Quantifying, assessing and managing Uncertainty in Mine Planning

By Dr. Luis Martinez Tipe
Initial statement

No one can predict the future with 100% certainty!

“I was trying to predict future market trends and the computer blew up!”
There is still some reliance from decision makers in working with a given expected mine value number. Why?
Lack of knowledge about the differences between making decisions based on expectations

**Mine evaluation process**

**Uncertain Input Variables**  \( E\{x\} \)  \( F() \)  \( F(E\{x\}) \)

**Non-linear Process**

**Final Results**

**Traditional thinking**

\[ x_1, x_2, x_3, \ldots, x_n \]

**New thinking**

\[ F(x_1), F(x_2), F(x_3), \ldots, F(x_n) \]

\[ E\{F(x)\} \]

\[ F(E\{x\}) \neq E\{F(x)\} \]

**Jensen’s inequality**
“the flaw of averages in mine project evaluation”
Mining imperative calls for new alternatives and tools to analyse and evaluate a mine operation in the face of uncertainty.

Mining companies can’t just dabble at the edges by keep using traditional processes and techniques which do not consider uncertainty.
Quantifying the effect of uncertainty
Monte Carlo Simulation
Assessing the effect of uncertainty in mine plan and design
Assessing and quantifying the effect of uncertainty in mine planning
Uncertainty in orebody modelling

Drill-holes data
Kriging interpolation

Kriging model
Mine plan

Owners & Stake holders

DCF Analysis

Average annual Copper grades

Project NPV

+10%

-10%
Quantifying the effect of the uncertainty in orebody modelling

Conditional simulated block models

 Owners & Stake holders

Q-DCF Analysis

Project NPV

Base case Cu grade
Quantifying the effect of the uncertainty in orebody modelling

Owners & Stake holders

Q-DCF Analysis

Project NPV
Current industry practice for price forecasting

Source: Metal prices and the differences between forward and consensus pricing Project Evaluation 2016 conference (Martinez and McKibben)
Quantifying the effect of the uncertainty in metal prices

Historical price data → Forecasted price data

Owners & Stake holders

Q-DCF Analysis → Cash Flow MC Simulation

Project NPV
Production cost uncertainty

- What is it going to cost?
Going beyond risk analysis

So, What can we do to protect from uncertainty? How can we minimise risk and maximise opportunities…
Managing uncertainty in mine planning

• Once we have a perception of both future project risk and potential, the next step is to implement different strategies or options to minimise/maximise future project risk/potential while maximising current project value.

• Experience plays an important role in managing uncertainty in mine planning, but ...

Experience based on perception not always provides the best Solution
Identifying best strategies/options in mine planning

Best strategy based on perception (Greedy optimisation technique)

\[
\text{NPV}_{\text{Greedy}} = \frac{\$4}{(1+10\%)^1} + \frac{\$4}{(1+10\%)^2} + \frac{\$3}{(1+10\%)^3} + \frac{\$4}{(1+10\%)^4} = \$11.9
\]
Identifying best strategies/options in mine planning

Best strategy based on optimisation (DP optimisation technique)

\[
NPV_{DP} = \frac{\$2}{(1+10\%)^1} + \frac{\$7}{(1+10\%)^2} + \frac{\$4}{(1+10\%)^3} + \frac{\$4}{(1+10\%)^4} = \$13.3
\]
Real options as tool to manage uncertainty in decision making

Bellman’s equation

\[ V_t^i(Q_t, S_t) = \max_{q_t} \left[ E \left( CF_t^Q(q_t, g_t^i) | S_t \right) + \max \left( \Phi_t, \Pi_t \right) \right]; \]

where:

- if \( V_t^i(Q_t = 0, S_t) \), then \( CF_t^Q = 0 \); and \( \Phi_t = 0 \);
Real options as tool to manage uncertainty in decision making

**Figure 1** Summary of the process of applying real options when valuing a mine project.
Valuing a silver mine project in the face of price uncertainty with options to close and defer investment

The technical/operational/economic characteristics of the mining project are:

• The project requires an initial investment of USD 48 million (CAPEX);
• Production cost assumed to be US$7.5 per ounce of silver produced;
• There are not variable extraction costs;
• Life of mine is estimated to be 5 years;
• The annual silver production (million Oz) for the next 5 years are estimated to be 0.051, 0.842, 2001, 3337, and 3416, respectively.
• Annual risk adjusted discount rate is 10%;
• Management has the option to invest now or defer project investment and development for 1 year at a cost of $1.0 million (paid at the end).
• Salvage value = Closure cost + selling of all assets, is expected to be breakeven (i.e., US$0).
• For practical and comparison purposes, all cash flow calculations will be done using the annual RADR of 10%, so all results can be compared against the benchmark, i.e., the traditional discounted cash flow (however for the sake of completeness the annual risk free rate is 4%);
Valuing a silver mine project in the face of price uncertainty with options to close and defer investment

Key management questions to be answered are:

• Given the size of investment outlay, the long term silver price scenarios, and the dynamics (volatility) of silver price over time, **is this a good investment?**

• Should management invest now, or should it wait and see how silver prices will develop next year?

