Integrating Short- and Long-term Mine Planning through Stochastic Optimization and Future data-Application and Comparisons

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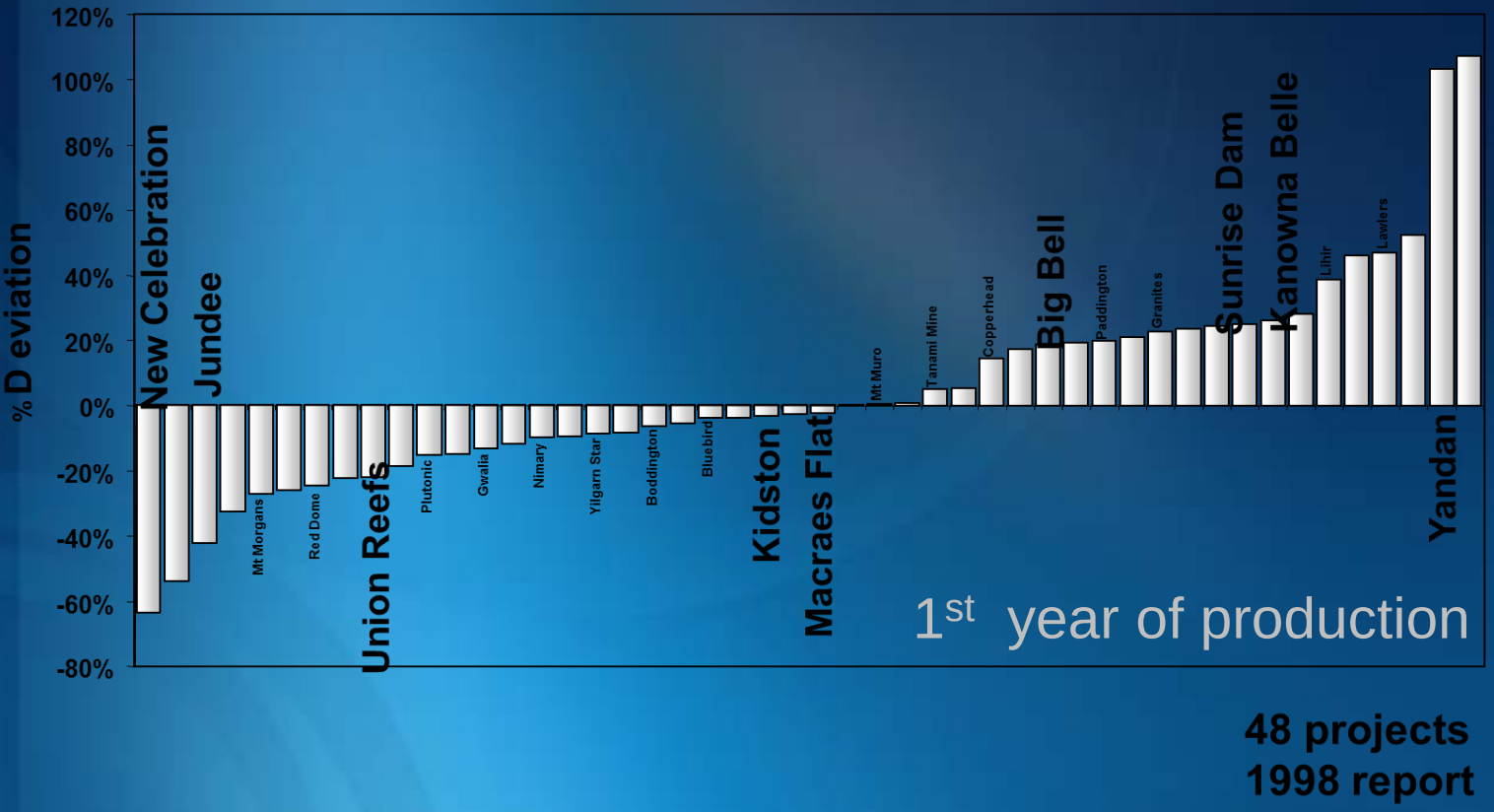
Content

- Introduction
- Quantifying geological uncertainty
- Simulating short- scale orebody variability
- Stochastic production scheduling
- Production scheduling with simulated ‘future’ data
- Application at gold mine
- Comparisons and the value of the approach
- Conclusions

Risk in Mining: Australasian Examples



48 projects
1998 report

About 85% of discrepancies are due to poor understanding/modelling of the orebody being mined

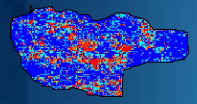
(After Baker and Giacomo, 1998)

Risk in Mining: A World Bank Survey (after Vallee, 2000)

- 60% of mines had an average rate of production LESS THAN 70% of planned rate
- In the first year after start up, 70% of mills or concentrators had an average rate of production LESS THAN 70% of design capacity
- Key contributor to mining risk felt in all downstream phases: ***Geology and reserves***

