ensured that a continuous mineralized deposit could not be divided amongst a series of owners, effectively preventing companies from preferentially claiming only the richest part of the deposit. The sale or other disposal of unwrought precious metals was also state-controlled. Interestingly, this meant a mine could not gift a gold-bearing rock sample without authority from the South African Police’s Gold Branch.

Janisch indicates that by the mid-1980s the “good traditional mining practice” of requiring mining to the average grade was beginning to be eclipsed by economic conditions, including variable pay limits (cost per tonne milled/cost per gram gold) caused by variations in the gold price.
It is important to note two things. First, although the average grade policy would appear to have been universally applied through individual lease approvals, the specific grade criterion was project dependent. That is, the required mining grade was based on the unique characteristics of the deposit under consideration. This is a significant difference from the static and universal approach of Alberta’s ID 2001-7. Second, the policy was not enshrined in the regulations or otherwise formally issued. Mine cut-off grades were established annually. This enabled timely reaction to changing economic conditions. Janisch reports that changes in gold prices and the South African Rand exchange rate in the 1980s tended to overturn the traditional average grade method of control over resource exploitation.

4.2.4 Directive 074

The ERCB’s Directive 074 “Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes” was issued February 3, 2009. The directive is the result of oil sands operators repeated failures to meet their own fluid tailings reduction targets. In order to reduce the production of fluid tailings the directive specifies minimum performance criteria for fines capture in dedicated disposal areas (DDAs), which must be formed and managed by the operator. The fines capture targets are in addition to fines captured in normal coarse tailings cell or beach construction activities.

The minimum fine tailings feed to the DDA requirements are:

- 20%, July 1, 2010 to June 20, 2011;
- 30%, July 1, 2011 to June 30, 2012; and,
- 50% annually after July 1, 2012.

The DDAs are subject to performance criteria:
• annually, material deposited in the prior year must exhibit minimum undrained shear strength of 5kPa; material not meeting this standard must be removed or remediated; and,

• within 5 years of the cessation of active deposition the DDA must be ready for reclamation. Being ready for reclamation, or “trafficable” by equipment, is defined as exhibiting a surface layer with minimum undrained shear strength of 10kPa.

The directive also specifies the content of the annual integrated tailings and mine plan, and the annual fluid tailings pond status reports due for each approval under the *Environmental Protection and Enhancement Act.*

As of the September 30, 2011 filings, only Suncor had indicated planned compliance with the directive. The directive did allow that:

Operators are required to make submissions to the ERCB on how they will meet the new requirements and identify any project-specific constraints that may have a bearing on meeting the requirements. Requirements will be phased in and adapted, as approved by the Board, to take account of particular mining and tailings plans, facilities, and the status of a project.

4.3 Oil Sands Mine Planning System

Fundamentally oil sands mine planning follows the same activities as conventional hard rock, metal mine planning. The activities identified in Appendix B and described in this section are representative of typical industry practices. The planning system’s activities will be described in detail where they vary from the activities described in Chapter 3.
As identified in Section 4.2, key differences in the considerations in oil sands mine planning include an increased focus on waste planning due to the formation of fluid tailings and the imposition of several regulatory constraints that may severely limit economic optimization options. The regulator participates directly in the development of the mine plan by defining specific mining criteria, including the minimum pit limit and the minimum cut-off grade (see Figure 4-6). The production scale of the operations and limited ex-pit footprint for waste dump and tailings impoundment construction also present challenges that influence the activities that form the planning system.
Figure 4-6: Select business planning aspects of the oil sands planning system. Note the direct participation of the regulator in the mine planning system.
4.3.1 Strategic Planning

A systems analysis of the oil sands mine planning system indicates that strategic planning of oil sands mines shows great variance from the conventional hard rock metal mining system (see Figure 4-7). The main activities that produce the strategic plan are subject to a larger number of externally-imposed constraints, and to constraints that limit the ability of the planner to make informed decisions based on economics and technology, normally the drivers of the strategic planning process.

![Strategic Planning Diagram](image)

**Figure 4-7: Oil sands planning activity diagram - strategic planning**
4.3.1.1 Pit Limit Analysis

Pit limit analysis in the oil sands is conducted by establishing a series of TV:BIP contours. The ERCB mandates a minimum TV:BIP of 12:1, although exceptions to this may be approved on a case by case basis. Once the 12:1 contour or contours are established a practical mining pit is created to encompass the material; waste islands may be left unmined within the final pit limits.

A series of TV:BIP contours may be developed for ratios above 12. Under most conditions this will maximize resource recovery and the total value of the project. A TV:BIP map with a 16:1 TV:BIP pit crest identified is presented in Figure 4-8. The activity flow for oil sands pit limit analysis is presented in Figure 4-9.
Figure 4-8: TV:BIP map showing 16:1 pit limit (Teck Resources Ltd.; SilverBirch Energy Corporation, 2011)
Pit analysis

- Make ore/waste determination (ID 2001-7)
- Capture geotechnical parameters
- Calculate bitumen volume for ore blocks
- Assign wall design parameters
- Create Total Volume: Bitumen in Place 12:1 contour

Assign 12:1 TV:BIP as pit limit

Create mineable pit limit

Create higher ratio TV:BIP contours

Examine pits for economic attractiveness

- [>12:1 ratio preferred]
- [12:1 limit preferred]

Assign as new pit limit

Identify ex-pit tailings and waste dump locations

Figure 4-9: Oil sands planning activity diagram - pit analysis
4.3.1.2 Waste Plan Development

Waste mining in an oil sands mine can limit ore production in one of two ways: the waste plan does not advance in time to ensure that there is exposed ore for mining (i.e. insufficient lead time or ore inventory) or the waste plan does not create sufficient storage space for tailings placement. The constraints on ex-pit waste dump storage and on the materials that are suitable for in-pit dyke construction require consideration at a very early stage.

Prior to detailed scheduling the waste plan should be considered to ensure that there is sufficient ex-pit and in-pit volume available to meet both the disposal needs of the mine and also the construction and disposal needs of tailings. Only a very preliminary assessment needs to be done. If sufficient LOM space is identified planning can proceed to detailed scheduling, otherwise the pit limit and lease layout need to be revisited.

The activities associated with this stage of waste planning are presented in conjunction with the tailings planning activities in Section 4.3.1.3 and may be found in Appendix B, diagrams B-4 and B-5.

4.3.1.3 Tailings Plan Development

The attention to waste planning in oil sands mine planning is a key differentiator. From a mass balance and volumetric perspective tailings planning in particular receives a greater focus.

Tailings planning is normally done by a specialized team, and may report to mining or extraction management. Regardless of the division that tailings planning resides in within the organization the development of the tailings plan is related directly to development of the mine plan and is an iterative process. The mine is reliant on the tailings plan providing adequate
storage for the tailings produced in any period; the tailings plan is reliant on the mine advancing the pit limit and construction of in-pit dykes to create tailings storage space.

The tailings plan will produce a LOM mass balance forecast by period, identify the tailings volume storage requirements by period, identify the portion of the volume storage requirements to be met by tailings-constructed structures, develop pond capacity and infilling schedules, and define the volume storage requirements to be met by in-pit containment by period (see Figure 4-10). Initially this can be done with an annual production tonnage forecast and average bitumen grade and fines content information produced by pit limit analysis. As the mine schedule is developed the plan is refined.

Figure 4-10: Oil sands planning activity diagram - tailings plan development

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The tailings plan is developed in conjunction with overburden and mined waste structure planning, and requires production forecasts to determine the tailings storage capacity requirements by period. With the start of mining activity to the north of the original mine sites for Suncor and Syncrude, dewatering requirements have increased and, where mine-impacted water discharge is not permitted, must be considered as part of the site material balance.

In addition to requirements under Directive 074, tailings plans are subject to close scrutiny during the review process that precedes the issuing of a mining approval. The introduction of Directive 074 reduces the operational flexibility that oil sands operators previously enjoyed. The impact of the directive on the planning process is primarily the need to incorporate new tailings handling and treatment methods, most of which are unproved from a commercial standpoint, and to develop management plans for dedicated disposal areas (DDAs) for fines capture. The process of forecasting the volume of tailings produced and of scheduling the construction of tailings impoundment construction remains the same.

Successful responses to Directive 074 may relieve some of the pressure on construction fluid tailings containment, however, most of the proposed technologies are unlikely to reduce the need for exhaustive tailings planning. Some of these new technologies, especially the thin lift drying of MFT, require large footprints for the volumes of tailings produced by oil sands mines. The limited areas available outside of the mining pit limit on oil sands leases will challenge planners and researchers to continue to identify and develop novel methods of tailings treatment.

It is difficult to quantify the cost that will be incurred with eventual reclamation of these tailings deposits (see Section 4.4). To date, no fine tailings deposit has been reclaimed and only limited treatment of MFT has been undertaken. Consolidation and reclamation of fine tailings material are currently an important research focus.
4.3.1.4 Waste Scheduling

The objective of most long range mine planning is to maximize the NPV of the project over the mine’s life.

In oil sands, the capital and operating costs associated with mining activity are low compared to the costs associated with the plant, and with upgrading bitumen to synthetic crude oil where the project includes an upgrader. The goal of detailed mine and tailings scheduling is therefore to maintain ore production at the rate demanded by the extraction plant.

Minimizing mining costs or maximizing the NPV of the mine is constrained in oil sands planning. It is normally adhered to by optimizing haul distances for ore and waste (i.e. minimizing haul distances early in the mine life). A more significant constraint is ensuring adequate tailings containment is available to meet the tailings forecast; without adequate tailings space the plant will be idled. Sufficient pit floor must be exposed to allow the construction of in-pit dykes in accordance with the tailings plan. Overburden removal and placement must be scheduled for construction of these dykes as the mine progresses, as well as for the tailings starter dyke. Overburden and ore quality are both important considerations but in most oil sands mines the geology and high production rates tend to minimize issues related to blending or waste material balance. Similarly the strip ratio tends to vary little over the LOM.

To support the commissioning and smooth ramp-up of both mine and plant production, and to provide enough material for construction of the ex-pit tailings disposal area, mining of overburden will begin in advance of ore mining. The timing and tonnages removed by preproduction stripping are dependent on the material balance and on the aggressiveness of the planning team with respect to establishing lead time for both ore production and tailings storage. Given the high ore production rates very early in the mine life, and the estimated 3 cubic meters
of tailings storage required per cubic meter of ore processed, prestripping requirements can be significant. Teck and SilverBirch (2011) indicate over 20M bank cubic meters (40.5Mt) of overburden stripping will be completed prior to ore production for the main pit at their Frontier project. The updated submission for the Jocelyn North Mine indicates approximately 36M bcm (74Mt) of prestripping activity (Deer Creek Energy Ltd., 2007).

Mine and tailings scheduling normally employs a mix of commercial CADD, GMP, other specialized software, and in-house models. The large number of constraints limits the number of feasible options for the schedule.

Most mines progress outwards from their starting pit in a series of near rectilinear annual advances. The advance sequence is strongly governed by the desire to minimize haul distance and to expose areas of the pit floor for in-pit tailings dyke construction (see Figure 4-11). As a result the initial pit or cut is normally located near the plant site.

Research work into the development of a mixed integer goal programming model for long term oil sands mine scheduling will be discussed in Section 4.5
4.3.2 Long Range Planning

Long range planning in the oil sands follows a similar activity flow to that presented in Chapter 3. The difference, as in strategic planning, is an increased focus on waste planning and integration of the mine plan with the tailings plan.

Variables in the traditional economic analysis of a mining project are constrained in oil sands planning, including, in particular, the definition of ore. An expansion of the pit limit

Figure 4-11: Teck and Syncrude planned annual mine advances (Teck Resources Ltd.; SilverBirch Energy Corporation, 2011), Syncrude (2010a)
beyond the 12:1 TV:BIP contour and optimization of the mining sequence in support of the tailings plan are the major activities of LRP in the oil sands (Figure 4-12). Activities in generating a detailed mine plan are discussed in this section. A full set of activity diagrams for oil sands long range mine planning is found in Appendix B, diagrams B-7 to B-15.

Figure 4-12: Oil sands planning activity diagram - long range planning
4.3.2.1 Site Layout

Site layout follows a similar activity flow in oil sands mining to that presented in Chapter 3. The most significant difference is the challenge presented by limited lease areas. An activity diagram for oil sands site layout is found in Appendix B, diagram B-9.

4.3.2.2 Equipment Selection

The equipment selection process for an oil sands mine is the same as for any other mine. The unique considerations in oil sands mining include soft ground conditions, highly abrasive ore, high production rates, extremes of temperature, and the need for high digging forces, especially in the winter. An activity diagram for an oil sands site layout is found in Appendix B, diagram B-10.

The oil sands industry has adopted large equipment across the board. Although there is debate over the cost-benefits of the largest ultra-class equipment, it is clear from operating experience that congestion issues alone can justify the use of large trucks.

A mix of rope and hydraulic shovels are employed in oil sands mines. The high production rates of the rope shovel make it suitable for the bulk loading required to meet the production demands of an oil sands mine. The ability of a hydraulic shovel to position its bucket and selectively mine the face makes it an attractive alternative where thin seams of ore or waste need to be separated out (see 4.2.3.2). Wide tracks are used on all oil sands shovels. The industry is sufficiently large that a number of oil sands-specific models exist, including the P&H4100 TS series and later BOSS (B series Oil Sands Shovel) shovels, the Bucyrus 495HF (High Flotation) shovel and the O&K RH4100 hydraulic shovel, developed in partnership with Syncrude.
4.3.2.3 Scheduling Mining

The creation of a feasible mining schedule for oil sands planning is focused on ensuring that the waste management plan (both mined waste and tailings) is supportive of the mining plan. The need for significant in-pit space for tailings placement during the life of the mine and uncertainties associated with tailings forecasting add complication to the waste plan that is not present in most metal mines. The sequence of activities is presented in Figure 4-13. Note the need to perform a life-of-mine (LOM) analysis of the waste mining and placement schedule to ensure not only that there is sufficient space for all mined wastes but also that there is sufficient waste, available at appropriate times, to meet dyke construction plans.

The final wall in sections of the pit that will host dyke construction needs to be defined several years in advance of tailings placement. This limits opportunities to respond to changing commodity prices, however, it should be noted that ore mining may continue or even relocate to the upstream side of the dam until such time as tailings placement begins. Location of waste facilities ex-pit may also challenge locating the pit limit; in some cases the ERCB may allow sterilization of ore to meet waste facility requirements.
Schedule mining

- Assign ore tonnes from model until period production met
- Calculate scheduled ore properties (grade, fines, etc.)
  - [Properties acceptable]
  - [Properties do not meet process requirements]
  - Consider different schedule

- Decide on number of concurrent mining faces, benches, and pushbacks (advances)

- Determine ramp & bench parameters and mining bench width
- Draft ramps and fixed infrastructure (e.g. crusher)

- Draft ramps and fixed infrastructure (e.g. crusher)

- Calculate NPV
  - [Sufficient level of analysis
   Select best schedule]

- [Revise waste plan]
  - [Revise site layout]
  - [Revise pit analysis]

Figure 4-13: Oil sands planning activity diagram - mine scheduling
The selection of lead time, or how far ahead of ore mining waste stripping will occur, is largely a function of acceptable risk. When compared with traditional hard rock mines, shortened lead times are supportable if an oil sands mine is run efficiently. The elimination of the drilling and blasting portion of the mining cycle, the relatively shallow overburden cover, and the continuity of the deposits support lower lead times. Shortened lead times in waste removal will defer waste related costs, increasing the NPV of the project. In the case of oil sands mining shortened lead times in the winter reduce issues associated with frost. The availability of mining contractors in the region also helps mitigate risks associated with aggressive waste deferral policies. Nevertheless, experience would indicate that a minimum of two months of lead time should be planned, and that SRP should take action to restore lead time if the waste advance ahead of ore mining falls below this level. The experience of individual operations with respect to plan stewardship should inform this decision.

4.3.2.3.1 Waste Planning

The development of the long range waste plan demands careful attention and requires significant involvement of groups outside of the normal mine planning team; this will continue in SRP. The activities and the group(s) of specialists involved in each are presented in Figure 4-14. The number of constraints and plan interdependencies make waste planning and scheduling highly iterative.

At this stage of planning, the LOM material balance should transition from the use of average grade and fines of the mineable resource to the expected grade and fines profile by year.

Tailings and OB scheduling are also iterative activities and on leases where quality dyke construction materials are limited, or where ex-pit space is at a premium, the process becomes
quite complex. The detailed activity flows for tailings and OB scheduling are presented in Figure 4-15 and Figure 4-16; the activities are interdependent.

Figure 4-14: Oil sands planning activity diagram - coordinated waste planning
The activities could be simply described as matching the volumes required with the volumes available, but space, time, and material availability constraints and the desire to minimize costs make this a challenging problem.
Schedule tailings

1. Schedule raw water import (communicate to utilities)
2. Communicate to overburden planning
3. Produce detailed LOM mass balance model by period (fluid & coarse tails, recycle water, raw water intake, other effluent, etc.)
4. Issue pond rise forecast
5. Schedule tailings sand construction to meet pond rise schedule
6. Schedule fluid tailings rehandle
7. Determine facility storage construction requirements and capacities for non-fluid tailings storage (e.g., DDA for thin lift tails drying)
8. Determine beach requirements
9. Communicate additional OB needs to mine
10. Schedule remaining tailings by placement priority
11. Determine material shortfall
12. Identify pipe/pump requirements
13. Communicate as necessary
14. Generate tailings facility infill plan based on schedule including rehandled/treated tails
15. Update mass balance model with 12 month schedule
16. Identify new requirements/relocations
17. Communicate as necessary
18. Create and issue new pond rise forecast
19. Communicate to OB planning
20. Check against mining & tailings plan
21. Issue plan

Figure 4-15: Oil sands planning activity diagram - tailings scheduling
Schedule overburden

- Develop pit LOM minimum OB construction requirements by period (tonnes, quality)
- Determine ex-pit waste capacity
- Determine in-pit waste capacity for engineered and non-engineered structures
- Determine overburden constructed dyke construction material requirements (tonnes, quality)
- Determine infrastructure material requirements (tonnes, quality)
- Develop pit LOM minimum OB construction requirements by period (tonnes, quality)
- Determine tailings material requirements
- Schedule minimum OB removal to meet ore production
- Address periods when advanced stripping required
- [Revise waste planning]
- [Construction requirements not met]
- [Increase mining capacity]
- [Material balance not met: Cannot address; revise waste planning]
- [Ore stripping and construction requirements met]
- [Construction requirements not met]
- Issue plan
- Identify and communicate Opportunities For infrastructure moves (crusher relocation etc)

Figure 4-16: Oil sands planning activity diagram - overburden scheduling
4.3.3 Short Range Planning

The short range planning activities follow a similar pattern to SRP in hard rock metal mines. As in long range oil sands mine planning, the emphasis on waste planning is increased. There is daily interaction between the overburden planners, the geotechnical group, and tailings volume planners. An operations’ focus on minimizing costs and maximizing ore today may cause longer range problems and field monitoring is critical to ensure plans are being stewarded to. Management must communicate the importance of stewarding to the plan to operations teams in the mine and tailings. Clear communication of the short range plan, the objectives, and the rationale is important to ensure success. While feedback from the operations is critical to planning success it is important that planning directs operations, rather than operations directing the plan.

