Planning the Mine and Mining the Plan. Dale S. Boucher¹ and Norman Chen², ¹Deltion Innovations Ltd, 26 Meehan St, Capreol, Ontario, Canada, P0M1H0, dboucher@deltion.ca; ²Hatch Ltd. - Sudbury Operations, Notre Dame Business Complex, 40 Elm Street, Unit ND255, Sudbury, Ontario, Canada, P3C1S8, norman.chen@hatch.com

Introduction: The development of a terrestrial mining operation follows a well understood planning cycle, designed to provide the mine operator with the means to evaluate and efficiently manage the build up of the mining operations to maximize the ore body’s potential and to help the operator understand mine life cycle constraints. This paper will discuss the development of mine plans for the express purpose of lunar mining of water ice/volatiles in support of global exploration activities.

Overview: In general, planning a mine can be divided into a 4-step Stage Gate process. Each stage has clearly defined activities and goals unique to the project. The gate at the end of the stage is used to filter the stage results and determine if the plan can advance to the next stage, force a rework, or abandon the project.

Each stage is built upon the Client Requirements Specification, similar to a multi level System Requirements Document process. The CRS is a live document and will evolve throughout the project and must be carried through each of the stages and gates as a means to ensure the mine planning activity remains focused on the appropriate end goals. Unlike multi-level SRD’s as used in mission planning, the CRS is somewhat flexible and must respond to changes in market and client conditions over time. The decision to proceed with any stage is based upon evaluations of: the expected benefit of the project end result, costing, and risk (technical and administrative).

Each Gate in the process is very similar to the Milestone Review process used in flight programs. The Gate provides a formalized means by which the Gate Review team can evaluate project viability, and provide an Authorization To Proceed for the next stage.

Concept Development: This is the primary stage of a mine development plan (similar to a Phase A Concept Study). It is focused upon definition of the requirements and a first look at the ore body capacity (quality, quantity). At least one option is proposed that will be evaluated in later stages as solutions to the mining plan. This stage will suggest a high level “functional” block diagram of mining operations that is improved in the following stages. This stage will generate the following evaluation results:

1) Basic assumptions underpinning the concept remain valid.
2) Context of the orebody (type of deposit, exploration work undertaken to date, reserve potential).
3) Project, resource and technology ownership.
4) Client Requirements, Specifications are valid.
5) Strategic case for the project; information for a preliminary economic assessment report.
6) Mine capacity and rate; waste disposal method.
7) Key Performance Criteria defined.
8) Alternative approaches defined.
9) Risks (technical, cost and management) defined and evaluated.
10) Plan for completion of the next stage is workable and realistic.

Technology Selection and Development: This evaluates the options proposed in the Concept Development with more rigor. A review of the discarded options is undertaken to determine if new knowledge would change the evaluation. One option proposed in Concept is selected and evaluated for viability. Evaluation of technologies and capabilities available (or may require development) is critical so that a detailed roadmap can be implemented. The focus is on the selected option (similar in nature to the Preliminary Design Stage of a flight program) and will generate:

1) Detailed validation of the project assumptions.
2) Most viable option for execution selected.
3) Risks eliminated/reduced.
4) Execution stage preliminary plan defined.
5) Evaluate the plan for completing the next stage.

Feasibility Evaluation: Produces the investment rationale (not the business case) for the mine plan. It is used to prepare the investment portfolio and can include completion of any legislated documentation regarding due diligence (ex. NI 43-101, JORC or SAMREC) for the purposes of financing the execution phase. The selected option is further defined and detailed designs are produced that support the solution in terms of cost, schedule, scope and client based requirements. This stage focuses on the execution planning, schedule alignment with other external factors (e.g., commodity pricing, demand, technology and capability readiness). The primary output is the development of a detailed expenditure programme, schedule and execution plan with all risks addressed, either retired or mitigated, and will yield the following:

1) Detailed validation of the underpinning assumptions of the project.
2) Detailed cost, schedule and risk analysis.
3) Client based opportunity validity remains defined.
4) Key Performance Criteria met or retired.
5) Risks identified for Execution Phase.
6) Evaluate the plan for completing the next stage.