• What is the cut-off investment (CAPEX) that management should consider to decide to either invest today or next year?

• What is the maximum cost management should negotiate to have the option to defer project investment for 1 year?

• How would the project value and decision making vary with different initial silver prices?

• What is the effect of delaying the project investment on project Internal Rate of Return (IRR)?

• In case of low silver prices (pessimistic scenarios) what is the best course of action to take?
Valuing a silver mine project in the face of price uncertainty with options to close and defer investment

PROJECT MAIN SOURCE OF UNCERTAINTY

• Uncertainty over the value of the project is closely related to the dynamics in future silver prices.
• Currently silver is priced at US$16/Oz.
• However, it is forecasted that silver prices will change in the following years with a volatility of 28%, and following an erratic movement over time which is modelled as a Geometric Brownian Motion (GBM).
Silver project valuation – using DCF

<table>
<thead>
<tr>
<th>Summary project DCF Valuation @ 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Year 0</td>
</tr>
<tr>
<td>Silver Price (US$/Oz)</td>
</tr>
<tr>
<td>Production cost (US$/Oz)</td>
</tr>
<tr>
<td>Right to wait 1 year (million US$)</td>
</tr>
<tr>
<td>CAPEX (million US$)</td>
</tr>
<tr>
<td>NPV (million US$)</td>
</tr>
<tr>
<td>IRR</td>
</tr>
</tbody>
</table>

14%
Silver price modelling - GBM

<table>
<thead>
<tr>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
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</thead>
<tbody>
<tr>
<td>$21.1</td>
<td>$27.7</td>
<td>$36.5</td>
<td>$48.1</td>
<td>$63.3</td>
<td>$48.1</td>
<td>$83.4</td>
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<tr>
<td>$16.0</td>
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<td>$12.2</td>
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<td>$7.0</td>
<td>$5.3</td>
<td>$4.0</td>
<td>$3.1</td>
<td>$4.0</td>
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</table>
Dynamic discounted cash flow and NPV

<table>
<thead>
<tr>
<th>Year 0</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prod. Period</td>
<td>2,015</td>
<td>2,016</td>
<td>2,017</td>
<td>2,018</td>
<td>2,019</td>
<td>2,020</td>
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<tr>
<td>56.49</td>
<td>0.43</td>
<td>67.88</td>
<td>0.52</td>
<td>54.76</td>
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<tr>
<td>34.00</td>
<td>0.49</td>
<td>36.55</td>
<td>0.56</td>
<td>11.13</td>
<td>0.54</td>
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<tr>
<td>13.80</td>
<td>0.57</td>
<td>-3.86</td>
<td>0.52</td>
<td>-14.03</td>
<td>0.52</td>
<td>-11.81</td>
</tr>
<tr>
<td>8.49</td>
<td></td>
<td>0.52</td>
<td></td>
<td>0.52</td>
<td></td>
<td>0.52</td>
</tr>
</tbody>
</table>
Dynamic discounted cash flow and
ENPV = NPV + ValOption

ValOption = $9.68 - $8.49 = $1.19
Analysing the option to delay one year project investment

Today

In Year 1

If Silver price goes UP in Year 1

\[ 41.4 = \max(90.44 - 48 - 1, 0) \]

If Silver price goes DOWN in Year 1

\[ 0 = \max(33.90 - 48 - 1, 0) \]
### Analysing the option to delay one year project investment

<table>
<thead>
<tr>
<th>Year</th>
<th>Option Price</th>
<th>Silver Price in Year 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016</td>
<td>16.26</td>
<td>41.44</td>
</tr>
<tr>
<td>2017</td>
<td>8.49</td>
<td></td>
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</tbody>
</table>

**Today:**

- If Silver price goes UP in Year 1, INVEST
- If Silver price goes DOWN in Year 1, NOT INVEST

**ValOption = $16.26 - $8.49 = $7.77**

41.4 = max(90.44 – 48 – 1, 0).

0 = max(33.90 – 48 – 1, 0)
Silver project - real options analysis

PROJECT VALUE - INITIAL CAPEX

PROJECT VALUE - INITIAL PRICE VARIATION

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Silver project - real options analysis
Uncertainty and risk in open pit mine planning and design (ultimate pit and production scheduling final limits)
Questions?
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