Conventional vs Stochastic Approaches

Single estimated model



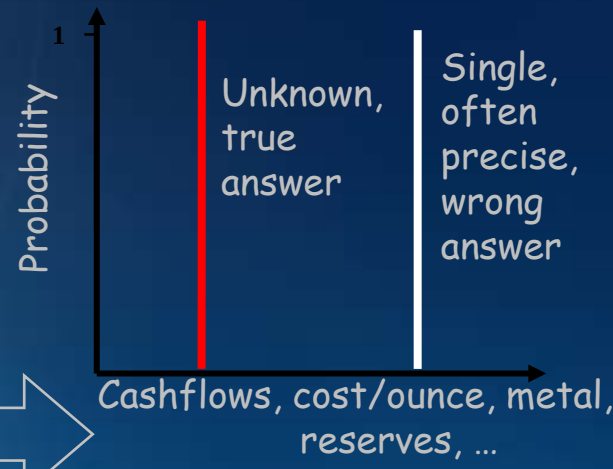
Traditional view

Mining Process or Transfer Function

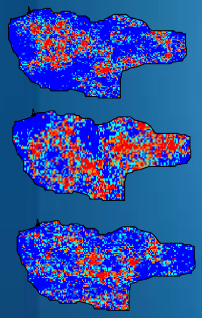
Orebody Model

Mine Design & Production Scheduling

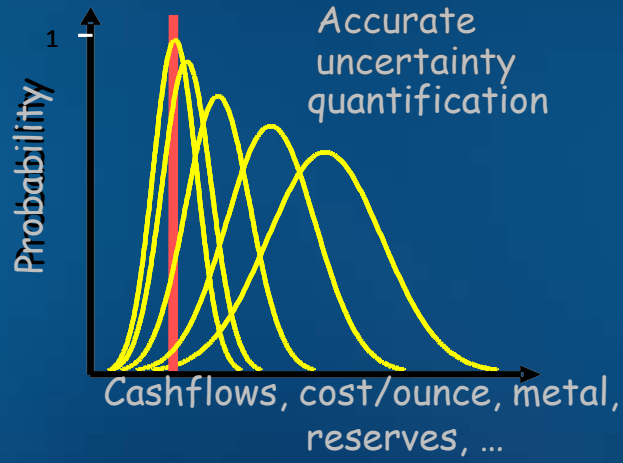
Financial and Production Forecasts



Multiple probable models



Risk oriented view

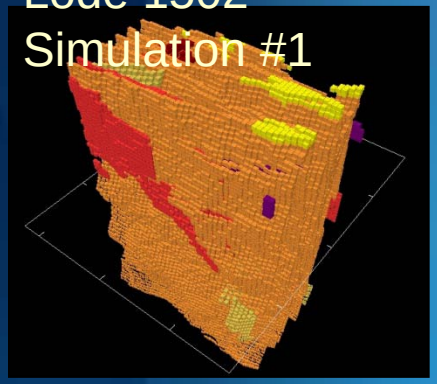


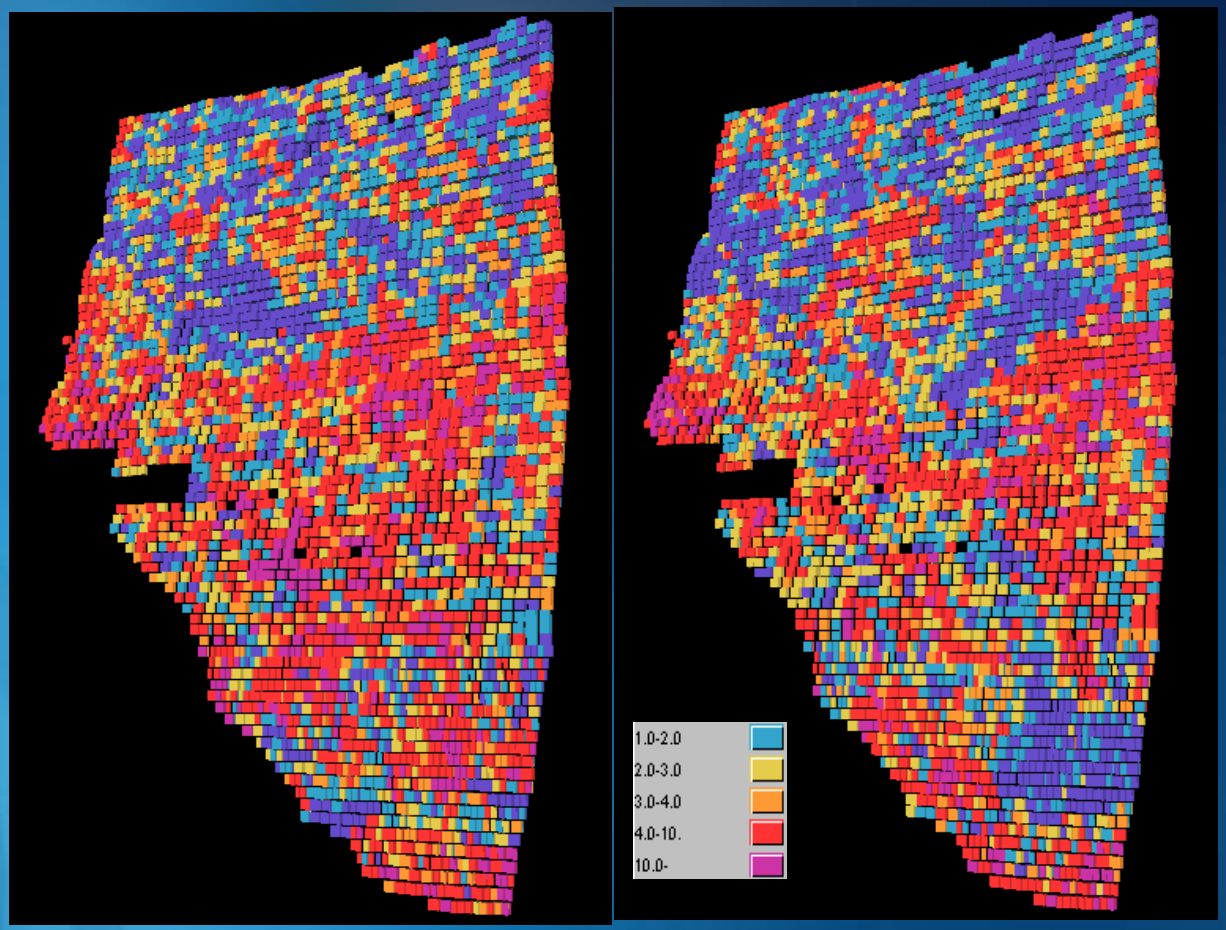
Quantitative Models of Geological Uncertainty:

Monte Carlo or stochastic or geostatistical conditional simulations

Quantification of Uncertainty about a Gold Deposit Monte Carlo Simulations

Lode 1502
Simulation #1





Future Drilling Data

Production sequencing with simulated grade control drilling

Mine Production Scheduling

- Short- and long- term mine production scheduling are based on exploration data
- Exploration data which does not capture the short-scale behavior of the orebody
- Grade control drilling: Available at time of mining not at the time of planning
- Integrate short scale behavior of the orebody at the time of planning with “future” grade control drilling?
- What is the value in doing so?

