MINING PROJECT MANAGEMENT - CAPITAL PROJECTS

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ABSTRACT

Developing mining capital projects, and indeed, projects in most industries, can be fraught with many difficulties. Given that projects tackle new ground, problems are inevitable and thus tend to be un-practised and un-rehearsed. Project management, then, is the management of change; working in unpredictable conditions. Uncertainty is therefore inherent in capital projects, as underlined, for example, by the order of magnitude error made in the estimate of investment needed to construct the Scottish Parliament, the dramatic failure of a section of the new terminal in the Charles de Gaulle airport in Paris and the ongoing financial position of the Channel Tunnel. Can anything be done to improve a seemingly endless history of project failures?

The answer, of course, is most definitely yes. A number of systems for managing capital projects have been developed over the years, to such a stage, where capital project failures should become a thing of the past. However, the use of such systems, is a matter for corporate policy makers to adopt and rigorously implement.

This paper outlines the developing approach of Codelco-Chile to the management of capital projects to ensure improved results from project engineering and subsequent project execution. Codelco-Chile arrived at the decision to adopt a capital investment system, following their experiences with project engineering and management over the years, and in particular the problems that arose during the expansion project of the Division El Teniente. Over-runs in costs and schedules coupled with under-performance following project implementation of the Teniente expansion project, gave the Codelco Board little choice but to adopt a different approach to project management practices.


INTRODUCTION TO CODELCO-CHILE

Codelco-Chile, together with BHP-Billiton may be considered as the “swing” producers of copper metal. Codelco reported in 2004 an annual output of 1.8 million tonnes of fine copper, or about 20% of global output, (together with 33,000 tonnes of fine molybdenum). Cash costs for the production of copper were reported as 32 c/lb of fine copper, nett of depreciation and Head Office spending, some 11 c/lb less than the previous year. However, this financial result was influenced by the increased selling price of molybdenum, the cash receipts of which are traditionally used to discount the production cost of copper. In the year 2004, US$1 billion were received from the sales of molybdenum (www.codelco.cl). Against this, copper sales of US$5.6 billion were achieved, made up of a number of metal products:

- Cathodes: 71%
- Concentrates: 17%
- Blister: 6%
- Fire Refined: 6%

The corporate structure of Codelco, today, is based upon seven Vice Presidencies and five Operations Divisions. The Vice Presidency of Projects was created

![Figure 1. The corporate structure of Codelco-Chile.](Figure 1. The corporate structure of Codelco-Chile.)
Figure 2. Division El Teniente and Andes mountain range, looking east towards Argentina.

Figure 3. General configuration of Division El Teniente mine.

<table>
<thead>
<tr>
<th>Area/Process</th>
<th>Capacity 1999</th>
<th>Increased Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine – minerals</td>
<td>98,000 tpd</td>
<td>126 to 130,000 tpd</td>
</tr>
<tr>
<td>Concentrator – concentrates</td>
<td>1,150,000 tpa</td>
<td>1,500,000 tpa</td>
</tr>
<tr>
<td>Smelter – cathodes</td>
<td>380,000 tpa</td>
<td>495,652 tpa</td>
</tr>
<tr>
<td>Leaching - cathodes</td>
<td>3,500 tpa</td>
<td>25,000 tpa</td>
</tr>
<tr>
<td>Power Supply</td>
<td>161 MW</td>
<td>257 MW</td>
</tr>
<tr>
<td>Industrial Water</td>
<td>1,400 l/sec</td>
<td>1,320 l/sec</td>
</tr>
<tr>
<td>SO₂ Capture</td>
<td>73%</td>
<td>92%</td>
</tr>
</tbody>
</table>

tpd = tonnes per day, tpa = tonnes per annum

Table 1. Development Project Goals.
and subsequently included within the corporate structure, following the Teniente expansion project difficulties (Figure 1).

Division El Teniente is the second largest producer of copper within Codelco, and is the largest underground producer, world-wide. The corporate production picture today, is set to change considerably over the coming years as the Chuquicamata open pit runs down and is closed. Over the same period, Division El Salvador will close and the Andina Division will develop a substantial open pit expansion project, which should more than make-up for any potential reduction in production from the Chuquicamata open pit. It is more than likely that Teniente will be called upon to increase output further.