The detailed activity flows for SRP are presented in Figure 4-17 through Figure 4-20, and in Appendix B, diagrams B-16 to B-20. Figure 4-21, reproduced on diagram B-21, provides a high-level description of the tailings planning workflow.

The distinct emphases on waste planning are evident when contrasting the oil sands and metal mine models. In oil sands planning, detailed tailings planning activities are included. The activities to generate the tailings plan are the same at all stages; only the accuracy and precision of the available forecast changes. Tailings SRP and operations offer less flexibility than mine SRP and operations. Pipeline relocations, rotations, and discharge locations are inflexible when compared to the movement of haul trucks, loading equipment, and the other mobile equipment used in the mine.

In oil sands mining, the mine plan must often be altered to accommodate the requirements of the tailings plan over both a short and long term horizon. The mine must also
understand the requirements of tailings, and the impact of mining activities on tailings activities. An unexpected shovel outage, for example, may have a significant impact on the ore blend delivered to the extraction plant. If the fines content of the ore feed is reduced significantly, pumping issues may be experienced in tailings, and different discharge locations may be required over the short term. Conversely, if the fines content of the ore increases significantly, the result may be low-quality tailings feed, unsuitable for paddock cell construction of tailings dykes and potentially damaging to existing construction.

The time horizons for SRP will vary amongst operators; however, there is normally an annual plan which directs development of detailed monthly plans. The monthly plans are updated regularly and used to feed an intermediate forecast, such as quarterly forecasting. The monthly plans direct the weekly plan, which in turn directs the daily plan (see Appendix B, diagram B-16). SRP must be able to respond quickly to evolving field conditions, equipment breakdown, unexpected plant outages, etc.
Twelve month planning

- Identify annual ore advance (tonnes and location)
- Identify waste advance
- Schedule waste placement
- Calculate equipment hours and numbers
- [Insufficient equipment in one or more quarters]
- [Sufficient equipment Identify periods of reduced demand for scheduling opportune mine maintenance ]
- [Schedule change possible]
- Assess ore and/or waste schedule change. Investigate Main’t schedule or plant demand change
- Assess rental/contractor fleet
- [Rental/contractor available within budget]
- [Changes not accommodated Continue planning exercise Trigger impact assessment & quantify impact Notify management]
- Prepare budget/issue plan

[Changes accommodated]

Figure 4-17: Oil sands planning activity diagram – annual planning
Monthly planning

Schedule major outages by week

Identify ore & OB production polygons by week

Identify construction activities by week

Communicate construction activities to tailings

Calculate equipment hours and numbers

[Insufficient equipment in one or more weeks]

Assess ore and/or waste schedule change, Investigate main’t schedule change, mill demand change

[Schedule change possible]

Assess reducing waste mining

[Schedule change not possible]

[Insufficient equipment in one or more weeks]

Assess ore and/or waste schedule change, Investigate main’t schedule change, mill demand change

[Reduction can be accommodated]

Assess reducing waste mining

[Reduction not accommodated]

[Rental/contractor available]

Issue plan/forecast budget variances

[Continue planning, reduce waste lead time, then restrict plant Assess LRP alternatives]

Quantify impacts/notify management

Figure 4-18: Oil sands planning activity diagram - monthly planning
Weekly planning/10 day planning

Forecast available mining capacity (tonnes per loader per shift)

Select production polygons by day

Assign loaders to production polygons

[Cannot meet plant demand]

[Can meet plant tonnage demand]

[Can meet blend requirements]

[Cannot meet blend]

Evaluate ore or waste loader(s)

Notify plant

Determine waste shovel priority

[Can meet blend requirements]

Determine trucks required

[Insufficient trucks]

[Can meet blend requirements]

Evaluate ore and waste priorities

Notify plant and tailings

Identify support activities & equipment requirements

Identify adjustments to monthly plan

[No changes required]

***Notify Maintenance of any opportune main't opportunities

Figure 4-19: Oil sands planning activity diagram - weekly planning
**Daily planning**

1. Calculate available mining capacity (tonnes per loader per shift).
2. Calculate available mining inventory by open mining face (tonnes and properties).
   - [Loader move(s) practical]
3. Determine ore loader priority by shift to meet plant demand (tonnes and blend).
   - [Cannot meet plant demand]
   - [Can meet plant demand]
   - [Cannot meet blend requirements]
   - [Can meet mill blend requirements]
   - [Move not practical]
4. Evaluate moving ore or waste loader(s).
5. Determine waste loader priority to maintain construction requirements.
   - [If excess shovel capacity notify maintenance of 'opportune mainT window]
6. Determine trucks & critical support equipment required.
   - [Insufficient equipment]
   - [Sufficient trucks if excess notify maintenance of opportune window]
7. Evaluate ore and waste priorities.
   - [Ore restriction preferable]
   - [Waste restriction preferable]
8. Adjust waste targets.
10. Identify support activities & assign equipment.
11. Identify updates to weekly plan.
   - [Update weekly plan]
12. End of daily planning activities.
    - React to changing field conditions.
    - Repeat daily.

**Figure 4-20: Oil sands planning activity diagram - daily planning**
Tailings planning activity workflow

Create detailed Mass Balance

Prioritise available tailings feed use & fluid transfers

Identify system maintenance outages (pipe rotation/replacement, pump work, etc.)

Schedule priority tailings construction & fluid transfer

Develop pipe layouts for critical activities

Schedule non-critical activities

Identify pipe layouts for non-critical activities

Check pipe layouts for pipe move timing, maximum pipe demands, etc.

Regenerate mass balance model

Ensure pond rise forecasts supported by planned mine and tailings construction activities

Consider scenario options

Schedule support activities (barge moves, etc.)

Identify pipe requirements

[Containment increase/pond rise schedules not compatible Tailings to address]

[System usage not consistent with main't plan]

[Schedule not attainable]

[System priorities not consistent with mass balance assumptions]

[Containment not met]

[Required containment met]
4.4 Establishing Appropriate Costs for Oil Sands Mine Planning

Economic uncertainty is an accepted fact in mine planning. Future costs, commodity prices, etc. are not known, and only forecasts are available. At the advanced stages of design, and during an oil sands mine’s operating life, most operating and capital costs can be forecast with a reasonable degree of certainty. There is a history of operating experience accrued by four different mine operators to guide these forecasts. The costs associated with tailings treatment and reclamation, however, are not easy to forecast. This is a function of:

- a limited history of fluid tailings treatment;
- limited reclamation activity resulting from the above; and,
- a lack of transparency on the part of industry and the Government of Alberta with respect to actual experience in reclamation costs and methods used to forecast future costs.

The only source of reclamation costs found in the scientific literature is Devenny (2010). He identifies that a value of $0.10/m³ of ore was used in a screening study conducted into tailings treatment technologies. No source or justification for the value is provided.

4.4.1 Tailings Treatment Costs and Directive 074

*Directive 074* sets performance targets for the treatment of fine fluid tailings (Section 4.2.4). The objective of the directive is to minimize MFT production, which should aid in more timely reclamation on oil sands mine sites.

*Directive 074* has intensified research into tailings treatment technologies in the oil sands. Most technologies are currently in the research and development stage, and promising technologies include thin lift drying (mud farming) and the centrifuging of MFT. Many of these
technologies are employed by other sectors of the mining industry where fine tailings are an issue, including in bauxite and phosphate processing. A version of mud farming has been in use by Florida phosphate operators since the mid-1980s (Olson, 1992). The challenge now is to adapt these technologies to the unique characteristics and requirements of oil sands tailings or identify and develop new technologies.

The early stage of implementation of these new technologies challenges cost estimation. Devenny (2010) undertook a screening study of various tailings treatment technologies including two thickener options, three CT options, centrifuging of the fines stream, and MFT treatment with centrifuge and the addition of dry swelling clay for solid disposal of the tailings. Undiscounted tailings life cycle costs were indicated to range between $1.35 (centrifuged dry tailings) to $3.71 (thickener densification of the fines stream) per cubic meter of average ore processed (approximately 2 tonnes of ore producing 1 barrel of oil). $3.46 per cubic meter was identified as the cost of the current “no treatment” approach. The developed costs included capital and operating costs, accounted for heat loss to tailings ponds, and included $0.10/m³ ore each for land reclamation and water treatment. BGC Engineering (2010) provides a relative cost assessment for a wider range of potential tailings treatment technologies.

4.4.2 Land Reclamation Costs and the Mine Financial Security Program

On April 1, 2011 Alberta Environment introduced the Mine Financial Security Program (MFSP) for coal and oil sands mines, replacing the use of the Environmental Protection Security Fund (EPSF). The MFSP establishes new criteria for reclamation security, and is in part a response to criticism of the inadequacy of security provided under the EPSF. The MFSP is to undergo a review by year end 2014. The full details of the MFSP are not relevant to this thesis;
however, the MFSP does contain information that may be relevant in estimating reclamation costs.

The MFSP represents the first time the government has provided an indication of expected reclamation costs for oil sands mines. The MFSP uses an asset: liability approach in setting the appropriate level of financial security for a project. That is, the liability incurred by the project is secured by the project value itself. This is adjusted when the asset to liability ratio falls below 3:1, when there are fewer than 15 years left in the mine life, or when an operator fails to meet its self-identified reclamation targets. This amounts to the provincial government underwriting the reclamation liability for most of the project’s life. Anticipated reclamation costs are required to understand the potential financial consequences of the risk the government is assuming.

In the Guide to the Mine Financial Security Program (2011) Alberta Environment indicates that undiscounted oil sands reclamation costs range from $45,000/ha to $75,000/ha. The guide indicates that the MFSP adopts $75,000/ha as a conservative (i.e. high) undiscounted reclamation cost in the event that an outstanding reclamation deposit must be calculated.

Under the MFSP oil sands mine operators are required to submit annual reports which will include the undiscounted, unescalated Asset Retirement Obligation (ARO) liability for the operation, the actual reclamation performed on an annual basis, and the actual reclamation cost on an annual basis in $/ha (Alberta Environment, 2011b). This information may be used to establish a new per hectare reclamation cost for the purposes of calculating an outstanding reclamation deposit.
4.4.3 Land Reclamation Costs and Corporate Asset Retirement Obligations

An Asset Retirement Obligation is the estimated cost for the retirement of an asset resulting from the normal use and development of the asset. In a mining context an ARO would include costs associated with any required reclamation of the mine site, decommissioning and demolition of the processing infrastructure, water treatment, etc. The ARO only includes incurred liability; liabilities associated with anticipated future development are excluded. AROs are reported in the financial statements of publicly traded companies. The ARO is normally reported as an aggregate value for the company, and not by individual project. AROs are subject to third party audit.

Two sources exist to assess industry’s understanding of oil sands mine reclamation costs via ARO disclosures. The first is Canadian Oil Sands Limited (COS), a publicly traded company that owns 36.74% of the Syncrude Joint Venture. Syncrude represents COS’s only physical asset, and the ARO reported by COS is therefore representative of the anticipated costs for their share of the Syncrude project. The ARO of COS is of particular interest as Syncrude has extensive reclamation experience. At year-end 2011, Syncrude has permanently reclaimed approximately 2,300 ha more land than any other operator, has reclaimed the highest percentage of land of any operator, and is the only operator to have obtained a reclamation certificate from the Alberta government (see Table 4-3). The second source of oil sands specific ARO data is Canadian Natural Resources Ltd. (CNRL), owner of the Horizon project. CNRL provides a separate ARO estimate for their oil sands mining and upgrading operation but is a relatively new producer.
Table 4-3: Land disturbance and reclamation by oil sands facilities, in km\(^2\)

<table>
<thead>
<tr>
<th>Mine Site/Facility</th>
<th>Mine Site Footprint</th>
<th>Plant Site Footprint</th>
<th>Total Active Footprint</th>
<th>Active (permanent reclamation placed)</th>
<th>Cleared</th>
<th>Disturbed: Mine or Plant Purposes</th>
<th>Ready for Reclamation: No Longer Used</th>
<th>Soils Placed (Terrestrial &amp; Wetlands &amp; Aquatics)</th>
<th>Permanent Reclamation (Terrestrial)</th>
<th>Permanent Reclamation (Wetlands &amp; Aquatics)</th>
<th>Temporary Reclamation (Terrestrial)</th>
<th>Certified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadian Natural Horizon</td>
<td>58</td>
<td>18</td>
<td>75</td>
<td>1</td>
<td>25</td>
<td>47</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Imperial Kearl</td>
<td>32</td>
<td>2</td>
<td>34</td>
<td>0</td>
<td>12</td>
<td>21</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shell Albian Sands Jackpine</td>
<td>34</td>
<td>1</td>
<td>35</td>
<td>0</td>
<td>8</td>
<td>27</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shell Albian Sands Muskeg River Mine</td>
<td>60</td>
<td>2</td>
<td>62</td>
<td>0</td>
<td>7</td>
<td>54</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Suncor Base Operations</td>
<td>192</td>
<td>5</td>
<td>197</td>
<td>13</td>
<td>43</td>
<td>135</td>
<td>4</td>
<td>2</td>
<td>13</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Suncor Fort Hills</td>
<td>57</td>
<td>2</td>
<td>58</td>
<td>0</td>
<td>44</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Syncrude Aurora North</td>
<td>58</td>
<td>1</td>
<td>59</td>
<td>1</td>
<td>7</td>
<td>49</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Syncrude Mildred Lake</td>
<td>188</td>
<td>5</td>
<td>194</td>
<td>35</td>
<td>24</td>
<td>122</td>
<td>0</td>
<td>9</td>
<td>22</td>
<td>12</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Regional Totals</td>
<td>679</td>
<td>36</td>
<td>714</td>
<td>50</td>
<td>170</td>
<td>469</td>
<td>4</td>
<td>15</td>
<td>37</td>
<td>12</td>
<td>7</td>
<td>1</td>
</tr>
</tbody>
</table>

Adapted after Oil Sands Information Portal (2011)

Numbers may not sum due to rounding errors
The AROs reported by COS and CNRL are presented in Table 4-4 and Table 4-5 respectively. Both current dollar and inflation adjusted 2011 constant dollar values are provided.

In 2010, under the MFSP, specific reporting standards for disturbed land classification were introduced; comparison with earlier classifications is not valid. The undiscounted per hectare costs calculated and presented are based on the year-end footprints reported by Alberta Environment. The “active footprint” was determined by subtracting the “active (permanent reclamation placed)” areas from the “total active footprint” for the projects (see Table 4-3). If land disturbance outpaces reclamation this will tend to underestimate the per hectare costs prior to 2011.
Table 4-4: Canadian Oil Sands Ltd.’s Asset Retirement Obligation for their share of the Syncrude project

<table>
<thead>
<tr>
<th>Year End</th>
<th>Discounted ARO Value*</th>
<th>Undiscounted ARO Value</th>
<th>Active Footprint (ha)</th>
<th>Undiscounted ARO $/ha</th>
<th>Inflation Adjusted $/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Canadian Oil Sands Limited’s Asset Retirement Obligations</td>
<td>Horizon Project’s Asset Retirement Obligations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>COS Syncrude**</td>
<td>COS Syncrude**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$ (millions)</td>
<td>$ (millions)</td>
<td>$/ha</td>
<td>$/ha</td>
<td>$/ha</td>
</tr>
<tr>
<td>2007</td>
<td>226</td>
<td>615</td>
<td>2 022</td>
<td>109 315</td>
<td>117 463</td>
</tr>
<tr>
<td>2008</td>
<td>235</td>
<td>640</td>
<td>2 107</td>
<td>113 875</td>
<td>119 539</td>
</tr>
<tr>
<td>2009</td>
<td>389</td>
<td>1059</td>
<td>2 458</td>
<td>132 855</td>
<td>137 388</td>
</tr>
<tr>
<td>2010</td>
<td>501***</td>
<td>1364</td>
<td>3 250</td>
<td>175 668</td>
<td>179 000</td>
</tr>
<tr>
<td>2011</td>
<td>1037</td>
<td>2823</td>
<td>6 015</td>
<td>325 148</td>
<td>325 148</td>
</tr>
</tbody>
</table>

* Discounted values as reported by COS. Annual expenditures vary.
2007, 2008 and 2009 ARO discounted at 6% over a 60 years.
2010 ARO discounted at 6% over 70 years. 2011 2.5% over 70 years.

** The Syncrude ARO is determined by extrapolating the COS pro rata share of reclamation obligations to 100%.

*** 2010 and 2011 ARO reported under IFRS (2010 ARO updated in 2011 to reflect this), 2007-2009 under Canadian GAPP.

Active footprint as reported by Alberta Environment

ARO data adapted from Canadian Oil Sands Annual Reports, 2007-2011.

Inflation adjusted values are in 2011 dollars and were determined using Statistics Canada's core Consumer Price Index.

Table 4-5: Canadian. Natural Resources Ltd.’s oil sands mining related Asset Retirement Obligation

<table>
<thead>
<tr>
<th>Year End</th>
<th>Discounted ARO*</th>
<th>Undiscounted ARO</th>
<th>Discount Rate %</th>
<th>Active Footprint (ha)</th>
<th>Undiscounted ARO $/ha</th>
<th>Inflation Adjusted $/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$ (millions)</td>
<td>$ (millions)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>93</td>
<td>12 568</td>
<td>12 504</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>1485</td>
<td>200 676</td>
<td>210 656</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>426</td>
<td>199 865</td>
<td>206 684</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>798</td>
<td>4.6</td>
<td>7 400</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Discounted values as reported by CNRL. Discount period not indicated.
Blank cells represent values not reported

Active footprint as reported by Alberta Environment

ARO data from CNRL Annual Reports, 2009-2011.