‘Future’ Grade Control Data

Bench/Section of pit already mined out

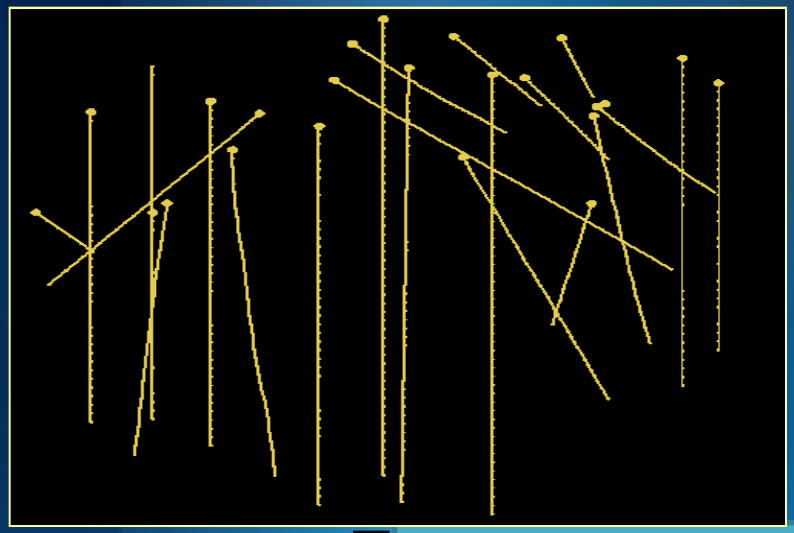
Exploration data
Grade control data

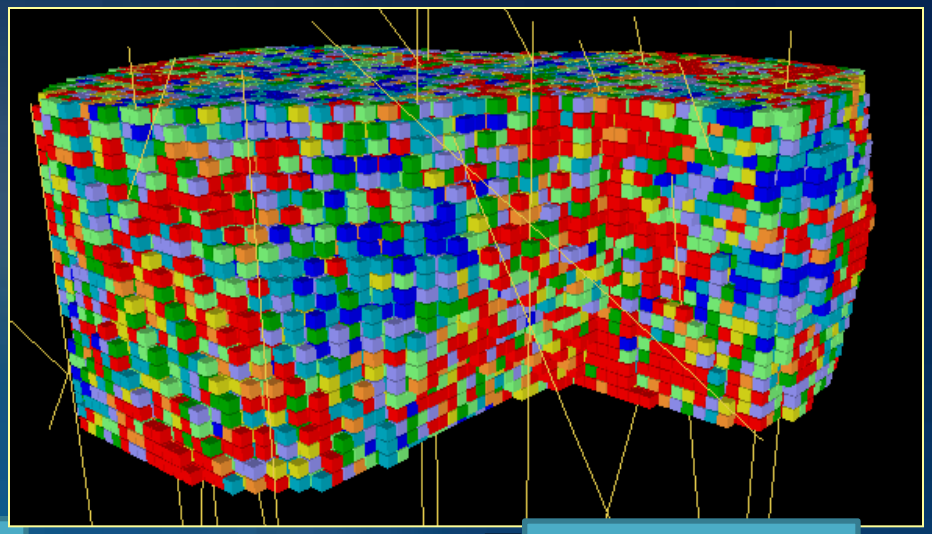
Define relationship

Exploration data
Simulate grade control data

Bench/Section of pit NOT yet mined out

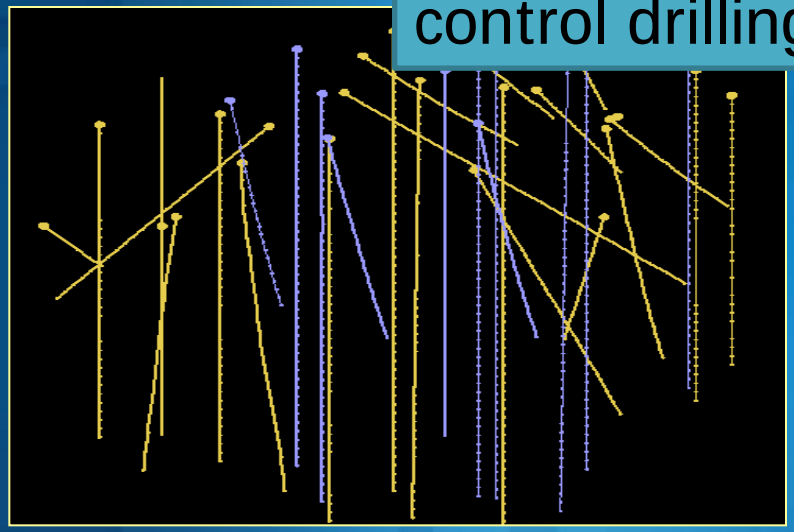
Updating Existing Orebody Models with New Data

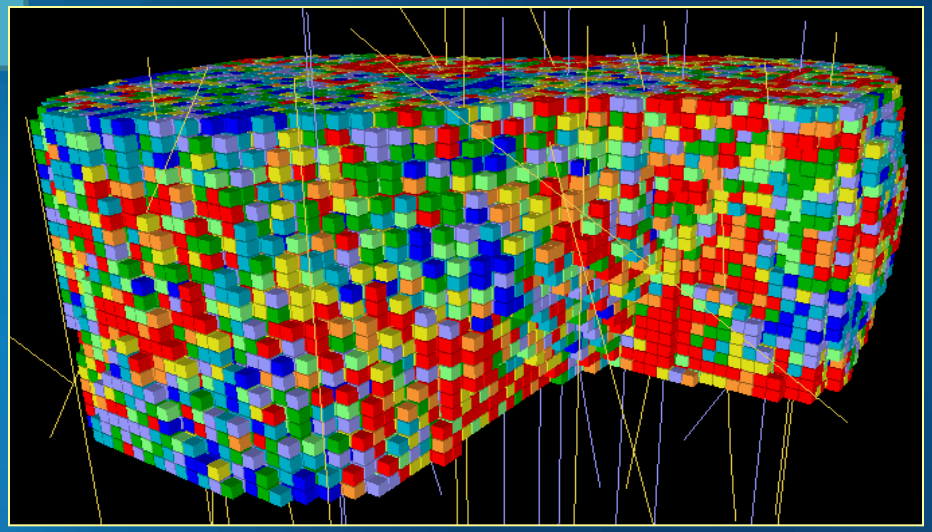




Simulated grade control drilling

Update





Stochastic Optimization & Production Scheduling

Using quantified geological uncertainty

Discounting geological risk while sequencing

A Stochastic Integer Programming Formulation

$$\text{Max} \sum_{t=1}^{P}\sum_{i=1}^{N} E(NPV)_i^t \; X_i^t - \sum_{s=1}^{S}\sum_{t=1}^{P}\sum_{r=1}^{R} ({}^{s}Cu_r^t \; Yu_r^t + {}^{s}Cl_r^t \; Yl_r^t)$$

P= number of periods: 4-monthly periods for 4 years = 12

N= number of blocks: 5,626 blocks of 30 x 30 x 7.5 m

S= number of simulated orebody models: 20 used

R= number of targets: 2 grade and ore production

X_i^t Binary variable

$E(NPV)_i^t$ Expected NPV for block i mined in period t

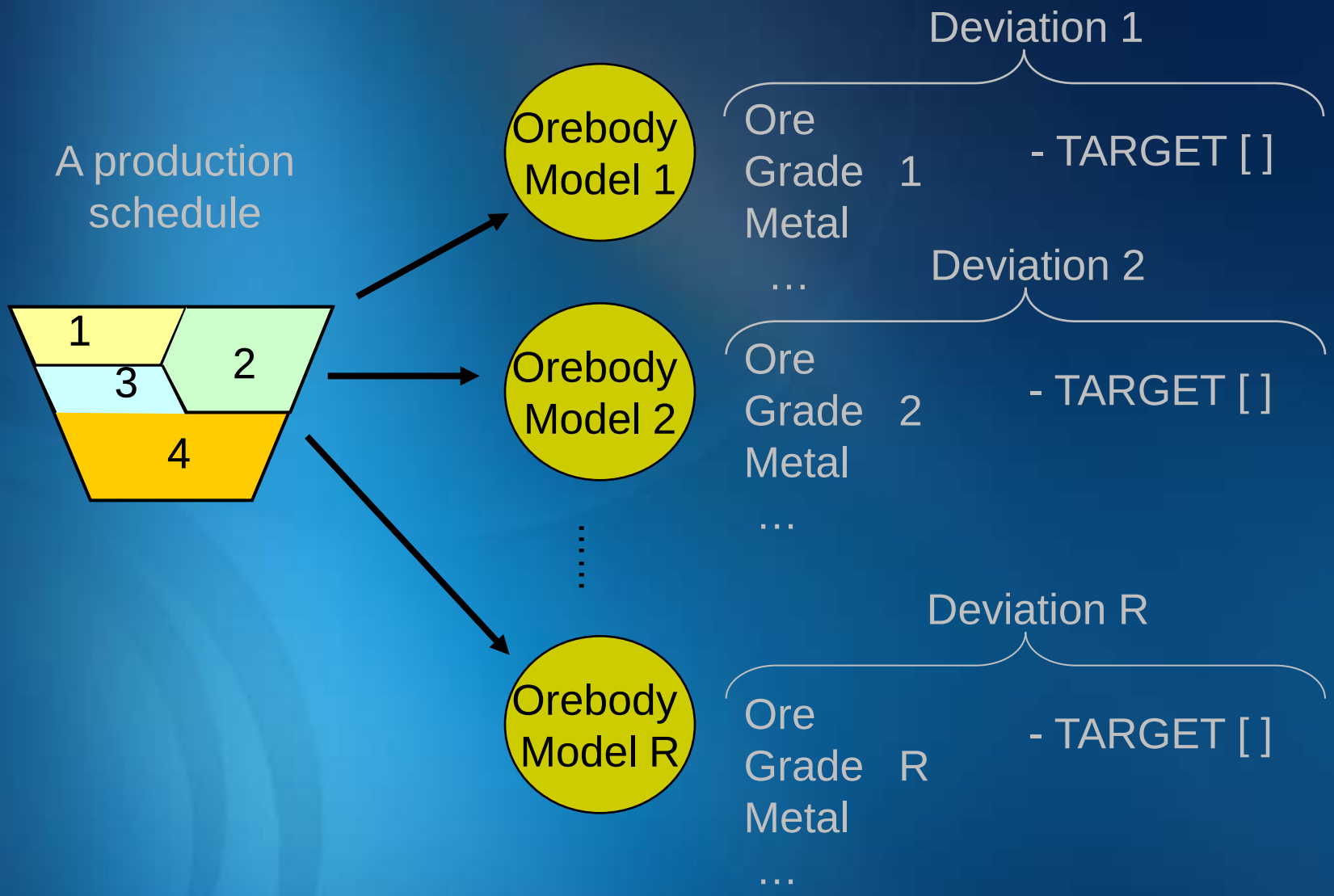
Yu_r^t Excess amount produced compared to the target