**TENIENTE DIVISION**

Teniente Division is located within the Andes mountain range, about two hours by road south of Santiago, Chile’s capital city (Figure 2). The Teniente mine, is configured to operate as several underground mines, of varying sizes and outputs (Figure 3). All the mines are caving mines, although a standard layout and methodology, which is capable of dealing with all the problems of the underground mine, has yet to be developed and implemented. The management and workforce have attempted numerous variations over the years, indeed the variety of layouts and mining sequences utilized in recent years is a tribute to their character and strength of purpose. The most significant difficulties are damaging seismic events and collapses of the production level. The financial performance of the mine is greatly aided by the existence of approximately 1 billion tonnes of material, with a copper grade of about 1%, overlying the productive sectors. The material comprises mineral resources not removed during the more than 100 years life of Teniente mining operations. A similar tonnage has been extracted during the life of the mine. Teniente is quite simply an incredible entity.

Against this background, during the close of the last century, corporate management demanded increased output from all the operating divisions. Accordingly, a substantial development project, Proyecto Desarrollo Teniente (PDT), was set in motion (Table 1). The development project was planned to reach the maximum output in about 2010 and to sustain this tonnage for a period of approximately 7 years (Figure 4). In reality, once achieved, the maximum rate of production would be sustained, given the size of the Teniente deposit, (currently the inferred mineral resource comprises 1.5 billion tonnes). The PDT economics were run on the production profile indicated above.

**PIPA NORTE**

The increased production from the Teniente mine was planned to originate from a number of mining sectors, both existing and planned (projects). Pipa Norte was one of the mining projects with a planned maximum rate of production of 10,000 tpd to be extracted from a reserve of 27 million tonnes at a grade of 1.0% Cu with a production level footprint of 57,600m² (Figure 5). The project incorporated a number of technologies new to the Teniente Division (Figure 6). The most significant of these is the semi-automatic LHD Automine™ system manufactured by Sandvik (Figure 7).

Since project start-up in July 2003 until January 2006, approximately 8 million tonnes have been removed, at a lower daily rate of production than planned, and at higher capital and operating costs than expected. Based upon the use of a three 13 yd³ LHD machine fleet, the system as engineered, was expected to produce 10,000 tpd. The system utilizes an operator located on surface supervising the operation of the LHDs – using remote control to lash rock from drawpoints and subsequently releasing the LHD under automatic control for the hauling and dumping activities. For various reasons, such as the inadequate performance of the initial communication system installed and failure consistently to achieve the projected machine availabilities, the Pipa Norte mining sector had difficulty achieving 10,000 tpd.

With the replacement of the communication system and increasing the machine fleet to four LHDs the sector is expected to produce on a consistent basis, and

![Figure 4. Profile of increased minerals production. Tonnes per day (tpd) against time.](image-url)
Figure 5. Location of Pipa Norte at the production level elevation (2191m. above mean sea level).

Figure 6. General arrangement of the materials handling system at Pipa Norte.
Mineral project management

It is hoped that the project will produce a rate of production of 10,000 tpd. Plans are currently in hand to position Pipa Norte to become one of the lowest cost operations of El Teniente, based upon a production extracted entirely by Automine™.

**Corporate Approach**

The corporate approach to the development and approval of capital projects, known as the Capital Investment System, is based upon the protocols developed by Enthalpy, an Australian company. The corporate owner of the Capital Investment System, is the Vice Presidency, Human Development & Finance. The system defines the structure and requirements of the Corporate Approval Protocols. Within this broad framework the requirements for feasibility studies are defined, indicating the lowest acceptable level of content, quality and accuracy.

However, the Vice Presidency Projects is charged with the management of capital projects and has developed a set of protocols to undertake the management, as opposed to the estimation of project net present value and the associated approval of the capital funds thought to be required. Such a corporate approach is in line with global practice of major corporations who apply matrix management systems to check and counter check project development at regular intervals along the development trail. The system of the Vice Presidency Projects is founded upon the recommendations made by IPA, arising from the audit of the Teniente PDT projects. Further, it is aligned to Codelco reality to develop brown field projects, such as large scale open pits, large scale underground mines and replacement of large scale infrastructure. The system of the Vice Presidency Projects in the process of development encompasses a number of components, the majority of which coincide with the Capital Investment System, and these are outlined below, following a broad description of what Project Management can achieve.