Inflation adjusted values are in 2011 dollars and were determined using Statistics Canada’s core Consumer Price Index.
It is clear from the two tables that the government’s stated range of undiscounted per hectare reclamation costs for oil sands mines is not consistent with the reclamation costs anticipated by mine operators. The estimate of per hectare reclamation costs of $75,000 under the MFSP compares with industry-anticipated costs of up to $325,000/ha. The ARO reported by COS has been above the values stated in the MFSP guide since at least 2007, and the ARO reported by CNRL for the Horizon Mine has been above the Alberta government’s range since 2009. The MFSP was introduced in 2011.

Beyond the inclusion of a contingency factor, it is unlikely that a publically traded company would choose to over-estimate the ARO associated with any of their assets. The presented AROs are likely calculated on the basis of preferred contractor rates or the use of mine fleet equipment to complete some or all of the required work. The ARO costs presented may therefore be assumed to be neutral to aggressive (low) in comparison to the third-party cost to reclaim the mine sites.

The large discrepancy between industry’s anticipated reclamation costs and the government’s purported reclamation cost range would seem to indicate that the Alberta government has either wholly failed to complete a due diligence study on potential reclamation costs or else is providing misleading information to the public (and new mine operators) in the Guide to the Mine Financial Security Program (2011). Either case may be reason for concern, given the decrease in reclamation assurance required under the MFSP for much of an oil sands mine’s active life (Thorley, 2012).

4.4.4 Land Reclamation Costs and Other Corporate Disclosures

Meaningful reclamation cost data have not historically been made public by oil sands mine operators. One exception to this is the reclamation cost and reclamation performance data
published by Syncrude in their biannual (formerly annual) sustainability reports. Although not a rigorous approach to cost estimation, an examination of incurred reclamation costs and achievements over time may provide an indication of the reclamation costs experienced by the industry. As noted in Section 4.4.3, Syncrude has more reclamation experience than any other oil sands operator.

Reclamation cost and achievement data are presented in Table 4-6. The data are adopted from Syncrude’s Synergy 2008/2009 Sustainability Report (2010) and are presented on both a current dollar and an inflation-adjusted, 2011 constant dollar basis. The years 2007 and 2008 saw temporary reclamation activities of 69ha and 5ha respectively. This temporary reclamation has not been included in calculating the reclamation costs per hectare as temporary reclamation is not completed to the same standard as permanent reclamation and is a periodic reclamation cost that does not normally contribute towards permanent reclamation achievements (i.e. temporary reclamation hectares are not expected to be upgraded to permanent). It should be noted that the reclamation standards used by Syncrude to define permanent land reclaimed in the 2008/2009 report may not correspond to the standards introduced under the MFSP. At the time of writing the 2010/2011 report is not available.
Table 4-6: Syncrude's reclamation costs and achievements (adapted from (Syncrude Canada Ltd., 2010c))

<table>
<thead>
<tr>
<th>Year</th>
<th>Reclamation Expenditures ($, millions)</th>
<th>Area Reclaimed (ha)</th>
<th>Reclamation Expenditure ($/ha)</th>
<th>Inflation Adjusted (2011 $/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>16.5</td>
<td>304</td>
<td>54 276</td>
<td>60 409</td>
</tr>
<tr>
<td>2006</td>
<td>33.5</td>
<td>315</td>
<td>106 349</td>
<td>115 964</td>
</tr>
<tr>
<td>2007</td>
<td>31.3</td>
<td>85</td>
<td>368 235</td>
<td>395 686</td>
</tr>
<tr>
<td>2008</td>
<td>52.9</td>
<td>104</td>
<td>508 654</td>
<td>533 951</td>
</tr>
<tr>
<td>2009</td>
<td>97</td>
<td>97</td>
<td>1 000 000</td>
<td>1 034 121</td>
</tr>
<tr>
<td>2010 (forecast)</td>
<td>180.5</td>
<td>367</td>
<td>491 826</td>
<td>501 153</td>
</tr>
</tbody>
</table>

Rolling Average

| 2005-2009 | 5 year average | 255 470 | 270 019 |
| 2007-2009 | 3 year average | 633 566 | 662 496 |

The table indicates significant and sustained increases in expenditures per hectare declared reclaimed in recent years, similar to the trend in COS’s ARO/hectare over 2007-2011. Only one year, 2005, falls within the reclamation cost range identified by the Guide to the MFSP and in most years the expenditure per hectare is significantly higher. The 5 year average expenditure per hectare is over 4 times the midpoint of the declared oil sands reclamation cost range and nearly 3.5 times the value Alberta established for the purposes of the MFSP.

4.4.5 Land Reclamation Costs for Mine Planning

A more detailed assessment of potential reclamation costs is required. The reclamation cost would be expected to vary based on factors including but not limited to:

- the ground conditions of the area being reclaimed;
- the end-use the area is being reclaimed for;
- the haul distances and rehandle of reclamation material required; and,
• the extent of work required to prepare the area for soil placement (slope trimming, contouring, development of swales and other drainage features, etc.)

It is clear from changes in COS’s reported ARO in recent years that industry’s understanding of the costs associated with reclamation and closure of oil sands mining projects is undergoing change.

In the production of 2.25Bbbl to year-end 2011 Syncrude has accrued an undiscounted ARO of $6.015 billion, or $2.7/bbl. This per barrel value is exclusive of prior reclamation expenditures, which would increase the per barrel reclamation cost of production to date by $0.2/bbl for the period 2005-2010 alone. A general-purpose oil sands reclamation cost of over $3.0/bbl (2011 dollars) is suggested by the experience of Syncrude.

4.5 Research in Oil Sands Mine Planning

Mine optimization has been a major research focus in open pit metal mining but has not received the same degree of attention in oil sands mining (Ben-Awuah & Askari-Nasab, 2011). There is very limited literature relating to oil sands planning in the public domain. An extensive search indicated only two contemporary research projects directly related to mine planning. This is not to say that extensive research is not carried out in the oil sands, but the current focus is not on what would traditionally be described as mine planning.

Researchers at the University of Alberta’s Mining Optimization Laboratory have investigated the optimization of oil sand mine scheduling, including overburden scheduling, and the planning of oil sands tailings (ibid). The lab has implemented a mixed integer goal programming (MIGP) model to optimize deposit NPV given material quality, mining, and dyke construction constraints and enabling penalty enforcement to prioritize ore or waste mining over
NPV (ibid). A fixed pit limit was assumed. A clustering algorithm was applied to group mining blocks on the basis of location, rock type, and grade distribution. The MIGP model was tested and then run on a model containing 61,490 blocks. A plan view of the mine advance is shown in Figure 4-22. The results correspond to the type of advance presented in Figure 4-11 presented in Section 4.3.1.4. It is not clear if the results of this work are being implemented by any of the operating companies. In practice the advances indicated by the optimization model might be smoothed to minimize the cost and volume of material required to construct in-pit dykes, just as the pit and pushback limit indicated by optimization in hard rock mine planning are adjusted for mining practicality.
A collaborative research effort between Laval University and Syncrude produced an optimization model for tailings distribution (Hammami, Abbaoui, Savoie, & Ait-Kadi, 2006). The model was intended to allow tailings volume planners to incorporate economics and, through scenario analysis, better understand planning associated risk and was developed using LINGO. When tested using historical production data from Syncrude’s in-house tailings models the new model generated results within 5%.

Ben-Awuah and Askari-Nasab (2011) note the absence of optimization research in oil sands mine planning and indicate that the oil sands have a unique waste management scenario.
With a potential relaxing of waste storage space demands under Directive 074 greater flexibility in mine sequencing may be possible. Further optimization studies may be a beneficial area of future study.

The use of the block model as the basis of mine planning requires that reserve estimation in the oil sands be briefly mentioned. Earlier work into the use of geostatistical methods, including kriging and conditional simulation, was carried out by Dimitrakopoulos (1986), Dimitrakopoulos and Griffin (1993) and by May and Ryan (1985). Government-sponsored development of a software system to perform geostatistical modeling for oil sands deposits was reported by Dimitrakopoulos et al (1990). O’Donnell and Ostrowski (1992) present a summary of Syncrude’s ore reserve estimation procedure at the time. Despite active research in the 1980’s into the use of geostatistical methods for oil sands ore reserve estimation, they indicate an undisclosed weighting method was being used for estimation. A transition to a new estimation system that would use geostatistical or inverse distance weighted algorithms was noted for future investigation.

Leuangthong, Schnetzler, and Deutsch (2004) note the contemporary prevalence of conventional estimation techniques, and the lack of geostatistical analysis, in the development of oil sands resource models. It is the author’s experience that specifically inverse distance weighting methods remain the dominant means of ore reserve estimation in the oil sands. Given the importance of the resource model in the application of ID 2001-7 this is an area that warrants further study.

The lack of planning research and reliance on simple planning techniques may be due to the “insular” nature of the industry, an issue identified by Devenny (2010). It may also be due in part to a fairly static workforce prior to the rapid growth of the industry in the last decade; new
employees often bring new ideas and methods. The associated problem of rapid growth is an increasingly young and inexperienced workforce entering the industry at a time when experienced planners are retiring, and when remaining expertise is spread thin among the many operating mines. A shortage of human resources may mean that companies and planning groups simply do not have the time available to investigate, validate, and incorporate new methods and technologies, particularly step-change technologies. For example, Cyr (2004) notes the contemporary use of frost ripping with bulldozers instead of frost blasting in winter months. He observes that blasting is more cost effective on a per unit mined basis and has been established to result in improved cycle times, reduced maintenance costs, and less shovel downtime. The increased planning and engineering support requirements associated with blasting are shown as detrimental to its use.
Chapter 5

Impact of Constraints on the Oil Sands Mine Planning System

The impacts of technical and regulatory constraints on the oil sands mine planning system introduced in Chapter 4 are significant. This chapter will present an examination of the impacts of these constraints on mine planning, as well as propose a new planning system, more suitable to the goals of economic optimization. An UML model has been developed to show the proposed planning system activities and their relationships.

5.1 The Impact of Climate on the Planning System

Climate does not impact the activities of the mine planning system but it does impact planning decisions. This is similar to the conventional planning system presented in Chapter 3. Climate influences the decisions made with respect to mining tactics, primarily equipment selection and the seasonally dependent aspects of short range planning.

In high grade oil sands pits the bitumen softening problem can be particularly acute and result in the large, 360t haul trucks used in the oil becoming mired. There are three ways to address this problem: 1) the under-loading of haul trucks in high-grade pits, which has an impact on productivity; 2) the preferential scheduling of high grade ores for mining outside of the summer season; or, 3) the use of “multi-bench” mining where the excavator is located on low grade, stiff oil sands or on the limestone that underlies the McMurray formation oil sands and bulldozers are used to push ore downslope towards the loading unit. The latter method is preferred and in use by operations where high grade conditions warrant. The potential height of the mining face makes the use of dozers to trim the slope and push material to the loader critical from a safety standpoint.
In winter the oil sands stiffens, and rolling resistance is lowered. Malhotra & List (1989) indicate that scheduling long hauls in the winter to take advantage of lower rolling resistances, and conserving competent overburden for use in dyke construction, some aspects of which are seasonal, are important planning considerations. Cyr (2004) also notes the influence of seasonal dyke construction on the mine plan.

When blasting is not practiced shovel digging conditions are poor in the winter months and dozers normally perform frost ripping prior to excavation. The inability of the crushers to handle frozen lumps results in the use of frozen lump stockpiles, from which the material is rehandled to the plant during the summer. This is typically the only stockpiling done in the oil sands and studies have indicated that weathering may have a severe, negative impact on bitumen recovery (SrinivasaRajagopalan, 2010). Frozen conditions create demanding mucking conditions and lower shovel productivities may be experienced. Frost is minimized by reducing the distance between mining face advances between the benches, minimizing the time in-situ material is exposed.

Dust is a concern in the summer when tailings beaches and construction areas are exposed and is a particular issue for operations near public highways. Steam from tailings discharge in the winter is also an issue, and careful planning of the tailings discharge locations should be used to ensure that “fogging” does not impact highways or regularly used on-site roads.

Oil sands mines are subject to occasional weather related delays due to snow, spring thaw/runoff, and summer thunderstorms, similar to many other Canadian mines.
5.2 The Impact of Mine and Tailings Waste on the Planning System

The management of mine and tailings waste has a significant impact on the activities and activity sequence in oil sands mine planning when compared to conventional open pit mine planning. This is demonstrated in the system activity diagrams presented in Chapter 4 and in Appendix B. Not only is detailed waste planning introduced at earlier stages than in conventional planning, but the interaction between ore and waste planning activities is also intensified.

The greater need to accommodate tailings demands introduces overlap between mine planning, geotechnical engineering, and tailings planning domains. The structure of the decision making process is changed, with an increased focus on the integration of a detailed waste plan with the ore plan. In conventional planning, mine waste planning is done to accommodate the ore schedule; in most circumstances favorable material balances support this and the waste scheduling is not a binding constraint. In oil sands planning the mine’s waste removal and waste containment construction schedule is more intricately linked to the tailings schedule, which in turn is dependent on the ore schedule. The tailings containment construction and placement schedules become high priority constraints in the production of the ore mining schedule. A more iterative system with a high degree of cross-departmental interaction results at the long and short range stages of planning.

Demand for tailings storage space complicates the planning process for both tailings and the mine, but in some ways it also simplifies planning decisions and mine scheduling. The capital and operating costs associated with the bitumen extraction and upgrading facilities are more than an order of magnitude higher than the costs associated with mining. The focus of mine planning activity is to deliver feed to the plant in a reliable fashion. The mine plan must therefore accommodate the tailings plan, as a lack of tailings and recycle water storage space would idle
the plant. This overriding constraint greatly reduces the feasible mine sequence and scheduling options. The impact on plans is visible in Figure 4-11. Even the development and application of an advanced optimization model has done little to change the blocky, radial progression of a typical oil sands mine, particularly in the earliest years of mine life when the creation of an in-pit tailings dyke footprint is a high priority (Figure 4-22).

The waste planning landscape is evolving rapidly in the oil sands. The impact of Directive 074 on waste planning will be discussed in Section 5.3.2. Potential mine planning system responses to the directive will be discussed in Chapter 6.

**5.3 The Impact of Regulatory Controls on the Planning System**

Alberta’s oil sands mining regulations have a significant impact on the mine planning system. Some of the goals of the *Oil Sands Conservation Act* and the directives presented in Chapter 4 include:

- preventing resource waste;
- ensuring efficient, economic development in the public interest;
- providing operating criteria to improve the efficiency and effectiveness of the regulatory review process;
- providing operational flexibility for mine operators; and,
- regulating and holding operators accountable for tailings management.

Regulation of the industry through *ID 2001-7* is highly prescriptive; *Directive 074* establishes performance criteria but enables operators to determine the specific methods they will employ to meet the criteria.
5.3.1 The Impact of *ID 2001-7*

*ID 2001-7* has a significant impact on strategic planning activities. It dictates the cut-off grade and establishes the minimum allowable pit limit on the basis of a TV:BIP ratio; normally two key strategic decisions made during planning. The directive also establishes uniform mining criteria for all bitumen-bearing material, ignoring variations in geology that impact recovery and tailings production.

*ID 2001-7* was developed with “regard for current technical, economic, geological conditions” and in consultation with industry. The directive does state that “industry has committed to a program of continuous improvement, which it hopes will allow it to exceed requirements.” The directive was to be reviewed in 2005 to assess its effectiveness in meeting its objectives (see Section 4.2.3) and to review the suitability of the criteria, presumably to account for evolving economic, technical, and geologic conditions. The enforcement ladder for addressing non-compliance was updated January 1, 2006, but, as of 2012, no changes have made to the originally stipulated criteria. It is unclear if any further reviews are planned.

*ID 2001-7* was conceived and implemented at the end of a period of low oil prices including a historic low in 1998 (see Figure 5-1). A review in 2005 should have identified evolving economic conditions; the price of oil had been rising since a low in 1997. In inflation-adjusted Canadian dollars, the price of oil had increased by over 2.5 times between 1997 and 2005 and was approximately 60% higher than the average price for the period from 1985 to 2000.
Figure 5-1: Historic oil prices (West Texas Intermediate grade)

5.3.1.1 In-situ Oil Sands Cut-off Grade

A simple 7% cut-off grade is established by ID 2001-7. Limited-term exceptions to the grade may be granted on application by the project operator in order to maintain plant feed quality. Historically poor process recovery makes oil sands below 7% unattractive as potential ore feed.

The static definition of ore ignores economics and, more importantly, the variable recoveries or processing performance associated with different oil sands ore facies. Oil sands recoveries are sensitive to clay content (ultra-fines below 2 micron diameter), the presence of organic rich solids, and the water chemistry associated with the formation water which forms a natural part of the ore (O'Carroll, 1999; Mikula, Kasperski, Burns, & MacKinnon, 1996; Mossop, 1980; Kasperski & Mikula, 2011) Equivalent grades of bitumen ore from different facies and with differing clay content will not yield equivalent amounts of bitumen. According to Wright
(as cited by Cyr, 2004), the recovery of bitumen from marine ore can drop by up to 50% with as little as 5% clay content in the ore.

The static cut-off grade definition further ignores the volume and characteristics of the tailings produced from the material sent for processing. Facies containing higher levels of fines may produce higher amounts of mature fine tailings. This can be correlated to the presence of higher concentrations (>2.5% to 3% weight) of the ultra-fine or clay particles (O'Carroll, 1999). The waste handling, storage and reclamation costs associated with these facies will be higher. Consequently, from an economic perspective they require a higher cut-off grade to achieve the same performance as facies with lower fine tailings production. Potential costs associated with tailings treatment were presented in Section 4.4. From the perspective of sustainability and waste management, the processing of materials which create difficult to handle waste by-products may suggest additional penalties be applied to such material when assessing whether it should be processed. A detailed study, including an accurate assessment of life-cycle costs, should be performed to determine the potential merit of a variable cut-off grade by facies.

5.3.1.2 Minimum Mining Thickness

Establishing criteria to minimize mining loss is justifiable from a resource conservation perspective. Forcing dilution by requiring narrow waste (interburden) bands to be included as ore feed is unlikely to result in increased bitumen production; depending on the facies (and clay content) forced dilution may negatively impact bitumen recovery as noted in Section 5.3.1.2. Forced dilution with clay rich material will result in increased fine tailings production.

With the digging equipment employed in oil sands mines, mining of cuts less than 3m is unproductive. This provides a disincentive to selectively mine waste. An operator is only likely to separate lean oil sand out at the mining face if the material is likely to reduce overall bitumen
production by a greater amount than it contributes. Operators should be allowed to exercise
greater discretion in selectively mining waste bands.