${}^{s}Cu_r^t$ Cost to penalize excess production

Yl_r^t Deficient amount produced compared to the target

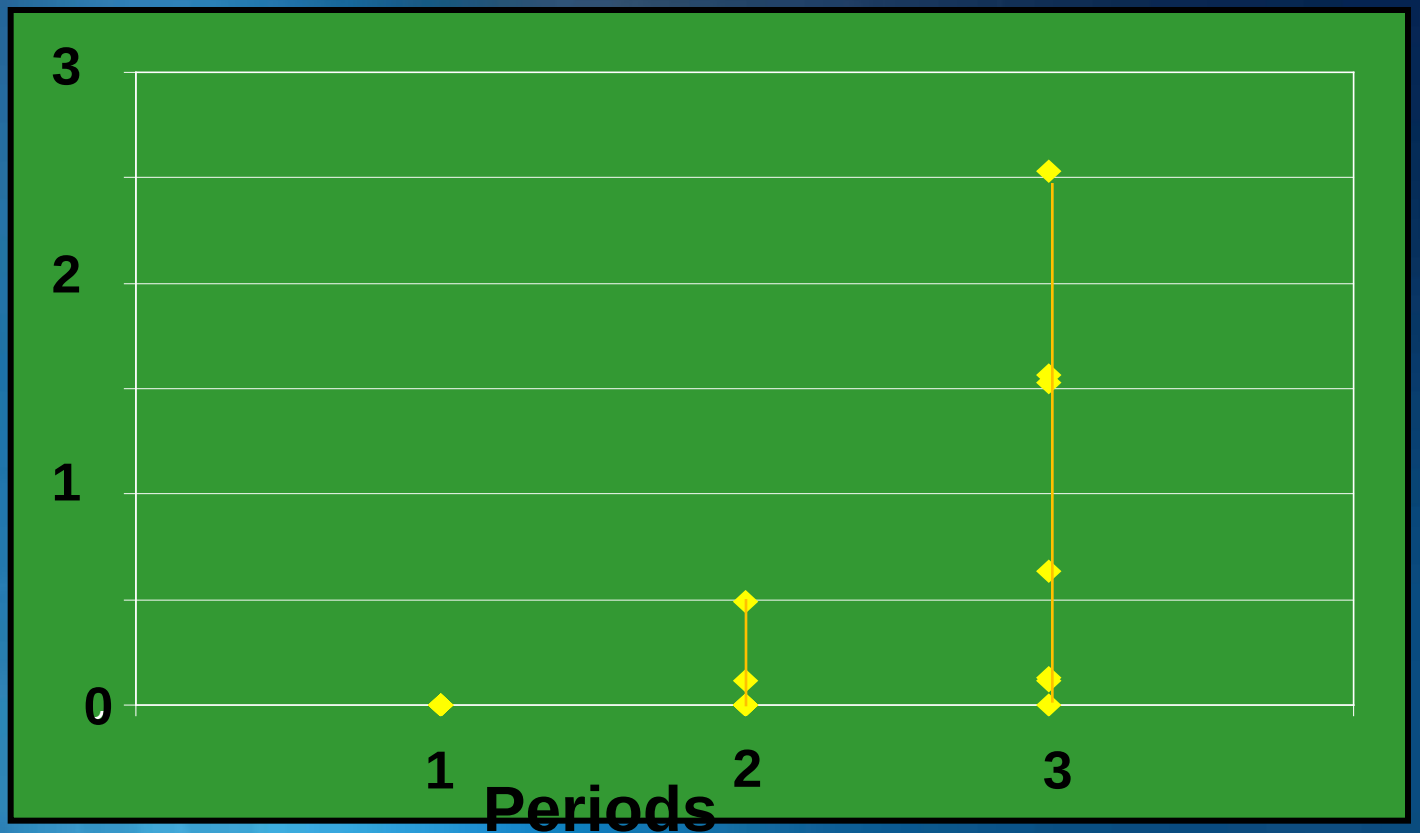
${}^{s}Cl_r^t$ Cost to penalize deficient production

Stochastic Integer Programming - SIP



Managing Risk Between Periods

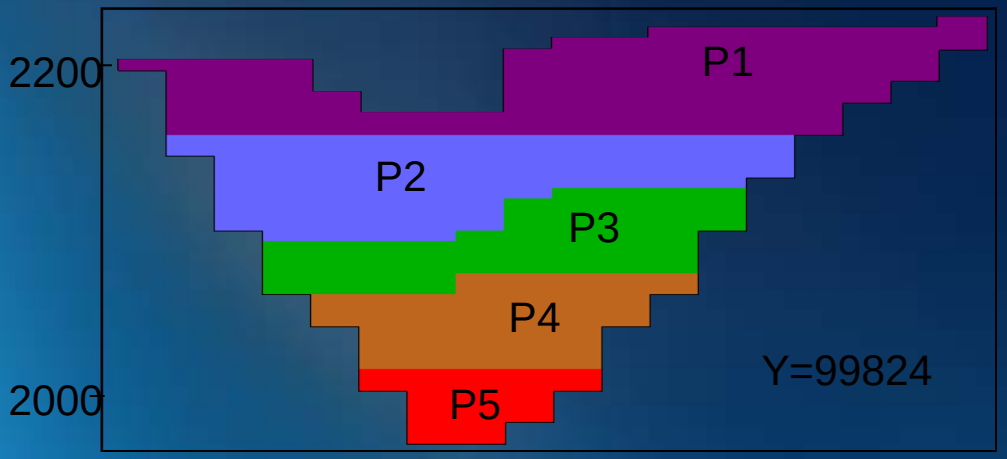
Deviations from production target



$C^t = C^{t-1} * RDF_{t-1}$ $RDF_t = 1/(1+r)^t$

RDF – risk discounting factor r – orebody risk discount rate

Application and Comparisons at a Gold Mine



- Exploration and grade control data
- Variable at short distances: grade control at 5 x 7 m
- Standard resource model (MIK) and “layer cake” schedule
- Reconciliations: Producing more than predicted