**Project Management**

In many ways, project management is a job rather like that of a night-watchman, who only gets noticed when something goes wrong, such as a fire or robbery. On the other hand, if things go well senior management will be heard to ask: “Why on earth did we employ a project manager?” Well a good Project Management System, properly applied, will ensure that:

- a project is well planned;
- the budget is properly estimated utilizing activity based costing; and finally
- all the activities and tasks are well managed and implemented according to plan.

In defence of project teams which have to operate in natural resources capital projects invariably tackle new ground, problems are thus inevitable, unpractised and unrehearsed; and it is therefore necessary to manage change, working in unpredictable conditions. However, a well-engineered project which has undergone a thorough ‘front end loading study’ and gate approvals phase, will be better placed to suffer the rigours of unpredictable conditions and events (Figure 8).

Well publicised project difficulties include the construction of the Scottish Parliament in which capital costs spiralled out of control from an expected £50 million to more than £430 million, and a new Terminal for the Charles de Gaulle airport, part of which collapsed resulting in a number of deaths. The work of a project manager is mainly focussed upon project planning, and subsequently the management of change. Project planning involves:

- 50% thinking ahead (with team members and corporate management);
- 25% communicating the plan
- 25% yardstick, or measurement of work completed and associated costs.
PROJECT MANAGEMENT SYSTEM ACTIVITIES AND COMPONENTS

The major component parts of a suitable system for the management of a typical mining concentrates production capital facility, should include:

1. Capital projects best practices – as recommended by IPA – which emphasizes the implementation of:
   - FEL planning phases
   - gates
   - value improving practices
   - scenario planning

2. PMI book of knowledge

3. Project engineering tools and techniques
   - Geology – (Mineral resources estimation)
   - Mining – (Geotechnical assessment)
   - Metallurgy – (Concentration and leaching)
   - Plant and infrastructure
   - Environment

4. AACEI cost estimation recommended practices
   - Value engineering

5. Economic model

CAPITAL PROJECTS BEST PRACTICE

Best practice demands that the percentage of engineering completion increases with each front end loading phase increases, as should the accuracy of estimates (Figure 8).

The essential elements of each front end loading phase include:

1. Business planning phase
   - Generate alternatives – scenario planning
   - Complete business/economic/financial analysis

2. Facility planning phase
   - Evaluate technology and site options
   - Select single alternative
   - Risk analysis and Management – most appropriate phase

3. Project planning phase
   - Finalize project scope & design basis package
   - Develop detailed project execution plan and control-grade cost estimate

4. Gate control

5. Value improving practices (VIPs)

Figure 8. Project ‘front end loading’ activities.

Figure 9. Scenario planning (Illbury and Sunter, 2001).
The generation of alternatives required for the completion of the business-planning phase is possibly the most important project activity that will establish project robustness. This is essential for the inevitable problems ahead. Scenario planning is a well known, (and highly recommended), method for the interrogation of the breadth and depth of possible scenarios for the development of project alternatives (Figure 9). Following the demonstration of favourable economics of a number of alternatives in the Business planning phase, the facility planning phase has the main objective of identifying the most promising alternative which is refined in the project planning phase, given the approval to do so.

A system of gate control is undertaken by most major corporations to manage the progress of project engineering and evaluation (Figure 10). An appropriate and complete set of deliverables are required for the gate approval process to begin, as opposed to meeting projectschedule constraints.

Application of value improving practices during the latter two phases of project front end loading is an essential aid to improving the value of projects:

1. Facility planning phase – (40% to 60%)
   - Formal technology selection
   - Process simplification
   - Classes of plant quality
   - Waste minimization
   - Initial constructability reviews
   - Process reliability modelling
   - Customized standards and specifications
   - Predictive maintenance
   - Design-to-capacity

2. Project planning phase
   - Energy optimization
   - Continue constructability reviews
   - Value engineering review
   - 3-D CAD

Value engineering reviews, essentially a formal process of replacing high cost activities and components, with lower cost activities and components, can usefully follow the protocols put forward by Lawrence D Miles, a manager of the General Electric Corporation. Equally, the utilization of 3-D CAD is imperative in the quest to improve project value, although it is surprising to find that in the 21st century it is not universally applied.