As noted in Section 4.5, deterministic methods are still the norm for ore reserve
estimation in the oil sands. This precludes calculation of block estimation errors. The lack of
drilling and blasting activity in oil sands mining severely limits the opportunity for ore sampling
in support of mine-process plant reconciliation. The estimation error for a 1m high block based
on drill holes spaced on an approximately 100m grid is likely significant (variograms would need
to be developed to determine the degree of the estimation error). These factors combine to make
the ability to accurately determine and enforce the minimum mining thickness criteria
questionable.

5.3.1.3 The TV: BIP ratio

The OSCA mandates the ERCB to “prevent waste of the oil sands resources of Alberta.”
However, in developing a TV:BIP ratio on the basis of static economic conditions, ID 2001-7 in
effect gives industry a license to “high-grade” during times of higher oil prices.

From a profit perspective a lower ratio ore block is more attractive to mine than a higher
ratio block. The lower ratio block will produce the same volume of bitumen (pre-recovery) but
with a lower total volume of ore and waste mined and potentially a lower volume of ore
processed. The cost per barrel will be lower for the lower ratio block. A higher ratio will yield
more total barrels across the lease due to an expanded pit limit, but at a higher cost per barrel.
Corporate objectives to maximize shareholder value may be at odds with the government’s desire
to “prevent waste”, which should require mining of all material above a break-even profit.

Among operating and approved projects the TV:BIP used to identify the planned pit
limits ranges from 12:1 (Suncor Energy Inc., 2010a) to 14:1 (Syncrude Canada Ltd., 2010a;
Syncrude Canada Ltd., 2010b) to 16:1 (Teck Resources Ltd.; SilverBirch Energy Corporation, 2011). Suncor (2010a) states that “[f]or mine planning purposes, the ultimate pit boundary for the Millennium Mine is based on the contour where TV/BIP is equal to 12, as per the industry standard criterion described in ID-2001-7 [emphasis added]…” A portion of the southeast wall of the Millennium mine is described as being designed using a 14:1 ratio, but solely to accommodate pit boundary considerations and the geotechnical stability of the reclaimed landscape.

Teck and SilverBirch (2011) indicate an increase in recoverable mineable bitumen resources for the Frontier Mine of nearly 900Mbbl, from 1.940Bbbl to 2.825Bbbl, on the basis of an increase in the TV:BIP ratio used to define their pit limit from 12:1 to 16:1. This represents 900Mbbl of bitumen that would likely be sterilized under ex-pit facilities or through the in-pit placement of waste if the project proponents did not investigate the increased TV:BIP ratio.

Based on the decision of some operators to use a higher ratio for planning purposes it would appear that current economic and technical conditions are supportive of an increased TV:BIP ratio, or of requiring operators to set pit walls based on more conventional “break-even” pit limit assessment methods. This would increase the demands on the regulator to periodically review mine plans, but would appear to be a highly value added activity on the basis of Frontier’s experience.

Although oil sands waste management planning requires some stability in establishing pit limits it does not require a static pit limit. Bitumen royalties contribute to Alberta’s revenue stream, and profitable material that is not mined during the first pass of equipment is likely to be sterilized through infrastructure or waste placement. The regulator is mandated to minimize
wastage and maximize the use of the resource. The use of a minimum TV:BIP ratio should be reevaluated by the ERCB in support of resource conservation.

The use of a stripping limit on a volume to volume basis is not an uncommon approach in mines where variability in the properties of the material being mined is limited. It has been established that there is significant variation in the processing and waste characteristics of oil sands facies. Although the BIP calculation does consider ore grade the ratio does not consider recoverable bitumen nor does it factor for the tailings generation potential of the ore, based on fines or clay (ultra-fines) content. This could be accomplished if a more conventional assessment method (i.e. application of a pit limit algorithm) were employed with reasonable recovery and cost assumptions developed.

5.3.2 The Impact of Directive 074

While most operators are not yet in compliance with Directive 074, it is having a significant impact on mine and tailings planning. New technologies are being explored for both preventing fluid fine tailings formation and treating MFT. The directive should result in a significant decrease in MFT generation, and may encourage operators to address legacy tailings issues.

One of the biggest impacts of the directive is on mine site layout and facility footprint. Reduced MFT formation may reduce the volume of fluid tails requiring short or long-term storage and increase the volume of water available for recycle. This should also have the additional benefit of reducing water withdrawal demands on the Athabasca River.

Reduced fluid tailings storage volumes should result in smaller ex-pit tailings dams, and reduce the amount of pit space required for tailings storage. This will allow increased mined
waste placement in-pit and reduce waste haul distances. The reduced storage demand may also reduce potential ore sterilization on leases that are space-limited. Some of these benefits may be offset by the establishment of new dedicated disposal areas for tailings material. Thin-lift drying technology in particular may demand a large footprint. A better understanding of the potential lift thicknesses and safe annual rise rates will be formed as development of this technology continues.

A further potential benefit of a reduced fluid tailings storage requirement is a potential increase in feasible mine schedules. An easing of the constraints associated with tailings storage demands may enable oil sands mines to better take advantage of conventional approaches to mine sequencing and scheduling as well as emerging opportunities in schedule optimization.

It is important to note that Directive 074 does not explicitly address treatment of existing fluid tailings inventories and it will not result in the elimination of fluid fine tailings generation. Fluid tailings containment will continue to be required although the rate at which some fluid tailings are treated may change. Shell, for example, indicates that for their Jackpine Mine expansion project the final inventory of MFT will be unchanged under Directive 074 (Shell Canada Ltd., 2010). Syncrude’s submissions under Directive 074 indicate an anticipated final fluid tailings inventory on the Mildred Lake site of 319Mm$^3$ in 2046, the majority of which will be sequestered in in-pit lakes (Syncrude Canada Ltd., 2010a). This is an approximately 25% reduction from their 2010 baseline inventory of 426Mm$^3$ (Syncrude Canada Ltd., 2010c).
Chapter 6

Proposal for a New Oil Sands Planning System

There are two key actors with separate agendas to consider in developing a planning system for the oil sands: the province and its responsible resource recovery objectives and the operating companies and their economic objectives. Although aspects of the province’s objectives constrain the planning options available to oil sands operating companies, and profit objectives may challenge aspects of the province’s responsible development objectives, the two agendas share some complementary aspects.

Prescribing static mining criteria through government regulation is problematic when economic conditions are dynamic. Failure to revisit these criteria may result in the original intention of the regulation not being met. This has happened with Alberta’s ID 2001-7.

The unconventional oil sands mine planning system that has evolved and is presented in Chapter 4 and Appendix B differs from the more conventional hard rock, metal mine planning system presented in Chapter 3 and Appendix A in two important ways: oil sands mine sites are waste bound making waste sequencing and placement planning vital; and, the economic criteria used to define ore and mining limits are static and imposed by the government. This chapter presents a proposal for a new planning system. A diagrammatic representation of the system is provided in Appendix C.

The proposed system respects the unique waste management considerations in oil sands planning and revisits the current regulatory approach to ensuring resource recovery. The proposed system is compatible with traditional approaches to economic analysis in open pit planning. It is
easily adapted to emerging best practices to manage technical and economic uncertainty, improve project optimization, and develop robust mine plans.

6.1 Respecting Government Requirements

The Province of Alberta’s OSCA mandates the effective and efficient extraction of bitumen resources with minimum resource waste. Minimizing resource waste and promoting responsible development is not an objective unique to regulators in Alberta or the oil sands. However, the prescriptive approach to the definition of key mine planning considerations is quite unique. The author has been unable to identify any other jurisdiction that currently imposes such a universal and static set of conditions on mine operators.

The oil sands are a mature industry. Bitumen mining, extraction, and upgrading technologies are well established. All of the major publically traded oil companies are active in oil sands development. The basis for oil sands mine planning is as stable as it is for any other commodity, with future oil prices being one of the greatest uncertainties operators face.

6.1.1 Pit Analysis

_ID 2001-7_ introduces a minimum TV:BIP ratio which operators must abide by. The intent is to ensure that marginal material is not left in-situ during first-pass mining activities as the placement of fluid tailings waste in-pit sterilizes adjacent ground.

The 12:1 TV:BIP ratio established by _ID 2001-7_ to identify the minimum pit limit in oil sands mining is problematic because it does not reflect the significant increase in oil prices since 2001. In the spirit of commitment to continuous improvement identified in _ID 2001-7_, some operators have recently chosen to proactively respond to increases in oil prices and voluntarily
adopted higher ratios; others have not. If profitable material falls outside of planned pit limits the ERCB’s mandate of conserving oil sands resources is not being met by the directive.

Changes in TV:BIP ratios have the potential to significantly increase recovered bitumen as evidenced by Teck and SilverBirch (2011) reporting an increase in recoverable mineable bitumen resources of nearly 900Mbbl, a 46% increase in resources, on the basis of an increase in the TV:BIP ratio used to define their pit limit from 12:1 to 16:1.

Requiring periodic updating of the final pit limit, including reporting on the assumed oil price and recoveries, would help address the issue of potential sterilization of potentially profitable materials. This is how pit limits and mineable reserves are identified by other sectors of the mining industry, with mine plans updated regularly and subject to approval. Operators should be required to provide an assessment of adjacent oil sands material any time they physically establish a final pit wall.

A change in how the pit limit is defined does not remove the ability of the regulator to approve or deny a proposed mining limit to meet resource conservation goals.

6.1.2 Cut-off Grade Definition and Waste Costs

ID 2001-7 removes strategic economic considerations from the planning process by removing the actual costs and benefits associated with mining and processing ore from the cut-off grade decision. A review of mine plans submitted to the ERCB under Directive 074 shows significant variation in anticipated ore fines content between sites and within the same site over different time periods. There is a trend towards overall higher fines contents in some newer projects. Varying fines contents have the potential to impact recovery as discussed in Chapter 4.
and Chapter 5. Higher clay content ores will produce a higher amount of MFT per unit weight or volume and negatively impact process recovery.

While Directive 074 will help to limit MFT formation it will not prevent fines reporting to the tailings streams. These fines will have to be treated either prior or subsequent to tailings discharge; there is a cost associated with fines treatment. Clay content, and its impact on process recovery and tailings treatment and reclamation costs, should be considered in defining ore. Global cost savings may be realized by treating marginal-grade, high clay material as mined waste rather than processing it as ore and incurring additional tailings treatment costs.

Devenny (2010) suggests that the discounting of reclamation costs in normal NPV project analysis may have led to an under appreciation of the true costs associated with waste in the oil sands. The ability to define ore on the basis of economic analysis, rather than applying the criteria of ID 2001-7, may help to refocus attention on the costs associated with oil sands waste, and in particular on understanding the variable costs associated with the variable fines content in oil sands. It is anticipated that inclusion of the true costs associated with the generation and treatment of fine tailings will result in otherwise economic material being recognized as uneconomic. The removal of material with high tailings generation potential from the process stream would reduce the volume of fluid fine tailings created per barrel of bitumen produced.

6.1.3 Accounting for Reclamation Costs

Suncor and Syncrude have over 75 years of combined operating experience in oil sands mining, processing, and upgrading. Both operators have exhausted their original mines. Nine additional mining projects have been approved since the original Suncor and Syncrude approvals. Over 3 billion barrels of oil have been produced from the surface mineable oil sands, yet progress on reclamation activities has been limited (see Table 4-3).
The costs associated with reclaiming and closing oil sands mine sites are not well understood by the government (see Section 4.4.5). The limited successes in reclamation, and the challenges experienced to date in fine tailings treatment, make this an area of significant economic and technical risk for the mine operators and for the Alberta government (Thorley, 2012). Improved disclosure under Directive 074 should help to improve the understanding of the costs and liabilities associated with unreclaimed land in the oil sands.

A legitimate understanding of reclamation costs is required so companies may accurately assess their anticipated reclamation and closure costs, future projects can be properly reviewed by the regulatory bodies, and government policy on mine reclamation assurance is formed on the basis of a current and accurate understanding of the costs and risks involved in reclamation.

There should be a transition from a prescribed definition of ore to one that considers variable waste costs (including reclamation costs). This will provide incentive to mine operators to develop realistic expectations of the costs associated with the treatment and long-term handling, storage, and reclamation of tailings waste. Knowledge of the specific costs anticipated for land reclamation based on the nature of the disturbance (waste dump, tailings dyke paddock cell, tailings pond beach, etc.) and the intended final land use are required.

6.2 Respecting Corporate Requirements

Private and publically traded corporations aim to be profitable in order to return funds to their owners or create value for their shareholders. There is acknowledgement by some mining companies, including oil sands operators, that in addition to creating wealth for their shareholders modern mining companies have a responsibility when developing a mine to provide benefit to the host country (King B., 2001; Monkhouse & Yeates, 2007; Ruigrok, 2004)
Oil sands mining is a mature industry and involves all of the major publically traded oil companies. Bitumen mining, extraction, and upgrading technologies are well established. The basis for oil sands mine planning is as stable as it is for any other commodity, with price changes being one of the greatest risks operators face.

6.2.1 Defining Oil Reserves in Canada

Oil reserves are an important factor in judging the value of an oil company (Morrell, 2010). Under National Instrument 51-101 (NI-51-101) and its related Companion Policy, oil reserves are defined as the remaining oil quantities “anticipated to be recoverable from known accumulations… based on [analysis of drilling and geological data, the use of established technology, and reasonable forecast costs and prices].”

There are three reserve classifications under NI 51-101:

1. Proved: Reserves that can be estimated with a high degree of certainty to be recoverable. There should be at least a 90% probability that the quantities recovered will exceed the estimated proved reserves.

2. Probable: Additional reserves that are less certain to be recovered than proved reserves. There should be at least a 50% probability that the actual remaining quantities recovered will be greater than the sum of the estimated proved plus probable reserves.

3. Possible: Additional reserves that are less certain to be recovered than probable reserves. There should be at least a 10% probability that the quantities recovered will exceed the sum of the estimated proved plus probable plus possible reserves.

Reserves may be divided into developed (producing or non-producing) and undeveloped reserves. Undeveloped reserves are expected to be recovered but require a significant expenditure to be brought into production. Although guidelines are provided for the level of certainty to be used in establishing the reserve classification it is acknowledged that most estimates will be prepared using deterministic estimation methods and will not have a
quantitative measure of probability. The certainty levels are qualitative. Resources are the quantities of oil for which a positive economic evaluation has not been generated. There is a lower level of geologic certainty associated with resources.

6.2.2 Pit Analysis

As oil prices increase, previously uneconomic material may become economic and be upgraded in reserve status. In the oil sands, the use of a TV:BIP ratio changes pit limit and mineable reserve definition slightly from traditional hard rock metal mining. As oil prices rise there may be competing interests between increasing TV:BIP and therefore the total reserve, or maintaining the TV:BIP and increasing the per barrel value of the existing reserve. The latter situation is preferable to generate short term cash flow and profits, and results in an improved NPV. Unfortunately oil sands mining in and ex-pit tailings and waste facility placement normally results in the sterilization of the adjacent or underlying bitumen resource. If the pit limit is not expanded and mined to as oil prices rise future resource recovery is unlikely. This situation is normally avoidable in hard rock mining as waste placement is not as constrained, and the perimeter of the pit can be expanded in any direction with a new pushback at a later date. With current technology the placement of tailings adjacent to lean oil sand sterilizes the oil sand.

The uncertainty associated with forecasting long-range oil prices complicates the selection of an appropriate pit limit. The use of a single-point price and cost forecast in developing a mine plan is accepted as being suboptimal for both shareholders and host governments (Monkhouse & Yeates, 2007; Martinez, 2009). There are a number of techniques identified in the literature that allow for the selection of a robust mine plan under conditions of future price uncertainty (Monkhouse & Yeates, 2007; Grobler, Elkington, & Rendu, 2011;
Single-point price and cost estimates should not be the basis of determining long-term project performance expectations. At a minimum, dynamic estimates, with sufficient scenario analysis, should form the basis of selecting an oil sands pit limit, determining the long-term mining schedule, and determining the classification (ore or waste) of material. In the short-to-medium term, any final walls established should be assessed to ensure that resource utilization is maximized and no profitable material is left unmined. This would respect government objectives relating to resource utilization while still providing the opportunity for profit. In a similar fashion, in low-price environments final pit walls may need to be reassessed to limit potential losses to the operator. The important point is that a pit wall should not be established and then treated as static throughout the life of a project.

### 6.2.3 Cut-off Grade Definition and Waste Costs

Cut-off grade is an important strategic parameter in mine planning. Variability in the process recovery and volume and nature produced by different oil sands facies means the economic cut-off grade should also vary by facies. Assessing the cost-benefit associated with marginal grade material that has high fines content may result in some marginal ore material being reclassified as waste. The issues associated with tailings management and reclamation in the oil sands may result in a variable cut-off grade being more congruous with government objectives of minimizing long-term environmental disturbance while also supporting corporate profit objectives.

Oil sands operators should consider the full costs associated with the processing and upgrading of oil sand, as well as with the handling, treatment and reclamation of the tailings.
produced by the oil sand, when determining cut-off grade. Some oil sands facies may prove undesirable as ore feed, and the operator should have the ability to waste such material. Greater operator discretion should be allowed in determining when to selectively mine waste bands. Blending sub economic material with economic material does not change the fact that the material is sub economic.

6.3 Proposal for a New Planning System

The proposed oil sands mine planning system reintroduces economic analysis as the basis for strategic and long-term planning decisions. The regulator is removed from directly prescribing mining criteria; resource conservation goals are met through regulatory oversight rather than regulatory directives (see Figure 6-1). The general flow of activities is not markedly different from the system currently in use, but it does introduce:

- incentive to better understand recovery and waste costs; and,
- value optimization opportunities through dynamic responses by companies and regulators to changing price and cost environments.

The government has a mandate to maximize resource recovery and minimize environmental degradation. The oil sands are profitable for the companies that own and operate mines and they also contribute to Alberta’s treasury through lease sales, royalties, and taxes.

The proposed mine planning system is intended to establish a better long-term balance between government and corporate objectives than exists under current Alberta government regulations. The proposed system guards against the potential for high-grading that ID 2001-7 is intended to prevent but has instead supported. The system also introduces a waste focus to strategic planning by allowing mine operators to include tailings costs in the cut-off decision.
This waste focus will support corporate profit objectives as well as government objectives to minimize the environmental impacts of mining projects.
Figure 6-1: Select business planning aspects of the proposed oil sands planning system. Note the regulator no longer directly prescribes planning criteria.
The key feature of the proposed system is that the criteria established under ID 2001-7 are removed. The value of the oil sands to Alberta justifies the potential increased costs in time, human resources, and dollars that may attend eliminating the simplified criteria of ID 2001-7 while still enforcing responsible resource development. The elimination of ID 2001-7 will enable

1. Dynamic reexamination of final pit limits by both mine operators and government regulators.

2. An economic definition of ore which considers the process recovery of individual facies and the impact of dilution on recovery.