**Execution:** This includes development and management of the actual capital investment, development of final design modifications (if required) to realize changes in scope, schedule, cost, quality, and other defined constraints/parameters. This stage is executed to deliver the defined outcomes and includes the actual start-up stage of the mine. It is considered a “live” exercise in that the mining activity begins with first shovel in the ground. Many items are considered energized at day one. Cost and schedule management is primary. Operational build up includes site preparation, support infrastructure build up, equipment purchase, deployment scheduling, logistics management (procurement, shipping, external support), subcontractor management, market and financing management, and overall project schedule management.

**Strawman Scenario:** A commercial water mining activity on the moon is envisioned. Some “typical” example results are shown for each of the stages to attempt to provide perspective. This plan is only intended to illustrate the overall process necessary to develop a workable mine on the lunar surface.

**Basic Assumptions:**
- **Client:** Lunar Lager Brewing Company LTD.
- **Mine Site:** Cabeus Crater
- **Production:** 1000 tonnes purified water per year
- **Life Cycle:** 10 year production
- **Delivery point:** Lunar outpost Shackleton rim Clive’s Bar and Grill, hamburger stand and refueling depot
- **Projected price point:** $500 per kg

**Stage 1: Concept Development:**
1) Cost cap budget for project set at $1600 million
2) Early results indicate 7% water ice by weight average over mining site of 100 hectares. Average depth is 2 m; overburden is 40 cm desiccated material. Rubble field geology requiring handling of large (1 m) rubble as overburden and embedded waste. Estimates show that 40% of the available area is accessible; remainder is under excessive rubble or trapped by rock outcroppings.
3) Small ISRU-specific mobile platforms (500 kg) are reasonably mature and can be used to provide most mobile services. Sampling technologies well developed for detailed ore body definition. Refining systems are at early TRL stages. Storage of product can be evolved from known technologies.
4) Technology development plans include excavation systems, command and control with Direct To Earth (DTE) link or via specialized orbiter or crater rim emplaced links. Power systems to be RTG stacks and/or crater rim mounted solar voltaic cells.

**Stage 2: Technology Selection and Development:**
1) CRS revised to include Level 2 requirements.
2) Open pit mining process selected. Overburden dump site selected for ease of access at later date in support of habitat requirements.
3) Plan revised to incorporate new fusion power system development.
4) Technology development roadmap completed. Contact made with OEM’s to begin development of target technologies in joint venture/speculation style sub-projects.
5) Execution Stage (Stage 4) concept will rely upon robotic pre-cursors to develop infrastructure, roadways, maintenance sites. Overburden from mine site will be used as required for fill.

**Stage 3: Feasibility Study:**
1) CRS revised to include Level 3 Requirements.
2) Time-based technology deployment completed. Fleet make up of 2 roadway maintenance rovers, 2 construction robots, 1 mobile exploration drill, 2 Load Haul Dump machines, 4 haulage trucks deployed in order indicated over 3 years.
3) Refining process to be in situ thermal release of water ice from regolith with water filtration plant for 98% purity.
4) Bulk storage tank farm with auto loaders for pure water storage.
5) Technical risks 80% retired: remaining risks are in the area of long term machine availability.
6) Management risks remain with long term financing and market volatility for end product.

**Stage 4: Execution:**
1) Establish project execution team.
2) Secure launch, cruise and lander contracts.
3) Secure OEM equipment procurement contracts and schedule.
4) Establish ground based command and control center.
5) Deploy road building systems to establish landing pads, basic infrastructure, mine pit roads.
6) Deploy construction robot team.
7) Deploy LHD robots.
8) Deploy long-haul trucks.
9) Commissioning of systems and ramp up to full production.
10) Hand-over to Operations.