Scheduling and Simulated ‘Future’ Data

Existing Stochastic LOM Scheduling Process

Proposed Multistage Approach with Short-scale Information

Simulation of orebody models from exploration data

Stage 1

Simulation of high density ‘future’ grade control information

Stage 2

Updating of the existing orebody models with the future data

Stochastic optimization and generation of production schedules

Stage 3

Stochastic optimization and generation of production schedules

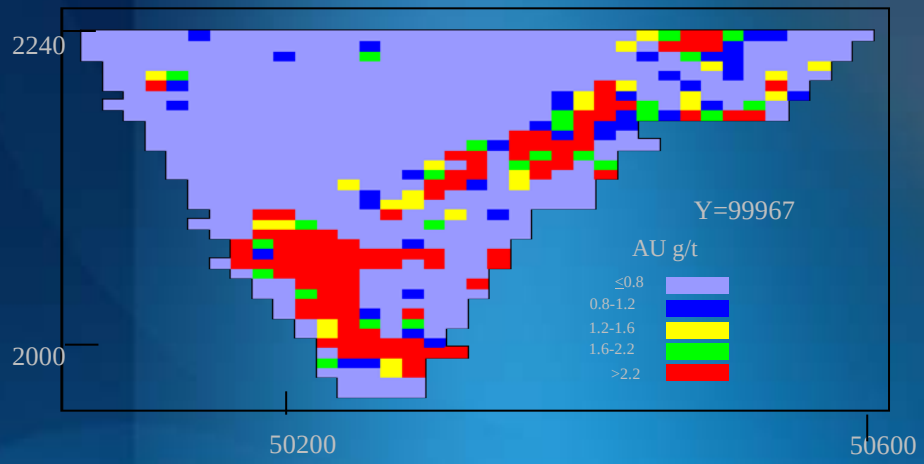
Stage 4

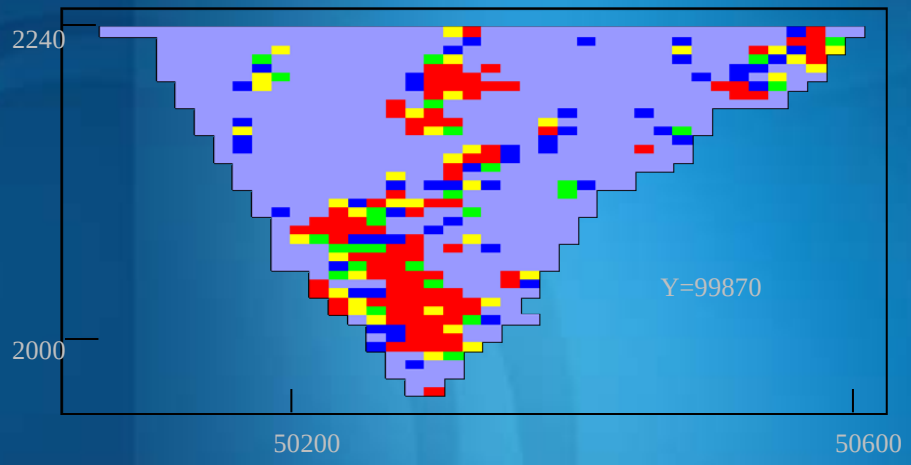
Quantification of risk and analysis of schedule

- Stage 1: ‘Future’ Grade Control Data
- Stage 2: Updating of Existing Simulated Models

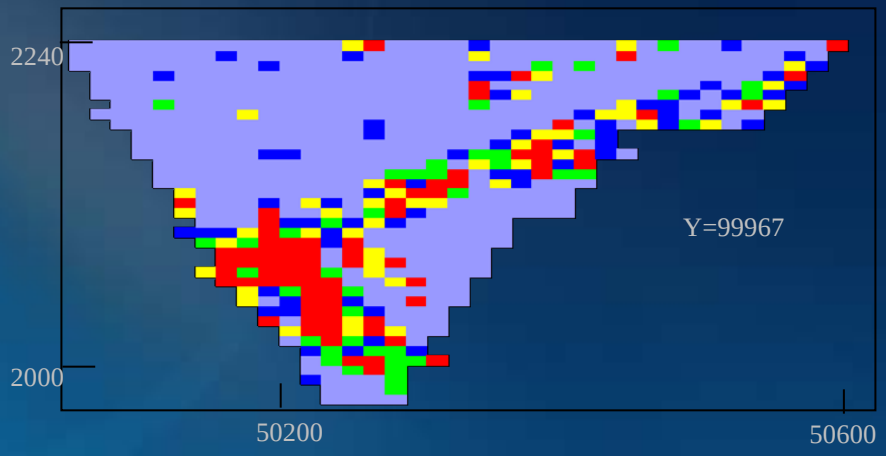
Simulations Without and With Future Data