3. An economic definition of ore which encourages clear identification of the tailings handling costs, including reclamation costs, associated with different facies (in particular material with high ultra-fines content).

UML activity diagrams are presented for the proposed planning system in Appendix C.

Key aspects of the system are presented and described in the following pages. The most significant impacts will be to the analysis used to develop strategies during LRP.

6.3.1 Strategic Planning Under the Proposed System

The new system restores the determination of economic criteria including the pit limit, the cut-off grade, and the degree of dilution acceptable to the mine operator. This has a significant impact on the analysis that is carried out during strategic planning (see Figure 6-2). A full set of activity diagrams for strategic planning are found in Appendix C, diagrams C-2 to C-7.

6.3.1.1 Pit Analysis

The pit limit will be defined by maximum value pit. The limit will be established on the basis of current price and cost forecasts, as is typical in other sectors of the mining industry. The
proposed pit limit will be subject to regulatory scrutiny to ensure that resource conservation goals are being met. The identified pit limit will be the basis for project planning, but as the project moves into development it will be regularly reassessed during long range planning.
Figure 6-2: Proposed oil sands planning system activity diagram - pit analysis
Greater flexibility in scheduling is anticipated from the introduction of a variable cut-off grade coupled with the increased regulatory demands for tailings treatment introduced under Directive 074. The anticipated reductions in fluid tailings storage should reduce demands for in-pit space for fluid storage. This in turn reduces the associated issue of sterilization of ore adjacent to fluid tailings deposits; if fluid tailings are not placed against pit walls it will be possible to revisit those walls at a future date and mine additional oil sands. The reduced waste storage demands introduce greater opportunity to optimize the mining sequence and schedule.

The introduction of a flexible cut-off grade enables mine operators to consider the process recovery and fluid tailings production consequences (the “tailings make”) associated with different ore types. This introduces the concept of fluid tailings prevention to mine planning.

The proposed system does require improved regulatory scrutiny of proposed mine projects. This is the norm in other mining jurisdictions in Canada and worldwide and is not anticipated to be unduly onerous for the regulators or operating companies.

6.3.2 Long Range Planning

Long range mine plans in the oil sands are currently slow to respond to positively changing economic conditions. When oil prices rise ID 2001-7 creates favorable conditions for oil sands mines to exploit the most valuable portions of a deposit while leaving lower value, but still profitable, material in place. As tailings placement follows closely behind mining activity, this results in the sterilization of marginal materials not mined at the earliest opportunity.

Eliminating the strictures of ID 2001-7 and returning a greater degree of strategic control to the operators will require responsible regulatory oversight to ensure that resource conservation
goals are being met. Other sectors of the mining industry face similar regulatory oversight. The value of the oil sands to the Province of Alberta justifies providing this oversight.

The activity diagram representing the generation of the detailed mine plan is presented in Figure 6-3. The full set of activity diagrams for long range planning under the proposed system can be found in Appendix C, diagrams C-7 through C-15.

The semi-fixed nature of oil sands pit walls is required to establish in-pit tailings containment. This does not mean that the pit wall definition must remain static. Over the short to medium-term the mine wall can be expanded behind dyke construction activity until the point in time when tailings deposition begins.

The change in pit analysis is shown in Figure 6-2. The most significant change is the introduction of additional inputs to the analysis. Introduced to pit analysis are mining and processing costs, process recoveries, oil price, and waste costs to the decision making process. Introducing cost and recovery values to the decision making process focuses company attention on accurately forecasting and explicitly considering the costs.
Figure 6-3: Proposed oil sands planning system activity diagram - detailed mine planning
6.3.2.1 Cut-off Grade Definition

Oil sands ore fines, in particular clay fines, have significant impact on the nature and volume of waste produced when oil sands are processed. Under the proposed system this is accounted for in determining the classification (ore or waste) of oil sands. If negative impacts on the process are significant, or the costs associated with treating the anticipated tailings high, a higher cut-off grade will be indicated.

6.3.2.2 Mine Scheduling

The proposed system assumes the use of currently available techniques, including analysis aided by software, in developing the mine plan. The activity diagram is presented in Figure 6-4. At some oil sands mines pushback selection and sequence and mine scheduling are still completed manually, with little benefit having been realized historically from the use of strategic planning software (Kennedy, 2008). The use of a commercial pit limit analysis and scheduling tool, where an economic definition of ore, and haulage and waste remediation costs are accounted for, would be of benefit to these operators. Even a small percentage increase in NPV translates to significant profit increases.

An introduction to current research in oil sands mine schedule optimization was provided in Section 4.5. The general progression of the mine schedule may not differ markedly from the schedule that would be produced by manual techniques; however, there was variability in the width and shape of the pushbacks versus those that would normally be attained by manual scheduling. This indicates that optimization should add additional value to the mine plan.
Schedule mining

Assign ore tonnes from model until period production met

WASTE PLANNING
C - 12

Calculate scheduled ore properties (grade, fines, etc.)

[Properties acceptable]

[Properties do not meet process requirements]

Consider different schedule

Determine ramp & bench parameters and mining bench width

Draft ramps and fixed infrastructure (e.g. crusher)

Decide on number of concurrent mining faces, benches, and pushbacks (advances)

[WASTE PLANNING C - 12]

[Revise waste plan]

[Revise site layout]

[Revise pit analysis]

Calculate NPV

[Sufficient level of analysis Select best schedule]

Figure 6-4: Proposed oil sands planning system activity diagram - mine scheduling
6.3.2.3 Other Aspects of Detailed Long Range Planning

Mine site layout in the oil sands is highly constrained. While some relaxation in this constraining factor is expected as a result of the fine tailings treatment mandated under Directive 074, it will not be eliminated. Resource conservation objectives and minimizing the sterilization of potential ore should be key criteria in placing facilities (process plant, ex-pit waste facilities, etc.). These facilities should not be located as close to the identified pit limit as possible. Instead the priority should be to locate them on the lowest value portions of the property. This strategy better supports the potential future recovery of marginal oil sands resources.

Oil sands mines operate at very high production rates. Congestion can limit productivity; the impact is estimated at times to be between 10% and 20% (Kennedy, 2008). Detailed simulation studies which model the mine’s activity, based on the mine schedule, should be employed. Such studies have the potential to proactively identify potential production constraints, such as a heavily used intersection or over-concentration of mining activity in a small area. These issues can then be addressed (additional access ways, changes in the schedule, more support equipment in the mining pits or at the dumps, etc.) to minimize any cost impacts.

6.3.3 Short Range Planning

The most significant impact on SRP under the new planning system is the potential requirement to identify ore on the basis of both bitumen and clay content. Without access to blast holes for additional sampling the mining model is developed on exploration drilling. Drill spacing is normally on the order of 100m. Fines content, but not clay content, is modeled. To support improved ore and waste classification clay content of the various facies needs to be modeled. Reconciliation of the deposit to the model should also be improved from the current visual methods that, in the author’s experience, are employed by most if not all operations.
The set of activity diagrams representing the SRP system are found in Appendix C, on diagrams C-16 through C-21.

### 6.4 Advantages of the New System

The key advantage of the new system is that it supports the development of mine plans that are responsive to changing economic conditions. This will ensure that as oil prices rise operators will be held accountable for re-examining their pit limits, and for expanding their mining limits as appropriate. The new system introduces the evaluation of ore on the basis of economic criteria and the recoverable bitumen grade and fines content of the material under evaluation. This is a shift from the simple consideration of a 7% cut-off grade under ID 2001-7.

The proposed system presents a challenge to mine operators and regulators to be more responsive to oil price changes. It requires, and supports, a more traditional approach to pit limit analysis, where mineralized (in this case bitumen-saturated) material is mined only if the value generated exceeds the cost to mine and process the material, including any costs associated with required overburden stripping. If material meets this criterion it should be mined. This is a major shift from the TV:BIP ratio in current use. This approach will require operators to expend greater effort in analyzing potential locations for ex-pit facilities; future ore sterilization should be considered.

The use of evolving dynamic economic considerations in defining mineable ore and re-evaluating the economic pit limit will improve total bitumen recovered. Short term forecast decreases in the oil price below the level at which the pit limit is established will have a minimal impact on the operators. Long term forecast decreases in oil price will result in reanalysis and
adjustment of the pit limit, as indicated by the analysis. This is the normal economic operating environment in the mining industry.

By incorporating more detailed economic analysis it is believed that the proposed system will encourage a waste-focused approach to design. This focus will:

1. Highlight the issue of high storage and reclamation costs associated with mine waste. There still appears to be a low level of appreciation of these costs.

2. Ensure that only ore is processed. If a block of material does not fully cover its own processing and tailings treatment costs, it is not ore. Blending marginal waste with ore dilutes the ore; it does not transform the waste into ore.

3. Encourage the use of modern practices in all aspects of mine planning. Volume ratio planning dates to the pre-computer era. If expertise to implement these forms of analysis is not available within the industry it should be sought from outside.
Chapter 7

Conclusions and Recommendations for Future Work

Open pit mining, by nature, has a physical footprint. The physical legacy of an open pit mine is permanent. As mines have increased in size, and as technology and economics have supported the development of lower-grade ore bodies, associated mining and tailings waste streams have also increased. In the case of oil sands mining, the nature of the fine fluid tailings produced results in significant lasting environmental impacts associated with the physical footprint of a mine. The mining of other commodities may also produce significant long-term environmental impacts, in particular where potentially acid generating ores are mined.

The strategic objective of mine planning is normally to maximize NPV; state-owned mining enterprises are sometimes an exception to this norm. The mine planner strives to achieve an optimal NPV in the face of physical constraints (precedence relationship in mine sequencing, maximum mining rates, practical realities of pushback design and width, etc.), capital expenditure constraints, safety constraints, environmental constraints, societal constraints, regulatory constraints, etc. Additional challenges are posed by significant levels of technical risk (geologic and geotechnical uncertainty, processing uncertainty, etc.), economic risk (price forecasts and to a lesser extent capital and operating cost estimates), and potentially regulatory and social risk (changes in tax and royalty regimes, potential nationalization, loss of goodwill, public protest, etc.). The time available to conduct analysis also forms a constraint on the planning process.

The unconventional mine planning system employed in oil sands mine planning varies from conventional open pit mine planning systems. Unique waste handling and storage demands coupled with space-constrained mining leases and a highly prescriptive regulatory environment
are two key differences. Alberta’s ID 2001-7 challenges the effective use of a conventional mine planning system.

- It assumes static economics.
  - In a rising price environment this has in effect given companies a license to high grade, an outcome diametrically opposed to the purpose of the directive
- In establishing a fixed cut-off grade it focuses on mining recovery ignoring the process recovery impacts associated with different ore facies.
  - High clay content in oil sands ore can have a significant negative impact on process recovery. High clay content is most often associated with ores deposited in a marine environment, which are generally of lower grade than estuarine ores.
- It does not account for the variability in tailings quality and quantity produced from different ores.
  - The production of fluid fine tailings is correlated to clay content in the ore. High clay content ore will produce more fine fluid tailings per tonne than low clay content ore.
- It enforces dilution of ore grade material (defined by the static 7% cut-off) with sub economic material.
  - Consideration is not given to the impact of this policy on the production of fluid fine tailings or recovery.
Oil sands mines are typically waste bound and require high volumes of tailings containment relative to the volume of mined material. This requires that the mine and tailings waste plans be highly integrated with the ore mining schedule. Traditional mine planning does not address this situation although research into this issue is being conducted (the author is not involved in this research).

7.1 Original Contributions of the Research

The goals of thesis included the original contributions listed.

- A high-level description of the activities in a generic, conventional hard rock open pit mine planning system. The description covers the spectrum of planning activities from strategic planning through detailed long range planning and short range planning.

- A description of the activities of the unconventional mine planning process used in oil sands mine planning.

- Identification of the influence of constraints unique to oil sands mine planning on the planning system.

- Development of a proposal for a new oil sands mine planning system that would support the use of modern mine planning techniques, including risk analysis and optimization techniques.

- The use of systems modeling to aid in the analysis and development of activity diagrams to document the three models described: a conventional, hard rock, metal mine planning system; an unconventional mine planning system used in oil sands planning; and, a proposal for a new oil sands mine planning system.
• A preliminary investigation into the costs of oil sands mine reclamation costs. The scientific literature is absent of any discussion of these costs.

7.2 Research Scope

This aim of this thesis is not to provide an exhaustive description of the planning processes modeled. Such an undertaking encompassing any single one of the three systems described could form the basis for a thesis or multiple theses; the full range of activities, including inputs and outputs, decision criteria, and constraints is too extensive to be modeled within the limits of a single thesis. Similarly, a description of the detailed design considerations and analysis processes used in all stages of oil sands planning is absent from the literature.

The scope of this research was therefore limited to a new presentation of a conventional mine planning system, and the first presentation in the public domain of the activities of the open pit truck-shovel oil sands mine planning system. Models expressing the evolution of planning activities from strategic through short range planning are unique in the literature.

7.3 Recommendations for Future Work

In order to effectively manage and mitigate the environmental impacts associated with mining, the industry must address the issues associated with moving great quantities of waste. Methods that properly account for the costs associated with the treatment or mitigation of fluid tailings and acid rock drainage, amongst other impacts, are required for effective open pit mine planning. Development of such methods will improve both impact assessment and environmental management systems, and support more effective planning for mine closure.

Outside of optimization studies there are few researchers working in the broad area of mine planning and design. The available tools, and many of those under research, do not always
meet the requirements of the user. In particular, regulatory issues may negate the benefit of exercises in NPV optimization. In Canada, prescriptive intervention by regulatory bodies has impacted mine planning for the Voisey’s Bay nickel mine in Labrador, and for all oil sands mines in Alberta. The potential for regulatory impacts on the planning system exists in all jurisdictions, particularly in cases where the state is involved in mine ownership. Novel planning methods approaches must be developed to address the development of mine plans under such conditions.

The research presented in this thesis has generated the following specific recommendations for future work.

1. **Analysis of oil sands mine reclamation and tailings treatment costs**

The question of oil sands mining costs, specifically mine site reclamation and tailings treatment costs, emerged as an understudied and potentially catastrophic issue during this research. Preliminary work in this area was presented in Section 4.4. It is apparent that the potential magnitude of oil sands reclamation costs is poorly understood by the government. Changes to financial assurance requirements for oil sands operators in Alberta introduced in 2011, which increase the government’s share in reclamation liability, make an accurate assessment of costs an important undertaking.

Research should include a rigorous development of detailed reclamation cost estimates based on anticipated requirements and costs for earthworks, re-vegetation, water treatment, etc. Wide variations in the nature and degree of land disturbance on oil sands mine sites, in the characteristics of the post-mining disturbed landscape, and in objectives for the reclaimed landscape, would suggest that these costs should be developed independently for various landform categories (overburden waste dump, tailings beach, tailings paddock cell constructed
feature, etc.), subgrade materials (sodic and non-sodic overburden, lean oil sand, coarse tailings, fine tailings, petroleum coke, etc.), and final land uses (forested area, wetland, etc.).

Development of the costs associate with the treatment of fluid fine tailings is also required. It is anticipated that bitumen-bearing facies with high tailings generation potential may be recognized as sub economic if tailings and reclamation costs are considered when identifying material to be processed vs. wasted.

2. Waste planning and management

Waste planning education and scientific literature focuses on (geotechnical) waste dump and tailings pond design, facility monitoring, the mitigation of acid rock drainage, water treatment, and reclamation of solid structures.

Oil sands waste management requires detailed planning. This is a field that deserves as much attention in research as ore planning. Poorly executed waste planning has the potential to significantly harm a project’s value. Tailings pipeline and pumping systems are inflexible when compared to mine shovels and haul trucks. This requires more robust planning; potential problems need to be identified and mitigating strategies developed in advance of the problems being realized. A ‘lean’ oil sands tailings plan is unlikely to succeed.

Practical guidelines to waste management, including best practices in planning, placement, construction techniques, and constraints (physical, technical, climatic, etc.) should be developed. The existing practice of developing Operations, Maintenance, and Surveillance Manuals, while important, does not address this critical need. An effective tailings plan should not depend solely on experience and pragmatism in the planner.
3. **Short range mine planning**

Little attention is paid in the literature to short range planning and the practical field implementation of the SRP. As with waste planning, poor short range planning has the potential to harm an operation’s value. Also in common with waste planning, short range planning often relies on long development times to create effective planners. Research and development that would be of value includes:

- documentation of best practices in planning;
- development of standardized planning methods and tools that are broadly applicable;
- detailed description of the process of implementing a short range plan based on a long range or business plan, including SRP in support of LRP goals; and,
- analysis of key performance indicators and other performance measures for their effectiveness in supporting SRP and LRP objectives.

4. **Geostatistical modeling and ore body reconciliation (oil sands)**

Mine planners deal with ore body models that are normally correct on average, but wrong in their prediction of specific grades at specific locations. Despite research into the application of geostatistical methods to oil sands modeling in the 1980s, oil sands ore body modeling techniques have not progressed past deterministic models. Specifically inverse distance weighted methods are still in wide use. The lack of blast hole data, or other typical analytical means by which to reconcile mining production to the ore body model, challenges production reconciliation. It is therefore difficult to assess the adequacy of existing modeling methods. As ore bodies increase in
complexity and higher-fines content ores become more common, more sophisticated methods of ore body evaluation may be required to support the development of mining strategies that minimize ore body risk.

Research into the application of geostatistical and probabilistic techniques in ore body modeling should be renewed.

5. Practical limits on mine scale

Large equipment fleets can create congestion, resulting in lowered lost productivities and potential safety concerns related to congestion. In some mines this can be offset through the use of larger pieces of equipment, or establishing additional haul routes. Oil sands mines already employ the largest surface mining shovels, trucks, and supporting equipment available. The industry has identified productivity impacts from congestion; there may be practical limits to the extent by which the largest operators can grow and continue to meet production targets.

Investigations into mine size limits should be undertaken before mine expansions are approved. Simulation studies can be conducted in support of this. Further field studies may also be of benefit in identifying potential limits to realizing full production potential on a mine by mine basis. Issues may include design practices; behavioral influences; planning practices, etc. Benchmarking, observational studies, data analysis, and qualitative research (interviews, etc.) may be necessary to support these activities.