**PMI Book of Knowledge**

The mechanics of running projects is most ably demonstrated in the book developed by the Project Management Institute (2004) (PMI) (Figures 11, 12 and 13). The importance of project planning is evident and should be structured as inter-related core and facilitating processes, Figure 13. Equally, the essential nature of project scope management to any project, cannot be emphasized enough, and is an area where many projects can go swiftly off the rails. Underlying this statement is the “Time-Quality-Cost” triangle which simply means that a change in any one of the three components directly impacts upon the other components. Thus, an increase in quality will demand more cost and invariably more time to achieve. Similarly, changes in scope inexorably lead to project delays and cost increases. Scope changes therefore need to be firmly managed, bearing in mind that many contractors depend upon scope/contract variations to increase the meagre profit margin upon which the project bidding process was won.

The relationship and sequence between the core planning processes is important to understand and follow, especially with respect to the cost estimating and risk management planning activities (Figure 13). Risk project management encompasses an assessment of the risks inherent in the project scope and how these can affect the project schedule and budget, and consequently project value. Risk management planning is especially relevant to undertake at the conceptual engineering/
<table>
<thead>
<tr>
<th>Knowledge Area</th>
<th>Initiating</th>
<th>Planning</th>
<th>Executing</th>
<th>Controlling</th>
<th>Closing</th>
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</thead>
<tbody>
<tr>
<td>4. Project Integration Management</td>
<td>4.1 Plan Establishment</td>
<td>4.2 Plan Development</td>
<td>4.3 Integrated Change Control</td>
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<td>5. Project Scope Management</td>
<td>5.1 Initiation</td>
<td>5.2 Scope Planning</td>
<td>5.3 Scope Definition</td>
<td>5.4 Scope Verification Control</td>
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<td>6. Project Time Management</td>
<td>6.1 Activity Definition</td>
<td>6.2 Activity Sequencing</td>
<td>6.3 Activity Duration Estimating</td>
<td>6.4 Schedule Development</td>
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<td>7. Project Cost Management</td>
<td>7.1 Resources Planning</td>
<td>7.2 Cost Estimating</td>
<td>7.3 Cost Budgeting</td>
<td>7.4 Cost Control</td>
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<td>8. Project Quality Management</td>
<td>8.1 Quality Planning Assurance</td>
<td>8.2 Quality Assurance</td>
<td>8.3 Quality Control</td>
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<td>9. Project Human Resource Management</td>
<td>9.1 Organizational Development</td>
<td>9.2 Staff Acquisition</td>
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<td>10. Project Communications Management</td>
<td>10.1 Communications Planning Distribution</td>
<td>10.2 Information Planning</td>
<td>10.3 Performance Reporting</td>
<td>10.4 Admin. Closure</td>
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<td>12. Project Procurement Management</td>
<td>12.1 Procurement Planning</td>
<td>12.2 Solicitation Planning</td>
<td>12.3 Solicitation Selection</td>
<td>12.4 Source Selection</td>
<td>12.5 Contract Administration</td>
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<td>12.6 Contract Closeout</td>
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**Figure 11.** Capital project knowledge areas and process groups (Project Management Institute, 2004).

**Figure 12.** Project scope management (Project Management Institute, 2004).
pre-feasibility study/facility planning phase in order that the relative merits and potential risks of the various alternatives can be considered on equal footing and be taken into account in the selection process. The PMI Book of Knowledge (2004) offers a particularly robust treatment of risk assessment, and is well worthwhile following, covering:

1. Risks and triggers

2. Qualitative risk analysis
   - Overall risk ranking for the project
   - List of prioritized risks
   - List of risks for additional analysis and management
   - Trends in qualitative risk analysis results

3. Quantitative risk analysis
   - Ranked list of quantified risk

4. Monte Carlo simulation / decision analysis
   - Probabilistic analysis of the project
   - Probability of achieving the cost and time objectives
   - Trends in quantitative risk analysis results

5. Risk response plan development
Tools and Techniques for Project Engineering

Codelco has made considerable efforts to develop and establish project-engineering protocols (Tulcanaza and Ferguson, 2002) (Figure 14). The engineering objectives in geoscientific data collection, development of information and generation of knowledge modelling is clearly understood. Accordingly, the influence of specific parameters upon project value can be readily determined and their importance to the assessment of project risks and subsequent management.