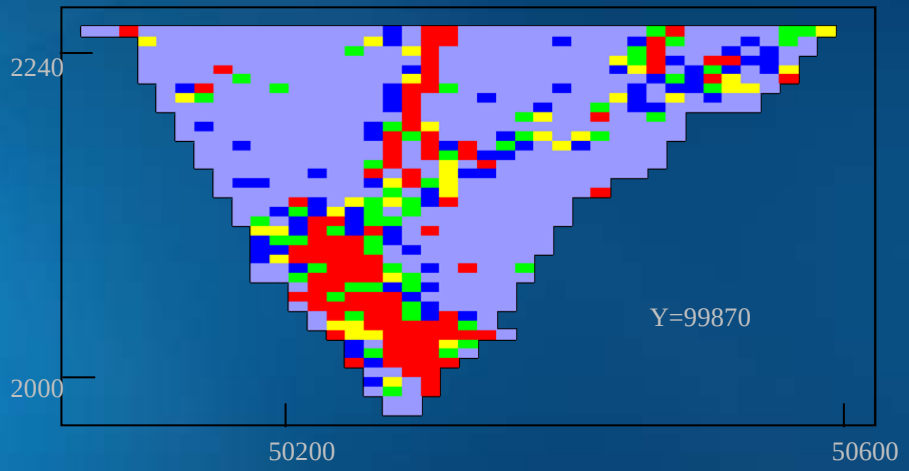
Based on exploration data





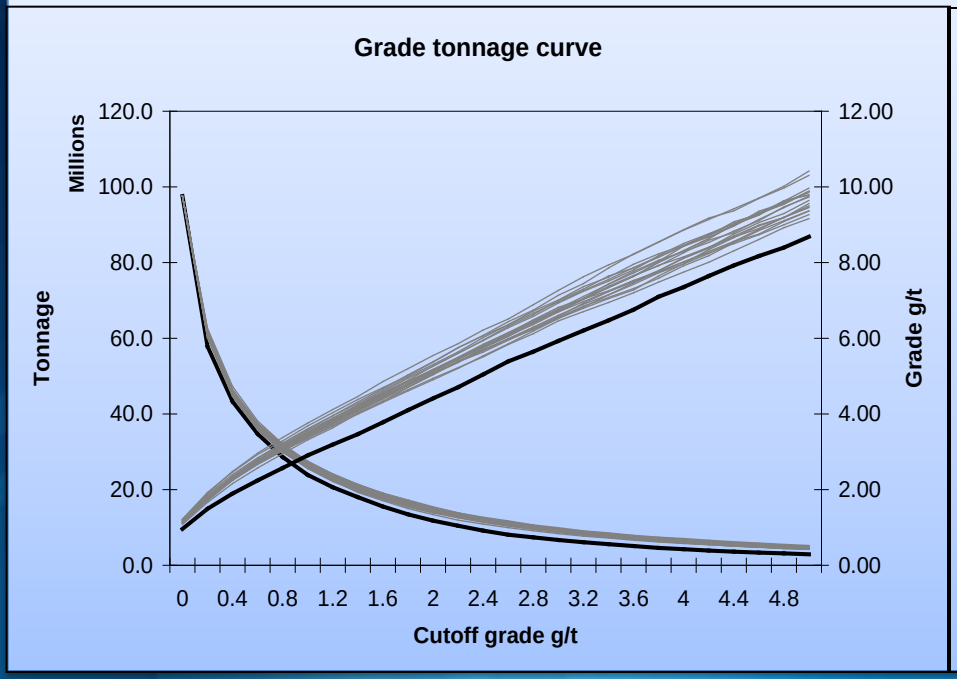
Based on simulated grade control data



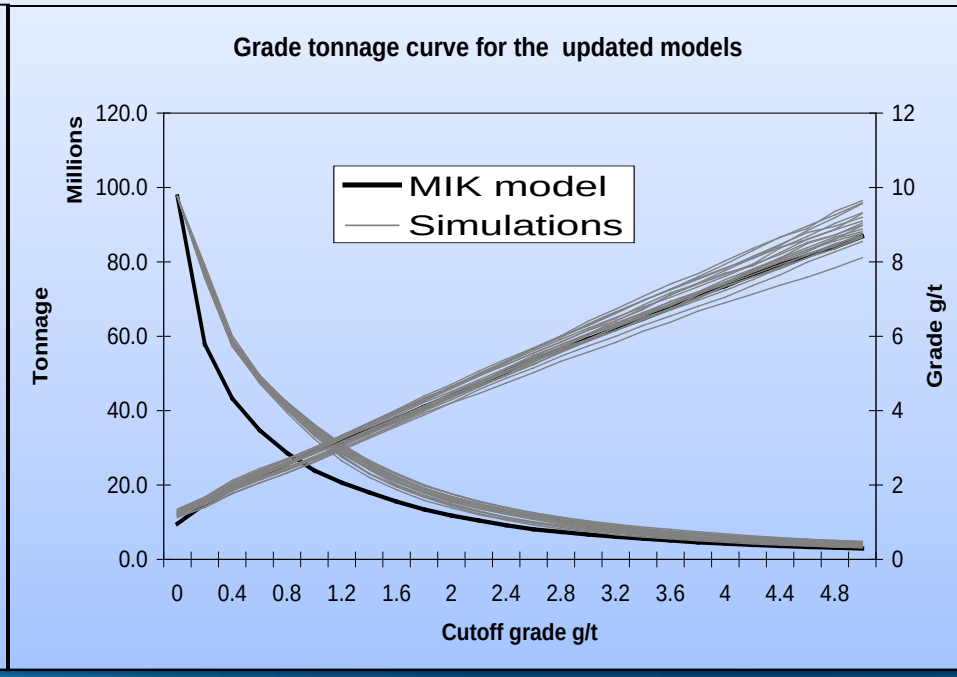


Recoverable Reserves

Based on exploration data



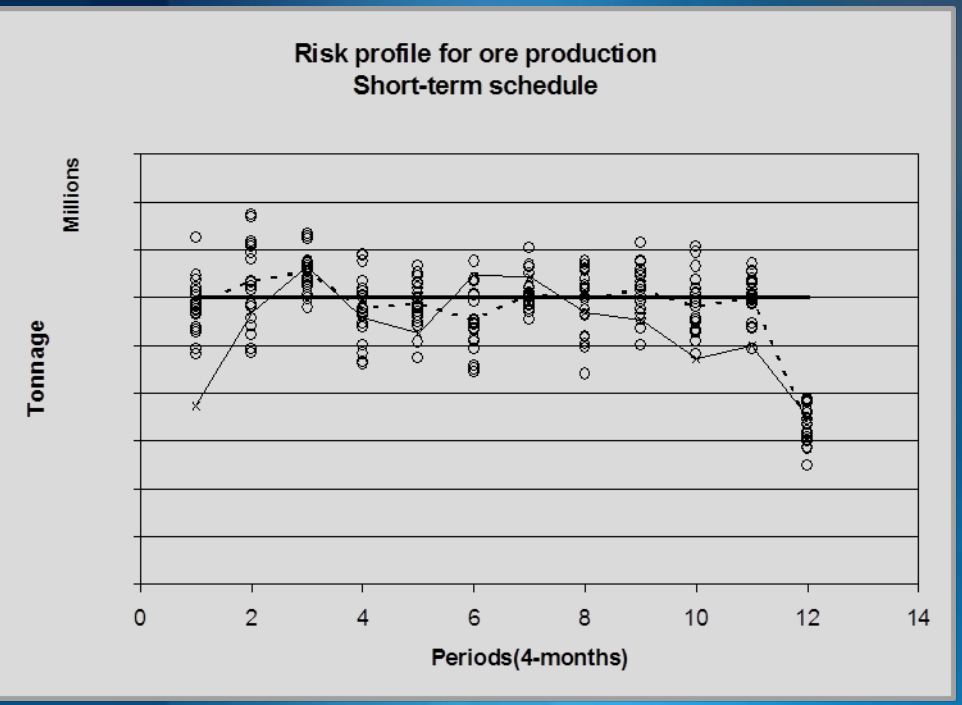
Based on simulated future grade control data