In the oil sands waste storage, treatment requirements for fluid tailings under Directive 074, and progressive reclamation expectations may also impact the practical scale of mine development. Practical mine development needs to be a consideration in any work undertaken. As King (2011) suggested, time might be better spent assessing the realism of planning scenarios than identifying new planning algorithms that incrementally increase a project’s NPV.
Outside of the oil sands, mine scale, or production capacity, is also of interest from the perspective of selecting an optimal production rate. The use of Taylor’s empirically derived rule of thumb for setting mine and mill capacity is widespread. Given the importance of project capacity in determining the economic feasibility, development of predictive techniques for establishing the production rate is warranted.

6. Demonstration of the proposed planning system via a mine model

The proposed planning system was developed as an activity flow model for flexibility in its application. The system can be implemented with existing mine planning technologies, including commercially available strategic planning software such as Datamine’s NPVScheduler, MineSight’s Strategic Planning Module, or Gemcom’s Whittle. At the same time it provides the ability to incorporate emerging planning techniques.

7. Policy Studies related to mineral economics

The author is not a policy expert. However, from an engineering standpoint it is apparent that ID 2001-7 is flawed. In the rising oil price environment that has existed since its implementation in 2001 it has virtually guaranteed that any final pit wall established from then to the present will have sterilized material that could have been profitably mined under the economic conditions of the day. The variable responses of the mine operators to the TV:BIP criterion underscores that the current directive is not meeting the government’s mandate of minimizing resource waste.

A policy perspective on the prescriptive use of static economic criteria in resource policy development is required; such approaches are extremely unusual. Best practices for effecting resource conservation internationally should be examined. The probable resource wastage in
Alberta over the last decade should serve as a cautionary example to other governments considering a static, prescriptive regulatory environment.
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Appendix A
Conventional Mine Planning Model
Conventional open pit planning system: Planning system interactions

Select Aspects of Business Planning System

Economic model development
Processing model development
Geotechnical model development
Geology model development

 Mine Planning System

Strategic Planning
Long Range Planning
Short Range Planning

Corporation
Investor
Professional & Technical Employees
Mine Planner
Regulator
Conventional open pit planning system: Strategic planning

Strategic Planning (SP)

- Assume production capacities on basis of modeled resource

  - Perform PIT ANALYSIS
    - A - 3

  - Evaluate CUT-OFF GRADE
    - A - 6

  - Determine PRODUCTION RATE
    - A - 5

  - Develop RECLAMATION PRINCIPLES
    - A - 7

  - SCHEDULE MINING
    - A - 8

- Financial evaluation

  - [Costs inconsistent with PIT ANALYSIS]
  - [Schedule not viable/attractive]
  - [Costs consistent with pit analysis]

- [Schedule satisfactory]

  - [Project attractive. Proceed to detailed long range planning]

- [Project not attractive. Shelve.]
Conventional open pit planning system: Pit analysis (SP, LRP)

Pit Analysis

- Assign values to blocks in block model
- Define PUSHBACK PARAMETERS A - 4
- Determine mining cost(s)
- Determine process cost(s)
- Determine smelter cost/return
- Determine concentrate transport cost(s)
- Determine expected commodity price(s)
- Perform pit optimization (eg. LG)
- Select revenue factors to produce nested pits and final pit limit

- [Parameters not consistent with cost assumptions]
- [Parameters consistent with cost assumptions]
- [Nested pits adequate]
- [Nested pits not adequate]
- Increase number of revenue factors for new analysis
- Review nested pits

- SELECT PUSHBACKS A - 4
- [Pushbacks meet parameters]

Output mining pushbacks (sequence) and ultimate pit limit
Conventional open pit planning system: Pushbacks (SP, LRP)

**Define Pushback Parameters**

- Define Pushback Parameters
- [Revise analysis of nested pits]
- [Revise analysis of nested pits]
- [Not consistent with cost assumptions]
- [Revise pit analysis cost decisions]
- [Revise pit analysis cost decisions]
- [Not consistent with cost assumptions]
- [Consistent with cost assumptions]
- Analyse development of nested pits and tonnage value curve
- Estimate working faces/benches required for blending
- Estimate required equipment sizes/quantities
- Assign minimum pushback width
- Select number of pushbacks
- [Revise analysis of nested pits]
- [Revise analysis of nested pits]
- [Consistent with cost assumptions]
- [Consistent with cost assumptions]
- [Tonnages and/or ratios require adjustment]
- Select pushbacks that meet criteria
- Rough check of stripping ratio and total tonnes per pushback selected
- [Tonnages and ratios acceptable]
- Output pushback sequence
- [Insufficient pits. Revise pit analysis. Increase number of pits]
- [Sufficient pits for selection of appropriate pushbacks]
- [Tonnages and ratios acceptable]
Conventional open pit planning system: Production rate (SP, LRP)

**Production rate determination**

1. **Determine ore tonnes**
2. **Apply Taylor’s rule (or variant) & set as the production rate**
3. **Determine NPV for Taylor’s rate**
   - **[Seek improved NPV iterative scenario analysis]**
   - **[Insufficient scenario analysis Potential NPV improvement]**
4. **Increase/decrease production rate**
   - **[Insufficient scenario analysis Potential NPV improvement]**
   - **[Old NPV greater]**
5. **Determine NPV for new production rate**
   - **[New NPV greater]**
   - **[Insufficient scenario analysis Potential NPV improvement]**
6. **Set new production rate as production rate**
7. **[Sufficient scenario analysis]**
8. **[Pit analysis costs assumptions not consistent with rate Revisit pit limit analysis]**
9. **[Pit analysis costs consistent with rate Proceed]**
10. **[Accept Taylor’s rate]**
Conventional open pit planning system: Evaluate cut-off grade (SP, LRP)

Cut-off evaluation

Determine mining, milling, and sale (smelting & marketing) cost assumptions

Determine metal recovery assumptions

[Heuristic optimization of breakeven grade variable cutoff grade]

Simple breakeven calculation: static cutoff grade

Apply breakeven formula to calculate cut-off grade

Determine initial capital investment and depreciation schedule

Determine minimum profit/tonne desired

Determine length of time for minimum profit to be applied

Calculate variable cutoffs for life of mine

---

Calculate variable cut-offs

Example:
1. Initial high profit period
   (milling cost + depreciation + minimum profit) / (realised revenue * recovery)

2. Period until initial capital fully depreciated
   (milling cost + depreciation) / (realised revenue * recovery)

3. Remaining life of mine breakeven cutoff period
   (milling cost) / (realised revenue * recovery)
Conventional open pit planning system: Reclamation principles (SP)

Reclamation principles

Identify regulatory requirements

Define and prioritize corporate requirements

Identify and prioritize stakeholder concerns

Develop site closure objectives

Develop waste structure design objectives

Develop dump and tailings design guiding principles

Identify waste material types

Identify materials of concern

Further geochemical testing prior to LRP

Determine material balance

Identify & assess design alternatives

Detailed geotechnical site investigation prior to LRP

Preliminary waste structure design and cost estimates
Conventional open pit planning system: Schedule mining (SP)

1. **Determine scheduling goal**: Assume goal is to maximize mill feed, then NPV.
2. **Assign ore tonnes from model until period production met**.
3. **Determine waste stripping required to uncover ore**; Assign waste to:
   - 1. Current period,
   - 2. Previous period (current -1), etc.
4. **Calculate properties of scheduled ore production**.
5. **Determine waste stripping required to uncover ore**; Assign waste to:
   - 1. Current period,
   - 2. Previous period (current -1), etc.
6. **[Properties do not meet process requirements]**, revise ore scheduling and refine sequence/timing.
7. **[Properties acceptable (grade, deletrious content, etc.)]**
8. **[Ore remaining in ultimate pit limit]**, revise pit limit analysis, pushback parameters & selection.
9. **[Alternative scheduling scenario possible]**
10. **[All ore within pit limit scheduled]**, calculate NPV.
11. **[NPV deviation from best case too great]**, revisit pit analysis, pushback parameters & selection, reduction rate, cutoff grade.
12. **[Schedule generates adequate NPV]**
13. **Assign waste tonnes to earlier period**.
14. **Assign waste to earlier period**.
15. **[Insufficient unused capacity, Waste cannot be scheduled]**, revise pit limit analysis, pushback parameters & selection.
16. **[Waste mining exceeds capacity]**, revise ore scheduling and refine sequence/timing.
17. **[Waste can be scheduled]**, assign waste tonnes to earlier period.
18. **[Excess capacity in earlier period, Waste can be scheduled]**, assign waste tonnes to earlier period.
19. **[All ore within pit limit scheduled]**, calculate NPV.
20. **[NPV deviation from best case too great]**, revisit pit analysis, pushback parameters & selection, reduction rate, cutoff grade.
21. **[Schedule generates adequate NPV]**

Diagram:
- **Determine scheduling goal**: Decision point for maximizing mill feed, then NPV.
- **Assign ore tonnes from model until period production met**.
- **Determine waste stripping required to uncover ore**;
  - 1. Current period,
  - 2. Previous period (current -1), etc.
- **Calculate properties of scheduled ore production**.
- **[Properties do not meet process requirements]**, revise ore scheduling and refine sequence/timing.
- **[Properties acceptable (grade, deletrious content, etc.)]**.
- **[Ore remaining in ultimate pit limit]**, revise pit limit analysis, pushback parameters & selection.
- **[Alternative scheduling scenario possible]**.
- **[All ore within pit limit scheduled]**, calculate NPV.
- **[NPV deviation from best case too great]**, revisit pit analysis, pushback parameters & selection, reduction rate, cutoff grade.
- **[Schedule generates adequate NPV]**.
Conventional open pit planning system: Long Range Planning

Long Range Planning (LRP)

- Set production capacities
- Determine production costs
- Perform PIT ANALYSIS A - 3
- Define PUSHBACK PARAMETERS A - 4
- Select PUSHBACKS A - 4
- Determine CUT-OFF GRADE A - 6
- Generate DETAILED MINE PLAN A - 10
- Produce budget

Subactivities follow SP flow and methodologies

- [Cut-off cooptimized with production rate increase/decrease production rate]
- [New scenario indicated increase/decrease production rate]
- [Pushback selection indicates change in costs]
- [Pushback decision possible]
- [Mine plan indicates improved cut-off strategy possible]
- [Detailed plan economics satisfactory]
- [More scenario analysis required]

- [More nested pits required]
- [Mine plan indicates different costs]
- [Mine plan indicates change in pushbacks]
- [Mine plan indicates different pushback design]
- [Mine plan indicates over/under utilization of capacity]
- [More scenario analysis required]
- [Sufficient scenario analysis]
Conventional open pit planning system: Detailed mine planning (LRP)

Detailed mine planning

- **LAYOUT SITE** A - 11
- **SELECT EQUIPMENT** A - 12
  - [Revise equipment]
  - [Revise pit analysis]

Create FUNCTIONAL MINE DESIGN A - 13
- [Design not feasible]
- [Revise pit analysis]

- **SCHEDULE MINING** A - 14
  - [Scheduling not feasible]

Forecast EQUIPMENT REQUIREMENTS A - 15
- [Scheduling exhausted]
  - Revisit pit analysis, prod. rate, cutoff

Simulation study: equipment interaction (as required)

Economic analysis
- [Plan does not meet expectations. Mine uneconomic.]
- [Plan meets economic expectations. Proceed with investment decision/continue mining.]

[Costs inconsistent]
[Revise pit analysis]

[Insufficient scheduling scenarios]
Conventional open pit planning system: Site layout (LRP)

Site layout

- Map proposed pit limit and pushback advances
- Locate mine related infrastructure
- Size and locate waste facilities-tailings and mining
- Develop mine road and tailings pipeline routes
- Quantify potential ore sterilization
- Perform hydrologic assessment
- Identify potential changes
- [Layout considered best option]
- [Potential haulage or pipe profile improvement]
- [Potential improvements to be considered]
Conventional open pit planning system: Select equipment (LRP)

Select equipment

- Select loader type
  - Size loader
    - Select truck match
      - Select ancillary equipment
        - Estimate operating and capital costs
          [Cost estimates inconsistent with pit optimization assumptions Reoptimize with updated costs]
          [Possible equipment configurations assessed]
          - Finalise equipment selection

[Other equipment configurations possible Further study required]
Conventional open pit planning system: Functional mine design (LRP)

Functional mine design

Determine ramp & bench design criteria

Identify desired pit entry/exit point(s)

Draft ramps and benches for each pit in mining sequence

Assess impact on tonnes mined (ore and waste) and pit wall location

[All configurations assessed]

Select best option

[Revise ramp/bench design]

[Other ramp locations/configurations viable]

[Revise equipment. Sizes not compatible with design requirements]

[Revise pit analysis or equipment selection]

[Pit impact too large]
Conventional open pit planning system: Schedule mining (LRP)

Schedule mining

1. Decide on number of concurrent mining faces, benches, and pushbacks

2. Assign ore tonnes from model until period production met using rational development sequences and respecting mining precedence rules

3. Calculate properties of scheduled ore production (e.g., grade and tonnes by ore type)

4. Determine waste stripping requirements for ore scheduled

   a. [Examine different scheduling scenario]

   b. [Properties meet process requirements (grade, deleterious content, etc.)]

5. Calculate properties of scheduled ore production

   a. [Waste mining exceeds capacity]

   b. [Properties meet process requirements (grade, deleterious content, etc.)]

6. Check waste material balance met

   a. [Waste mining exceeds capacity]

   b. [Waste can be scheduled]

7. Assign waste tonnes to earlier period

   a. [Waste can be scheduled]

   b. [Waste mining exceeds capacity]

8. Decide on number of concurrent mining faces, benches, and pushbacks

9. Calculate NPV

   a. [Schedule generates adequate NPV]

   b. [NPV deviation from best case too great. Other schedules possible]

10. Check waste material balance met

    a. [Waste mining exceeds capacity]

    b. [Waste can be scheduled]

11. Assign waste tonnes to earlier period

    a. [Waste can be scheduled]

    b. [Waste mining exceeds capacity]

12. Decide on number of concurrent mining faces, benches, and pushbacks

13. Calculate NPV

    a. [Schedule generates adequate NPV]

    b. [NPV deviation from best case too great. Other schedules possible]

14. Check waste material balance met

    a. [Waste mining exceeds capacity]

    b. [Waste can be scheduled]

15. Assign waste tonnes to earlier period

    a. [Waste can be scheduled]

    b. [Waste mining exceeds capacity]

16. Decide on number of concurrent mining faces, benches, and pushbacks

17. Calculate NPV

    a. [Schedule generates adequate NPV]

    b. [NPV deviation from best case too great. Other schedules possible]

18. Check waste material balance met

    a. [Waste mining exceeds capacity]

    b. [Waste can be scheduled]

19. Assign waste tonnes to earlier period

    a. [Waste can be scheduled]

    b. [Waste mining exceeds capacity]

20. Decide on number of concurrent mining faces, benches, and pushbacks

21. Calculate NPV

    a. [Schedule generates adequate NPV]

    b. [NPV deviation from best case too great. Other schedules possible]

22. Check waste material balance met

    a. [Waste mining exceeds capacity]

    b. [Waste can be scheduled]

23. Assign waste tonnes to earlier period

    a. [Waste can be scheduled]

    b. [Waste mining exceeds capacity]

24. Decide on number of concurrent mining faces, benches, and pushbacks

25. Calculate NPV

    a. [Schedule generates adequate NPV]

    b. [NPV deviation from best case too great. Other schedules possible]

26. Check waste material balance met

    a. [Waste mining exceeds capacity]

    b. [Waste can be scheduled]

27. Assign waste tonnes to earlier period

    a. [Waste can be scheduled]

    b. [Waste mining exceeds capacity]
Conventional open pit planning system: Forecast equipment (LRP)

Forecast equipment requirements

- Determine shovel hours per period
- Determine truck hours per period
- Determine number of loaders & haulers
- Determine support equipment requirements/numbers
- Output equipment requirements/numbers
- Perform simulation study to assess fleet productivity
- Develop equipment requirements schedule

- [Requirements cannot be accommodated or cost too high. Revise scheduling]
- [Hours erratic]
- [Equipment hours smoothed]
- [Requirements within cost assumptions]
- [Revise ore schedule]
- [Revise equipment selection]
- [Revise detailed mine planning]
- [Production assumptions valid]
- [Production assumptions valid]
Conventional open pit planning system: Short Range Planning

Short range planning (SRP)

- 12 MONTH PLAN incl. budget A - 17
- Quarterly forecast & budget variance reporting
- MONTHLY PLAN A - 18
- WEEKLY PLAN A - 19
- DAILY PLAN A - 20

[Forecast/budget update required]
[Monthly plan revision required]
[Weekly plan revision required]
[Begin next planning cycle]

*Monthly plan revision required*
Conventional open pit planning system: Twelve month planning (SRP)

Twelve month planning

- Identify annual ore advance (tonnes and location)
  - Meet mill demand forecast (tonnes and blend) by month
  - Minimize loader moves
  - Minimize ramp redevelopment/temporary ramps, etc.

- Identify waste advance
  - Maintain LRP stripping ratio (quarterly)
  - Minimize loader relocation
  - Meet dump construction needs (PAG-PAN balance, etc.)
  - Meet reclamation requirements
  - Minimize ramp redevelopment/temporary ramps, etc.

- Calculate equipment hours and numbers
  - [Changes accommodated]
  - [Schedule change possible]
  - [Insufficient equipment in one or more quarters]
  - Assess ore and/or waste schedule change
    - [Schedule change not possible]
    - Assess rental/contractor fleet
      - [Rental/contractor not feasible.]
      - Pursue changes outages & plant demand forecast.

- Plan dump development

- Prepare budget
Conventional open pit planning system: Monthly planning (SRP)

Monthly planning

Schedule major outages

Select production polygons weekly

Calculate equipment hours and numbers

[Insufficient equipment in one or more weeks]

[Schedule change possible]

Assess ore and/or waste schedule change, Investigate main’t schedule change, mill demand change

[Schedule change not possible]

Assess reducing waste mining

[Reduction can be accommodated]

[Reduction not advisable.]