Typical Cost Estimating Process

A significant weakness in the estimation of project costs, and in particular operating costs has been evident in recent project engineering, notwithstanding the availability of suitable protocols for the estimation of capital costs (Figure 15). A major failure has been ignoring actual operating costs and a consequential analysis of such costs upon project value, and more importantly, how they could be lowered. In large-scale mining projects, with significant lives, operating costs have a greater impact upon net present value than capital costs. It is therefore essential that operating costs are carefully developed and that the assumptions are interrogated in a rigorous manner. Unlike theatrical plays where everything turns out well on the opening night despite terrible rehearsals, operating costs have a tendency not to meet expectations, which together with under-performance of project productive capacity, can completely negate expected project value.

Economic Model

The need for a well-established and well-utilized economic model, incorporating the corporation’s economic parameters is obvious. Such a model should be used throughout the project development, construction and operational implementation phases to reconcile expectations with reality, and to subsequently feedback into future projects.
CURRENT AND PAST PROJECTS

The experiences of Codelco with respect to the Teniente PDT projects is probably a blessing in disguise given the need to replace and increase current productive capacity. Major corporate projects presently under development include:

1. Replacement of the Chuquicamata open pit with an underground mine, (+60,000 tpd).
2. Deepening of the Teniente mine below the current main infrastructure, (150,000 tpd).
3. Replacement of the Andina underground operation with a substantial open pit mine, (+/- 200,000 tpd).

Whilst the projects are brown field, the size of the operations envisaged in each Division, must surely be a daunting prospect for all concerned. The need therefore for sound protocols and to follow them rigidly could not be greater. The coming years will not be for the faint hearted.

A question worth asking is whether the Pipa Norte project could have benefited from the application of the project management protocols under development and implementation. It is quite possible that semi-automation of the loading operation would not have been adopted. It is the first of its kind in the mining world, and today the corporation requires that projects are based upon conventional technology. Consequently, the loading operation would have been based upon smaller, manually operated LHDs leading to a reduced drawpoint spacing and smaller production level tunnels. A conventional production level layout would have incorporated ore passes within the level to reduce the length of LHD hauls, so impacting upon the rock handling and sizing facilities. An increased ore storage would have resulted compared to the capacity available today. Optimistic cost estimates would hopefully be replaced by more pragmatic expectations.

As a general comment, expectations of lower costs for automatic operations should be challenged, largely on the basis that automation requires a significant component of automation communication maintenance. In both the Pipa Norte and the main mine haulage automation projects, such automation maintenance costs were substantially underestimated. Automation also influences the type of equipment repairs required.

CONCLUSIONS

Key components and conclusions drawn in this paper include:

1. Project management is the management of change and working in unpredictable conditions. Uncertainty is therefore inherent in capital projects, and demands rigorous risk assessment and management.
2. Global practice of major corporations is to apply matrix management systems to check and counter check project development at regular intervals along the development trail.
3. It is essential to perform the front end loading processes to a high standard to ensure project success.
4. The generation of alternatives required for the completion of the business planning phase is possibly the most important project activity that will establish project robustness. Scenario planning is a well known (and highly recommended) method for the interrogation of the breadth and depth of possible scenarios for the development of project alternatives.

5. The utilization of 3-D CAD is imperative in the quest to improve project value, although it is surprising to find that in the 21st century it is not universally applied.

6. Project scope management is an essential activity for the control of costs and project schedules.

7. The problems experienced by the Teniente projects provided a timely opportunity to improve project management standards for the future megaprojects currently under consideration.

8. Close attention needs to be paid to the estimation of operating costs of large-scale mining projects.

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REFERENCES