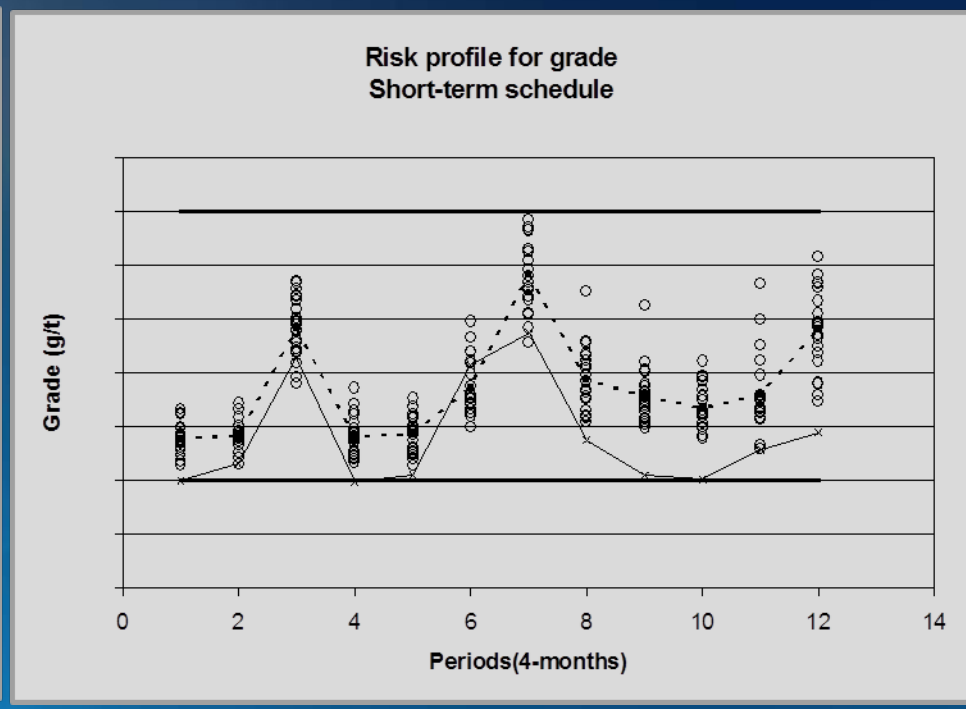


Stage 3: Stochastic Production Schedule

Stage 4: Risk Analysis

Schedule (quarters) – Simulations based on Exploration Data





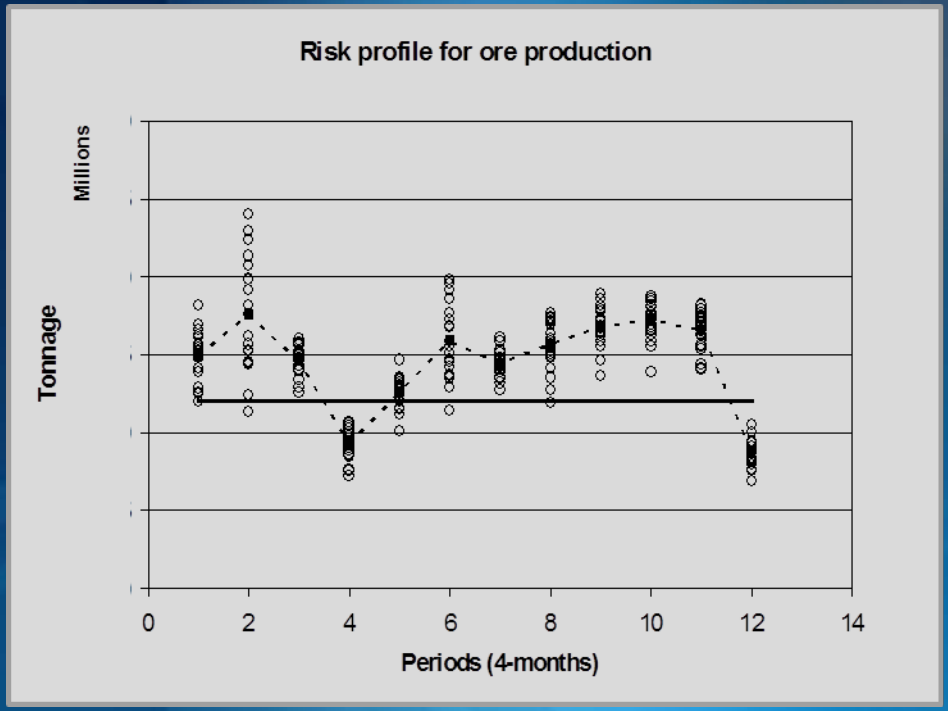
Mill target

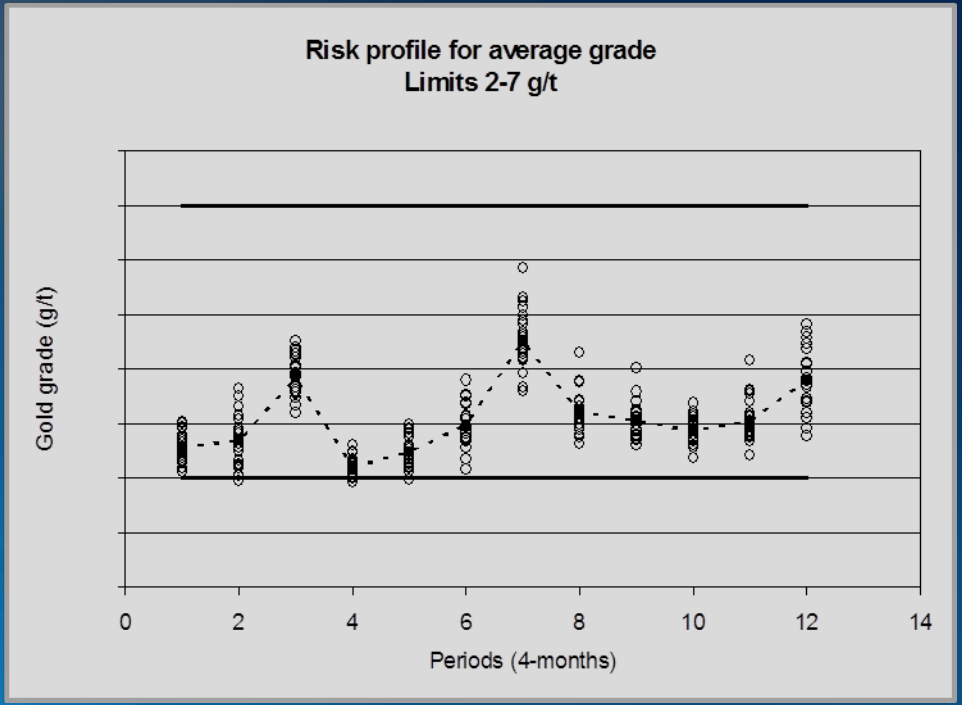
MIK model

Average of the simulations

Simulations

Viability of the derived schedule given grade control information



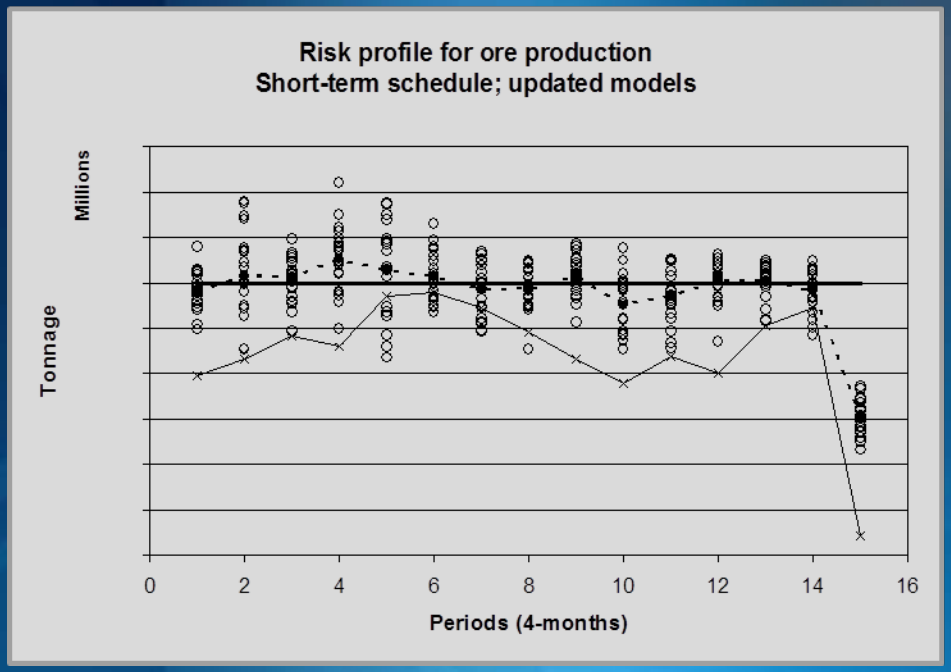


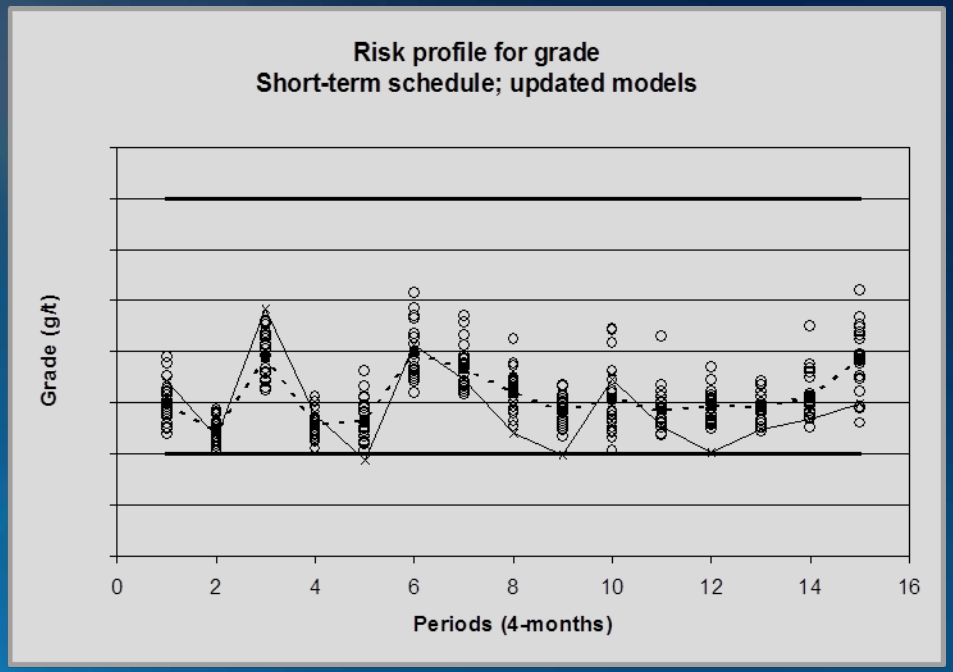
Mill target

Average of the simulations

Simulations

Schedule (quarters) – Simulations based on Simulated Future Grade Control





Mill target

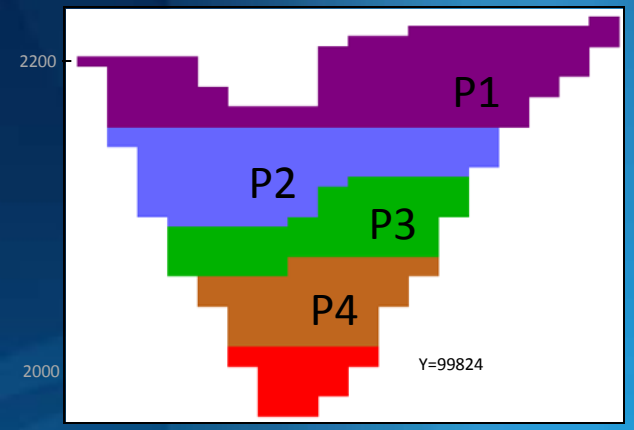
MIK model

Average of the simulations