Plan dump development

Identify budget variances

Assess rental/contractor fleet

[Continue planning by reducing waste lead time then restricting mill]

Assess LRP alternatives/consequences

Quantify impacts/notify management

{Equipment hours, maintenance personnel available, etc.}
Conventional open pit planning system: Weekly planning (SRP)

Weekly planning

- Forecast available mining capacity (tonnes per loader per shift)
- Select production polygons by day
  - Assign loaders to production polygons
  - [Cannot meet mill demand]
    - Evaluate moving ore or waste loader(s)
  - [Can meet mill tonnage demand]
    - [Cannot meet blend requirements]
      - Notify mill
      - Reduce tonnage
    - [Can meet mill blend requirements]
  - Determine waste shovel priority to maintain lead time
  - Determine trucks required
    - [Insufficient trucks]
      - Evaluate ore and waste priorities
      - Adjust waste plan
    - Notify mill
  - Identify drill patterns to maintain inventory
  - Identify blast patterns to maintain inventory
  - Identify support activities

***Notify Maintenance of any opportune equipment availabilities

[Loader move(s) practical]

[Can meet mill tonnage demand]

[Can meet mill blend requirements]

[Cannot meet blend requirements]

Notify mill

Evaluate moving ore or waste loader(s)

Move not practical

Reduce tonnage

Can meet mill demand

Cannot meet mill demand

Can meet mill tonnage demand

Cannot meet mill blend requirements

Determine trucks required

Insufficient trucks

Evaluate ore and waste priorities

Waste restriction preferable

Ore restriction preferable

Reduced tonnes and/or change blend

Notify mill

Adjust waste plan

Insufficient trucks
Daily planning

1. Calculate available mining capacity (tonnes per loader per shift)
2. Calculate available mining inventory by open mining face (tonnes and properties)
3. Determine ore loader priority by shift to meet mill demand (tonnes and blend)
4. Determine waste shovel priority to maintain lead time
5. Identify drill patterns for drilling to steward to 2 week plan
6. Identify blast patterns for loading

- [Cannot meet mill demand]
  - Evaluate moving ore or waste loader(s)
  - [Move not practical]
    - Reduce tonnage
    - Notify mill
- [Can meet mill tonnage demand]
  - [Can meet blend requirements]
    - [Cannot meet blend requirements]
      - [Move not practical]
        - Reduce tonnage
        - Notify mill
      - [Can meet blend requirements]
        - Notify mill
- [If excess shovel capacity notify maintenance of 'opportune main't' window]
  - Determine trucks required
    - [Sufficient trucks]
      - If excess notify maintenance of opportune window
      - Adjust waste plan
      - Identify drill patterns for drilling to steward to 2 week plan
  - [Insufficient trucks]
    - Evaluate ore and waste priorities
      - [Ore restriction preferable]
        - Reduced tonnes and/or blend constraints
        - Notify mill
      - [Waste restriction preferable]
        - Adjust waste plan
        - Identify drill patterns for drilling to steward to 2 week plan
    - Identify support activities
Appendix B

Unconventional Mine Planning Model: Oil Sands Mine Planning Case Study
Unconventional oil sands planning system: Planning system interactions

Select Aspects of Business Planning System

- Economic model development
- Processing model development
- Geotechnical model development
- Geology model development
- Tailings model development

Mine Planning System

- Strategic Planning
- Long Range Planning
- Short Range Planning

Corporation

Professional & Technical Employees

Investor

Regulator

Mine Planner

Interacts

Prescribes criteria

Uses

Uses

Uses
Unconventional oil sands planning system: Strategic Planning

Strategic Planning

- Perform PIT ANALYSIS B - 3
  - [Project not attractive] -> [Lease cannot accommodate proposed pit and waste plan Revise PIT ANALYSIS]

- Develop WASTE PLAN B - 4
  - [Waste lead insufficient Revise WASTE PLANNING]

- SCHEDULE MINING & tailings B - 6
  - [Project attractive Proceed to detailed planning]
  - Financial evaluation
  - [Project not attractive Shelve]
Unconventional oil sands planning system: Pit analysis (SP, LRP)

Pit analysis

- Make ore/waste determination (ID 2001-7)
- Capture geotechnical parameters
- Calculate bitumen volume for ore blocks
- Assign wall design parameters
- Create Total Volume:Bitumen in Place 12:1 contour
- Assign 12:1 TV:BIP as pit limit
- Create mineable pit limit
- Create higher ratio TV:BIP contours
- Examine pits for economic attractiveness
  - [>12:1 ratio preferred]
  - [12:1 limit preferred]
  - [Corporate philosophy]
  - Identify ex-pit tailings and waste dump locations

{Geotechnical parameters: wall slope(s)}
{Corporate philosophy}
Waste planning

- Identify regulatory requirements
- Define and prioritize corporate requirements
- Identify and prioritize stakeholder concerns
- Develop site closure objectives

Develop dump and tailings design guiding principles

Identify & assess design alternatives

Preliminary waste structure design and cost estimates

Detailed geotechnical site investigation prior to LRP

Develop MINED WASTE plan B - 5

Develop TAILINGS plan B - 5

[Insufficient space Revise design]

Unconventional oil sands planning system: Waste planning (SP)
Unconventional oil sands planning system: Mined waste and tailings planning (SP)

**Waste plan development**

- Develop pit material balance
- Determine in-pit waste capacity
- Determine ex-pit waste capacity
- Assess space available vs. required (incl. tailings forecast)

  - Insufficient space
    - Revise design or pit analysis
  - Space sufficient
    - Proceed to scheduling

**Tailings plan development**

- Produce mass balance model
- Calculate structure and pond storage capacities by elevation
- Generate pond infill surfaces
- Determine depositional lifespan of external pond

  - External basin sufficient
    - Provide storage requirement forecast to mine
    - Proceed to scheduling
  - Insufficient space
    - Revise design or pit analysis

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Unconventional oil sands planning system: Schedule mining (SP)

Determine scheduling goal

- Normally maximize bitumen production constrained by waste mining schedule, tailings production schedule, minimizing haul distance

Decide on number of concurrent mining faces, benches, and pushbacks/panels

- Normally maximize bitumen production constrained by waste mining schedule, tailings production schedule, minimizing haul distance

Assign ore tonnes until period production met (i.e. identify annual mine advance)

- [Alternative schedule possible]
- [Ore meets quality requirements]
- [Revise pit analysis]
- [Identify issue to process planners Detailed work required]

Determine waste stripping required

- [Ore remaining in pit limit]
- [Ore meets quality requirements]
- [Revise waste schedule]
- [Unable to meet waste schedule]
- [All ore within pit limit scheduled]

Assign advance stripping to previous period and remaining waste to current period

- [Alternative scheduling scenario possible]

Calculate NPV

- [New pushback parameters/design required]
- [Alternative scheduling scenario possible]

Select best schedule

- [Sufficient scheduling scenarios considered]
- [Unable to meet waste schedule]
Set ore production demand

Perform PIT ANALYSIS

Generate DETAILED MINE PLAN

Select plan & produce budget

New mining strategy possible
Revised PIT ANALYSIS

New scheduling scenario possible

Sufficient scenarios analysed

Subactivities follow SP flow and methodologies

Mine plan indicates different TV:BIP
Revise PIT ANALYSIS

Unconventional oil sands planning system: Long Range Planning
Detailed mine planning

- LAYOUT SITE B-9
- SELECT EQUIPMENT B-10

- SCHEDULE MINING (LRP) B-11
  - Economic analysis
    - [Equipment fleet scheduled] Y
      - [Sufficient studies conducted to indicate plan is 'optimal']
        - [Plan meets economic expectations Proceed with investment decision or mining & budget production]
      - [Scheduling not feasible Revise pit analysis]
        - [Facilities cannot be accommodated Revise pit analysis]
    - [Scheduling not feasible Revise pit analysis]
      - [Revise mining schedule]

- FORECAST EQUIPMENT requirements B-15
  - [Revise equipment selection]

- [Different scheduling scenario possible]
Unconventional oil sands planning system: Layout site (LRP)

Layout site

- Map proposed pit limit and pushback advances
- Size and locate waste facilities-tailings and mining
  - [Sufficient space]
  - [Insufficient space, Revise pit analysis]
- Locate mine related infrastructure
  - [Insufficient space, Revise pit analysis]
- Develop mine road and tailings pipeline routes
- Quantify potential ore sterilization
- Perform hydrologic assessment
- Identify potential changes
  - [Layout considered best option]
Unconventional oil sands planning system: Select equipment (LRP)

Select equipment

- Select loader type
  - Size loader
  - Select truck match
    - Select ancillary equipment
      - Estimate operating and capital costs
        - [Possible equipment configurations assessed]
          - Finalise equipment selection

[Other equipment configurations possible. Further study required]
Unconventional oil sands planning system: Schedule mining (LRP)

Schedule mining

Determine ramp & bench parameters and mining bench width

Draft ramps and fixed infrastructure (e.g. crusher)

Assign ore tonnes from model until period production met

Decide on number of concurrent mining faces, benches, and pushbacks (advances)

Calculate scheduled ore properties (grade, fines, etc.)

_properties acceptable_

_properties do not meet process requirements_

WASTE PLANNING B - 12

Calculate NPV

Sufficient level of analysis
Select best schedule

[Consider different schedule]

[Revise waste plan]

[Revise site layout]

[Revise pit analysis]
Unconventional oil sands planning system: Waste planning (LRP)

Waste planning

**Tailings Material Planning**
- Simplified mass balance modeling
- Identify tailings technology/treatment options (may include regulatory affairs, closure/reclamation, extraction, operations, etc.)

**Geotechnical Engineering**
- Preliminary facility design including dykes & waste dumps (location & volume focus)
- Determine facility construction requirements (materials & quantities) and facility storage volumes

**Mine Planning**
- Ore Planning
  - Ore characteristics by period for LOM

**Overburden Planning**
- Perform decision analysis & select preferred option(s) (includes all of the above or a subset of that group)
- Update mass balance
- Develop infill schedule by tailings type/disposal area

- [Infill volume not met]
- [Infill volume met]
- SCHEDULE TAILINGS placement B - 14
- Update mass balance
- Identify and assess risks associated with facility design, construction schedule, infill schedule, etc.
- [Risk level acceptable]
- Detailed facility design

- [Alternative waste design]
- [Alternative waste strategy]
- [Revise pit analysis]
- [Plan risk too high]
- SCHEDULE OVERBURDEN mining and placement B - 13

- Detailed facility design
Unconventional oil sands planning system: Schedule overburden (LRP)

Schedule overburden

Determine ex-pit waste capacity

Determine in-pit waste capacity for engineered and non-engineered structures

Determine overburden constructed dyke construction material requirements (tonnes, quality)

Determine infrastructure material requirements (tonnes, quality)

Develop pit LOM minimum OB construction requirements by period (tonnes, quality)

Determine tailings material requirements

Schedule minimum OB removal to meet ore production

Address periods when advanced stripping required

[Revise waste planning]

[Increase mining capacity]

[Construction requirements not met]

[Ore stripping and construction requirements met]

[Material balance not met; Cannot address; revise waste planning]

Identify and communicate Opportunities for infrastructure moves (crusher relocation etc)

Issue plan

[Construction requirements not met]
Unconventional oil sands planning system: Schedule tailings (LRP)

**Schedule tailings**

1. **Schedule raw water import (communicate to utilities)**
2. **Produce detailed LOM mass balance model by period (fluid & coarse tails, recycle water, raw water intake, other effluent, etc)**
3. **Issue pond rise forecast**
4. **Communicate to overburden planning**
5. **Schedule tailings sand construction to meet pond rise schedule**
6. **Determine facility storage construction requirements and capacities for non-fluid tailings storage (e.g., DDA for thin lift tails drying)**
7. **Develop pipeline plan (discharge locations by period)**
8. **Update mass balance model with 12 month schedule**
9. **Identify new requirements/relocations (Communicate as necessary)**
10. **Plan other infrastructure (barge, dredge locations and activities)**
11. **Create and issue new pond rise forecast**
12. **Communicate to OB planning**
13. **Issue plan**
14. **Check against mining & tailings plan**
15. **Issue pond rise forecast not supported by tailings plan**

- **[Tailings feed meets construction requirements]**
- **[Schedule containment construction meets pond rise forecasts]**
Unconventional oil sands planning system: Forecast equipment (LRP)

Forecast equipment requirements

- Determine shovel hours per period
- Determine truck hours per period
- Determine number of loaders & haulers
- Determine support equipment requirements/numbers
- Output equipment requirements/numbers
- Develop equipment requirements schedule

[Requirements cannot be accommodated or cost too high. Revise scheduling]

[Revise scheduling]

[Consider contract mining]

[Hours erratic]

[Equipment hours smoothed]

[Requirements within cost assumptions]
Unconventional oil sands planning system: Short Range Planning

Short range planning (SRP)

- 12 MONTH PLAN incl. budget B - 17
- Quarterly forecast & budget variance reporting
- MONTHLY PLAN B - 18
- WEEKLY PLAN B - 19
- DAILY PLAN B - 20

[Monthly plan revision required]
[Weekly plan revision required]
[Begin next planning cycle]

[Forecast/budget update required]
Unconventional oil sands planning system: Twelve month plan (SRP)

Twelve month planning

1. Identify annual ore advance (tonnes and location)
2. Identify waste advance
3. Schedule waste placement
4. Calculate equipment hours and numbers
   - Insufficient equipment in one or more quarters
     - Sufficient equipment identified
       - Identify periods of reduced demand for scheduling opportune mine maintenance
5. Assess ore and/or waste schedule change. Investigate main’t schedule or plant demand change
   - Schedule change possible
     - Rental/contractor available within budget
       - Rental/contractor fleet available
         - Changes accommodated
           - Pursue changes to plant demand forecast
           - Trigger impact assessment & quantify impact
           - Notify management
         - Not feasible
           - Changes not accommodated
             - Continue planning exercise
           - Change not possible
6. Prepare budget/issue plan
Unconventional oil sands planning system: Monthly planning (SRP)

Monthly planning

- Schedule major outages by week
- Identify ore & OB production polygons by week
- Identify construction activities by week
- Communicate construction activities to tailings

[Schedule change possible]

- Calculate equipment hours and numbers
  - Insufficient equipment in one or more weeks
    - Assess ore and/or waste schedule change, investigate main’t schedule change, mill demand change
      - Schedule change not possible
        - Assess reducing waste mining
          - Rental/contractor available
            - Reduction can be accommodated
              - Sufficient equipment
              - Reduction not accommodated
            - Reduction not accommodated
              - Continue planning, reduce waste lead time, then restrict plant
              - Assess LRP alternatives
            - Rental/contractor not available
              - Reduction not accommodated
          - Reduction not accommodated
        - Insufficient equipment
          - Schedule change not possible
            - Assess reducing waste mining

[Schedule change not possible]

- Issue plan/forecast budget variances
- Quantify impacts/notify management
Unconventional oil sands planning system: Weekly planning (SRP)

Weekly planning/10 day planning

- Forecast available mining capacity (tonnes per loader per shift)
- Select production polygons by day
- Assign loaders to production polygons
- Evaluate moving ore or waste loader(s)
- Determine waste shovel priority
- Determine trucks required
- Evaluate ore and waste priorities
- Notify plant
- Notify plant and tailings
- Identify support activities & equipment requirements
- Identify adjustments to monthly plan
- Notify Maintenance of any opportune main’t opportunities

[Loader move(s) practical]
[Cannot meet plant demand]
[Can meet plant tonnage demand]
[Can meet blend requirements]
[Cannot meet blend]
[Move not practical Reduced ore tonnage]
[Insufficient trucks]
[Sufficient trucks]
[Ore restriction preferable]
[Waste restriction preferable]
[Update monthly plan]
[No changes required]
Unconventional oil sands planning system: Daily planning (SRP)

Daily planning

- Calculate available mining capacity (tonnes per loader per shift)
- Calculate available mining inventory by open mining face (tonnes and properties)

[Loader move(s) practical]

- Determine ore loader priority by shift to meet plant demand (tonnes and blend)
  - [Cannot meet plant demand]
  - [Can meet plant demand]
    - [Can meet mill blend requirements]
    - [Cannot meet blend requirements]
    - Evaluate moving ore or waste loader(s)
      - [Move not practical]
      - [Can meet mill blend requirements]
        - Notify plant

- Determine waste loader priority to maintain construction requirements
  - [If excess shovel capacity notify maintenance of ‘opportunue main’ window]

- Determine trucks & critical support equipment required
  - [Insufficient equipment]
  - [Sufficient trucks]
    - If excess notify maintenance of opportune window
      - Evaluate ore and waste priorities
        - [Ore restriction preferable]
        - [Waste restriction preferable]
          - Adjust waste targets
          - Notify plant

- Identify support activities & assign equipment
- Identify updates to weekly plan

[Update weekly plan]

- End of daily planning activities
- React to changing field conditions
- Repeat daily
Unconventional oil sands planning system: Tailings planning workflow

Tailings planning activity workflow

- Create detailed Mass Balance
- Prioritise available tailings feed use & fluid transfers
- Identify system maintenance outages (pipe rotation/replacement, pump work, etc.)
  - [System priorities not consistent with mass balance assumptions]
- Schedule priority tailings construction & fluid transfer
- Develop pipe layouts for critical activities
- Schedule non-critical activities
- Identify pipe layouts for non-critical activities
  - [Schedule not attainable]
- Check pipe layouts for pipe move timing, maximum pipe demands, etc.
- Regenerate mass balance model
- Ensure pond rise forecasts supported by planned mine and tailings construction activities
  - [Containment not met]
  - [Required containment met]
- Identify pipe requirements
- Consider scenario options
- Schedule support activities (barge moves, etc.)
  - [Containment increase/pond rise schedules not compatible Tailings to address]
  - [System usage not consistent with main't plan]
  - [System priorities not consistent with mass balance assumptions]

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Appendix C

Unconventional Mine Planning Model: Proposal for a New Oil Sands Planning System
Proposed oil sands planning system: Planning system interactions

Select Aspects of Business Planning System

- Economic model development
- Processing model development
- Geotechnical model development
- Geology model development
- Tailings model development

Mine Planning System

- Strategic Planning
  - Uses
  - Long Range Planning
  - Short Range Planning
  - Uses

Interacts

- Corporation
- Regulator
  - Interacts
- Investor
- Professional & Technical Employees
- Mine Planner
Proposed oil sands planning system: Strategic Planning

Strategic Planning

- Perform PIT ANALYSIS C-3
  - Cutoff grade strategy
  - [WASTE PLANNING]
  - Develop WASTE PLAN C-4
    - [Waste and tailings plan not consistent]
    - Schedule MINING & tailings C-6
      - [Waste lead insufficient Revise WASTE PLANNING]
      - [Lease cannot accommodate pit and waste plan Revise PIT ANALYSIS]
      - [Sufficient analysis to set plan]
      - Financial evaluation
        - [Project attractive Proceed to detailed planning]
        - [Project not attractive Shelve]

- Economic & process recovery criteria
  - [Other scenarios to be evaluated]
Proposed oil sands planning system: Pit analysis (SP, LRP)

Pit analysis

- Determine mining cost
- Determine waste treatment & reclamation costs
- Determine bitumen recovery and tailings production
- Determine upgrading & shipment costs
- Determine process costs
- Determine expected commodity price
- Determine tailings costs