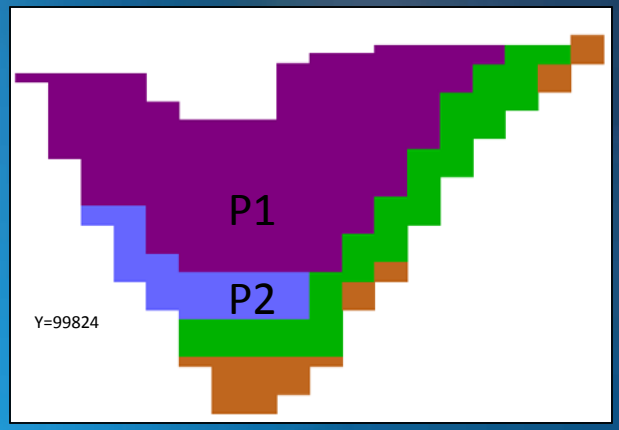
Simulations

Scheduling and Simulated Future Data

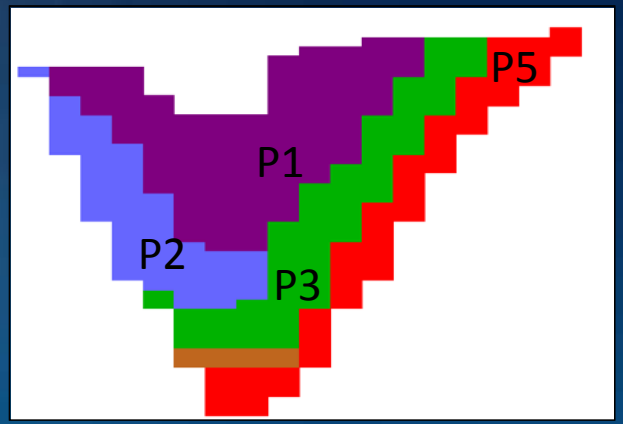
Mine's Schedule



SIP & Simulated Orebody (exploration based)



SIP & Future data (grade control based)

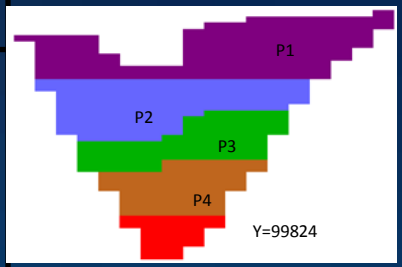


Period (years)
1 2005
2 2006
3 2007
4 2008
5 2009

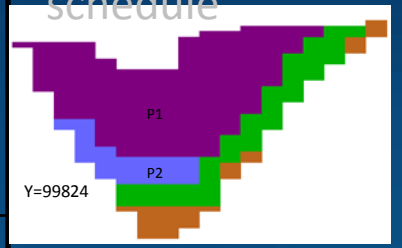
Scheduling and Simulated Future Data

	Simulations (exploration data)	Updated simulations (future data)	Mines schedule (future data)
Ore Tonnes (Mt)	14	18	10
Metal Tonnes (Mgrams)	52	55	38
Cumulative NPV (Million AUD)	552	560	330

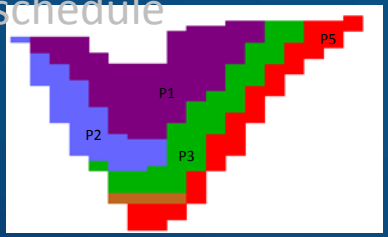
Mines schedule



Exploration based schedule



Grade control based schedule



THANK YOU