Assign values to blocks

Select commodity prices to produce nested pits and final pit limit

Perform pit optimization (eg. LG)

Identify ore & waste quantities and properties

Identify ex-pit tailings and waste dump locations

Define pushback parameters

Select sequence

[Pit limit and waste storage requirements not compatible]
Proposed oil sands planning system: Waste planning (SP)

Waste planning

- Identify regulatory requirements
- Define and prioritize corporate requirements
- Identify and prioritize stakeholder concerns
- Develop dump and tailings design guiding principles
- Develop waste structure design objectives
- Identify & assess design alternatives
- Preliminary waste structure design and cost estimates
- Detailed geotechnical site investigation prior to LRP
- Develop MINED WASTE plan C - S
- Develop TAILINGS plan C - S
- Insufficient space
- Revise design

Develop MINED WASTE plan C - S
Develop TAILINGS plan C - S

Detailed geotechnical site investigation prior to LRP

Develop waste structure design objectives

Develop dump and tailings design guiding principles
Proposed oil sands planning system: Mined waste and tailings planning (SP)

Waste plan development

- Determine in-pit waste capacity
- Determine ex-pit waste capacity
- Develop pit material balance
- Calculate structure and pond storage capacities by elevation
- Produce mass balance model
- Generate pond infill surfaces
- Assess space available vs. required (incl. tailings forecast)
- Determine depositional lifespan of external pond
- [Insufficient space
  - Revise design or pit analysis]
- [Space sufficient
  - Proceed to scheduling]
- [External basin sufficient]
  - Provide storage requirement forecast to mine
  - Proceed to scheduling]
- [Insufficient space
  - Revise design or pit analysis]
Proposed oil sands planning system: Schedule mining (SP)

**Schedule mining**

1. **Determine scheduling goal**
   - Normally maximize bitumen production constrained by waste mining schedule, tailings production schedule, minimizing haul distance

2. **Decide on number of concurrent mining faces, benches, and pushbacks/panels**
   - [Alternative pushback parameters/design possible]

3. **Assign ore tonnes until period production met (i.e. identify annual mine advance)**
   - [Alternative scheduling scenario possible]
   - [Ore meets quality requirements]
   - [Ore remaining in pit limit]
   - [Revise waste plan]

4. **Determine waste stripping required Assign advance stripping to previous period and remaining waste to current period**
   - [Unable to meet waste schedule]
   - [All ore within pit limit scheduled]
   - [Revise pit analysis]
   - [Identify issue to process planners Detailed work required]

5. **Calculate NPV**
   - [Alternative scheduling scenario possible]

6. **Select best schedule**
   - [Sufficient scheduling scenarios considered]
Proposed oil sands planning system: Long Range Planning

Long Range Planning (LRP)

Set ore production demand

Perform PIT ANALYSIS
C - 3

[New mining strategy possible
Revise pit analysis]

[Plan indicates different pit limit
Revise pit analysis]

Generate DETAILED MINE PLAN
C - 8

[New scheduling scenario possible]

[Sufficient scenarios analysed]

Select plan & produce budget
(may be used in project evaluation or to develop business plan)

Subactions follow strategic planning flow and methods
Proposed oil sands planning system: Detailed mine planning (LRP)

- LAYOUT SITE C-9
- SELECT EQUIPMENT C-10
- SCHEDULE MINING (LRP) C-11
- FORECAST EQUIPMENT requirements C-15
- Economic analysis

Flowchart:
1. LAYOUT SITE C-9
   - Select equipment C-10
     - Schedule mining (LRP) C-11
       - Forecast equipment requirements C-15
         - Economic analysis
           - Sufficient studies conducted to indicate plan is 'optimal'
             - Plan meets economic expectations
               Proceed with investment decision or mining & budget production
             - Does not meet expectations
               Mine uneconomic
           - Facility cannot be accommodated
             - Revise pit analysis
           - Scheduling not feasible
             - Revise pit analysis
           - Different scheduling scenario possible
         - Fleet can’t meet production rates
           - Revise pit analysis
         - Fleet can’t meet production rates
           - Revise equipment selection
   - Revise mining schedule

2. Economic analysis
   - Sufficient studies conducted to indicate plan is ‘optimal’
     - Plan meets economic expectations
       Proceed with investment decision or mining & budget production
     - Does not meet expectations
       Mine uneconomic
   - Facility cannot be accommodated
     - Revise pit analysis
   - Scheduling not feasible
     - Revise pit analysis
   - Different scheduling scenario possible

3. Fleet can’t meet production rates
   - Revise pit analysis
   - Revise equipment selection

4. Economic analysis
   - Sufficient studies conducted to indicate plan is ‘optimal’
     - Plan meets economic expectations
       Proceed with investment decision or mining & budget production
     - Does not meet expectations
       Mine uneconomic
   - Facility cannot be accommodated
     - Revise pit analysis
   - Scheduling not feasible
     - Revise pit analysis
   - Different scheduling scenario possible

5. Facility cannot be accommodated
   - Revise pit analysis
   - Revise equipment selection

6. Scheduling not feasible
   - Revise pit analysis
   - Different scheduling scenario possible

7. Different scheduling scenario possible
   - Facility cannot be accommodated
     - Revise pit analysis
   - Revise equipment selection

8. Economic analysis
   - Sufficient studies conducted to indicate plan is ‘optimal’
     - Plan meets economic expectations
       Proceed with investment decision or mining & budget production
     - Does not meet expectations
       Mine uneconomic
   - Facility cannot be accommodated
     - Revise pit analysis
   - Scheduling not feasible
     - Revise pit analysis
   - Different scheduling scenario possible

9. Fleet can’t meet production rates
   - Revise pit analysis
   - Revise equipment selection

10. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

11. Facility cannot be accommodated
    - Revise pit analysis
    - Revise equipment selection

12. Scheduling not feasible
    - Revise pit analysis
    - Different scheduling scenario possible

13. Different scheduling scenario possible
    - Facility cannot be accommodated
      - Revise pit analysis
    - Revise equipment selection

14. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

15. Fleet can’t meet production rates
    - Revise pit analysis
    - Revise equipment selection

16. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

17. Facility cannot be accommodated
    - Revise pit analysis
    - Revise equipment selection

18. Scheduling not feasible
    - Revise pit analysis
    - Different scheduling scenario possible

19. Different scheduling scenario possible
    - Facility cannot be accommodated
      - Revise pit analysis
    - Revise equipment selection

20. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

21. Fleet can’t meet production rates
    - Revise pit analysis
    - Revise equipment selection

22. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

23. Facility cannot be accommodated
    - Revise pit analysis
    - Revise equipment selection

24. Scheduling not feasible
    - Revise pit analysis
    - Different scheduling scenario possible

25. Different scheduling scenario possible
    - Facility cannot be accommodated
      - Revise pit analysis
    - Revise equipment selection

26. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

27. Fleet can’t meet production rates
    - Revise pit analysis
    - Revise equipment selection

28. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

29. Facility cannot be accommodated
    - Revise pit analysis
    - Revise equipment selection

30. Scheduling not feasible
    - Revise pit analysis
    - Different scheduling scenario possible

31. Different scheduling scenario possible
    - Facility cannot be accommodated
      - Revise pit analysis
    - Revise equipment selection

32. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

33. Fleet can’t meet production rates
    - Revise pit analysis
    - Revise equipment selection

34. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

35. Facility cannot be accommodated
    - Revise pit analysis
    - Revise equipment selection

36. Scheduling not feasible
    - Revise pit analysis
    - Different scheduling scenario possible

37. Different scheduling scenario possible
    - Facility cannot be accommodated
      - Revise pit analysis
    - Revise equipment selection

38. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

39. Fleet can’t meet production rates
    - Revise pit analysis
    - Revise equipment selection

40. Economic analysis
    - Sufficient studies conducted to indicate plan is ‘optimal’
        - Plan meets economic expectations
          Proceed with investment decision or mining & budget production
        - Does not meet expectations
          Mine uneconomic
    - Facility cannot be accommodated
      - Revise pit analysis
    - Scheduling not feasible
      - Revise pit analysis
    - Different scheduling scenario possible

41. Facility cannot be accommodated
    - Revise pit analysis
    - Revise equipment selection

42. Scheduling not feasible
    - Revise pit analysis
    - Different scheduling scenario possible

43. Different scheduling scenario possible
    - Facility cannot be accommodated
      - Revise pit analysis
    - Revise equipment selection
Proposed oil sands planning system: Layout site (LRP)

Map proposed pit limit and pushback advances

Size and locate waste facilities-tailings and mining

[Sufficient space]

[Insufficient space]

Revise pit analysis

Locate mine related infrastructure

[Insufficient space]

Revise pit analysis

Develop mine road and tailings pipeline routes

[Alternative infrastructure plan]

Quantify potential ore sterilization

Perform hydrologic assessment

Identify potential changes

[Layout considered best option]
Proposed oil sands planning system: Select Equipment (LRP)

Select equipment

- Select loader type
- Size loader
- Select truck match
- Select ancillary equipment
- Estimate operating and capital costs
- [Possible equipment configurations assessed]
- Finalise equipment selection

[Other equipment configurations possible. Further study required]
Proposed oil sands planning system: Schedule mining (LRP)

Schedule mining

- Determine ramp & bench parameters and mining bench width
- Draft ramps and fixed infrastructure (e.g. crusher)
- Assign ore tonnes from model until period production met
- Decide on number of concurrent mining faces, benches, and pushbacks (advances)
- Calculate scheduled ore properties (grade, fines, etc.)
  - [Properties acceptable]
  - [Properties do not meet process requirements]
- WASTE PLANNING C - 12
  - [Revise waste plan]
  - [Revise site layout]
  - [Revise pit analysis]
- Calculate NPV
  - [Sufficient level of analysis]
  - Select best schedule
- [Consider different schedule]
Waste planning

Tailings Material Planning

- Simplified mass balance modeling
- Identify tailings technology/treatment options (may include regulatory affairs, closure/reclamation, extraction, operations, etc.)
- Perform decision analysis & select preferred option(s) (includes all of the above or a subset of that group)
- Update mass balance

Geotechnical Engineering

- Preliminary facility design including dykes & waste dumps (location & volume focus)
- Determine facility construction requirements (materials & quantities) and facility storage volumes
- Develop infill schedule by tailings type/disposal area
- [Infill volume met]
- [Infill volume not met]

Tailings

- SCHEDULE TAILINGS placement C - 14
- Update mass balance
- Identify and assess risks associated with facility design, construction schedule, infill schedule, etc.
- [Risk level acceptable]

Mine Planning

- Ore Planning
- Ore characteristics by period for LOM

Overburden Planning

- SCHEDULE OVERBURDEN mining and placement C - 13
- Plan risk too high
- [Plan risk too high]
- [Alternative waste design]
- [Revise pit analysis]
- [Alternative waste strategy]

[Ore Planning]

- Identify and assess risks associated with facility design, construction schedule, infill schedule, etc.
- [Risk level acceptable]

Detailed facility design

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Proposed oil sands planning system: Schedule overburden (LRP)

Schedule overburden

- Determine ex-pit waste capacity
- Determine in-pit waste capacity for engineered and non-engineered structures
- Determine overburden constructed dyke construction material requirements (tonnes, quality)
- Determine infrastructure material requirements (tonnes, quality)
- Develop pit LOM minimum OB construction requirements by period (tonnes, quality)
- Determine tailings material requirements
- Schedule minimum OB removal to meet ore production

[Revise waste planning]

[Increase mining capacity]

[Construction requirements not met]

Address periods when advanced stripping required

[Material balance not met; cannot address; revise waste planning]

[Ore stripping and construction requirements met]

[Ore stripping and construction requirements met]

Issue plan

Identify and communicate opportunities for infrastructure moves (crusher relocation etc.)
Proposed oil sands planning system: Schedule tailings (LRP)

Schedule tailings

- Schedule raw water import (communicate to utilities)
- Communicate to overburden planning
- Produce detailed LOM mass balance model by period (fluid & coarse tails, recycle water, raw water intake, other effluent, etc)
- Issue pond rise forecast
- Schedule tailings sand construction to meet pond rise schedule
- Schedule fluid tailings rehandle
- Determine facility storage construction requirements and capacities for non-fluid tailings storage (e.g. DDA for thin lift tails drying)
- Determine beach requirements
- Issue pond rise forecast
- Communicate to overburden planning

- Schedule remaining tailings by placement priority
- Determine material shortfall
- [Tailings feed meets construction requirements]
- Develop pipeline plan (discharge locations by period)
- [Pond rise forecast not supported by tailings plan]

- Identify pipe/pump requirements
- Communicate as necessary
- Identify new requirements/relocations
- Communicate as necessary
- Generate tailings facility infill plan based on schedule including rehandled/treated tails
- Plan other infrastructure (barge, dredge locations and activities)
- Update mass balance model with 12 month schedule
- Create and issue new pond rise forecast
- Communicate additional OB needs to mine
- Communicate as necessary
- Communicate additional OB needs to mine
- Communicate as necessary
- Issue plan

[Scheduled containment construction meets pond rise forecasts]
Proposed oil sands planning system: Forecast equipment (LRP)

Forecast equipment requirements

- Determine shovel hours per period
- Determine truck hours per period
- Determine number of loaders & haulers
- Determine support equipment requirements/numbers
- Output equipment requirements/numbers

[Requirements cannot be accommodated or cost too high. Revise scheduling]

- Determine rental or contractor requirements and cost
- [Consider contract mining]
- [Equipment hours smoothed]
- [Requirements within cost assumptions]
- [Revise scheduling]
- [Hours erratic]

- Perform simulation study to assess fleet productivity
  - [Production assumptions valid]
  - [Revise detailed mine planning]
  - [Revise equipment selection]
  - [Revise ore schedule. Notify other planning areas]

- Develop equipment requirements schedule

Develop equipment requirements schedule
Proposed oil sands planning system: Short Range Planning

Short range planning (SRP)

- 12 MONTH PLAN incl. budget C - 17
  - Quarterly forecast & budget variance reporting
    - [Forecast/budget update required]
  - [Monthly plan revision required]
- MONTHLY PLAN C - 18
- WEEKLY PLAN C - 19
  - [Weekly plan revision required]
- DAILY PLAN C - 20
  - [Begin next planning cycle]
Proposed oil sands planning system: Twelve month planning (SRP)

Twelve month planning

- Identify annual ore advance (tonnes and location)
- Identify waste advance
- Schedule waste placement
- Calculate equipment hours and numbers
  - Insufficient equipment in one or more quarters
  - Sufficient equipment
    - Identify periods of reduced demand for scheduling opportunite mine maintenance
- Assess ore and/or waste schedule change. Investigate Main’t schedule or plant demand change
  - Change not possible
  - Rental/contractor available
    - Rental/contractor available within budget
    - Not feasible
  - Changes not accommodated
    - Continue planning exercise
    - Trigger impact assessment & quantify impact
    - Notify management
- Prepare budget/issue plan
Proposed oil sands planning system: Monthly planning (SRP)

Monthly planning

Schedule major outages by week

Identify ore & OB production polygons by week

Identify construction activities by week

Communicate construction activities to tailings

Calculate equipment hours and numbers

[Schedule change possible]

Assess ore and/or waste schedule change, Investigate main’t schedule change, mill demand change

[Schedule change not possible]

Assess reducing waste mining

[Insufficient equipment in one or more weeks]

[Sufficient equipment]

[Reduction can be accommodated]

[Reduction not accommodated]

[Rental/contractor available]

Issue plan/forecast budget variances

Quantify impacts/notify management

[Continue planning, reduce waste lead time, then restrict plant Assess LRP alternatives]
Proposed oil sands planning system: Weekly planning (SRP)

Weekly planning/10 day planning

- Forecast available mining capacity (tonnes per loader per shift)
- Select production polygons by day
- Assign loaders to production polygons
- Determine waste shovel priority
- Determine trucks required
- Identify support activities & equipment requirement
- Identify adjustments to monthly plan

Decision Points:
- Cannot meet plant demand
- Can meet plant demand
- Cannot meet blend
- Can meet blend requirements
- Insufficient trucks
- Sufficient trucks
- Ore restriction preferable
- Waste restriction preferable

Tasks:
- Evaluate moving ore or waste loader(s)
- Notify plant
- Notify plant and tailings

Notes:
- Loader move(s) practical
- Move not practical
- Reduced ore tonnage
- Can meet blend
- Cannot meet blend
- Can meet tonnage demand
- Cannot meet tonnage demand
- Sufficient trucks
- Insufficient trucks
- Notify Maintenance of any opportune main’t opportunities

Outcomes:
- No changes required
- Update monthly plan
- **Notify Maintenance of any opportune main’t opportunities**
Proposed oil sands planning system: Daily planning (SRP)

**Daily planning**

- **Calculate available mining capacity (tonnes per loader per shift)**
- **Calculate available mining inventory by open mining face (tonnes and properties)**
  - [Loader move(s) practical]
- **Determine ore loader priority by shift to meet plant demand (tonnes and blend)**
  - [Cannot meet plant demand]
  - [Can meet plant demand]
  - [Cannot meet blend requirements]
  - [Can meet mill blend requirements]
- **Determine waste loader priority to maintain construction requirements**
  - [If excess shovel capacity notify maintenance of 'opportune maint' window]
- **Determine trucks & critical support equipment required**
  - [Insufficient equipment]
  - [Sufficient trucks if excess notify maintenance of opportune window]
- **Evaluate ore and waste priorities**
  - [Ore restriction preferable]
  - [Waste restriction preferable]
- **Adjust waste targets**
- **Identify support activities & assign equipment**
- **Identify updates to weekly plan**
  - [Update weekly plan]

End of daily planning activities
React to changing field conditions
Repeat daily
Proposed oil sands planning system: Tailings planning workflow

**Tailings planning activity workflow**

1. **Create detailed Mass Balance**
2. **Prioritise available tailings feed use & fluid transfers**
3. **Identify system maintenance outages** (pipe rotation/replacement, pump work, etc.)
4. **Schedule priority tailings construction & fluid transfer**
5. **Develop pipe layouts for critical activities**
6. **Schedule non-critical activities**
7. **Identify pipe layouts for non-critical activities**
8. **Check pipe layouts for pipe move timing, maximum pipe demands, etc.**
9. **Regenerate mass balance model**
10. **Ensure pond rise forecasts supported by planned mine and tailings construction activities**
    - **Containment not met**
    - **Required containment met**
11. **Consider scenario options**
12. **Schedule support activities** (barge moves, etc.)
13. **Identify pipe requirements**