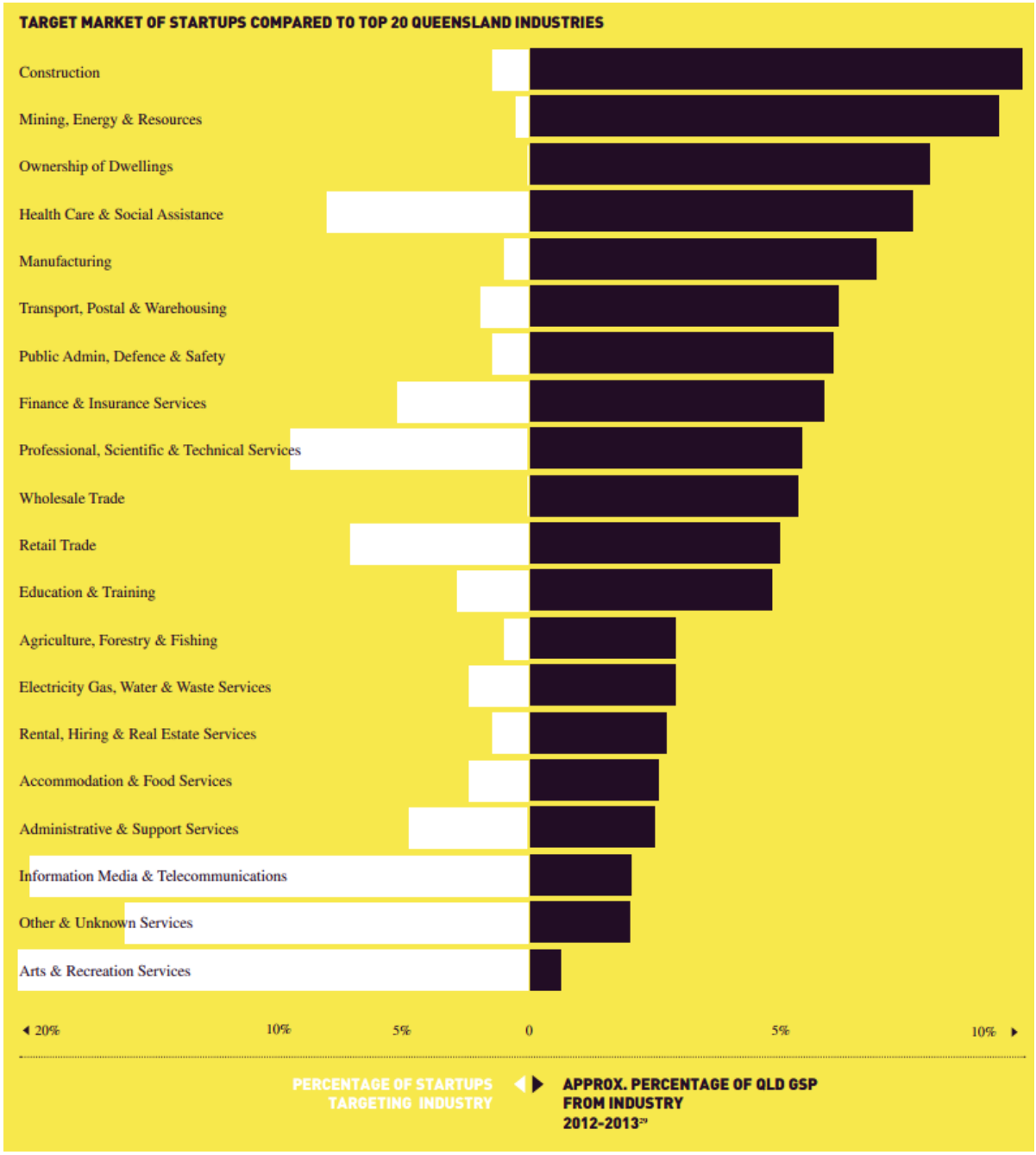
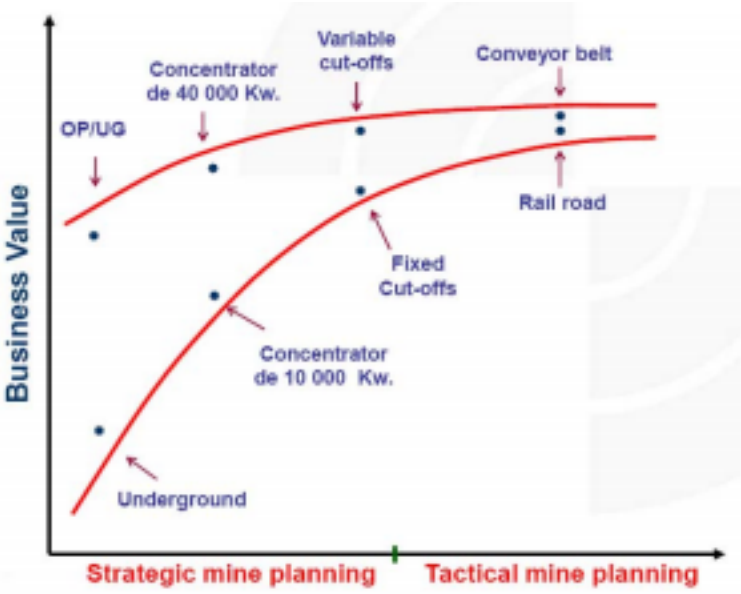
BAM 2016

Mine Design in an Uncertain World

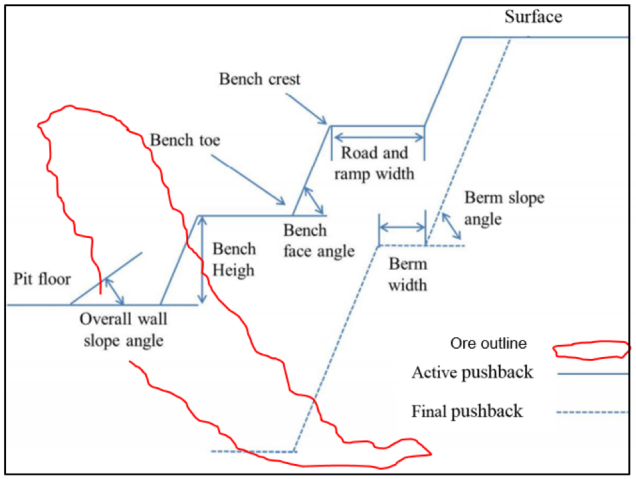

TARGET MARKET OF STARTUPS COMPARED TO TOP 20 QUEENSLAND INDUSTRIES
Construction
Mining, Energy & Resources
Ownership of Dwellings
Health Care & Social Assistance
Manufacturing
Transport, Postal & Warehousing
Public Admin, Defence & Safety
Finance & Insurance Services
Professional, Scientific & Technical Services
Wholesale Trade
Retail Trade
Education & Training
Agriculture, Forestry & Fishing
Electricity Gas, Water & Waste Services
Rental, Hiring & Real Estate Services
Accommodation & Food Services
Administrative & Support Services
Information Media & Telecommunications
Other & Unknown Services
Arts & Recreation Services
20%
10%
5%
0
5%
10%
PERCENTAGE OF STARTUPS TARGETING INDUSTRY
APPROX. PERCENTAGE OF QLD GSP FROM INDUSTRY 2012-2013[29]

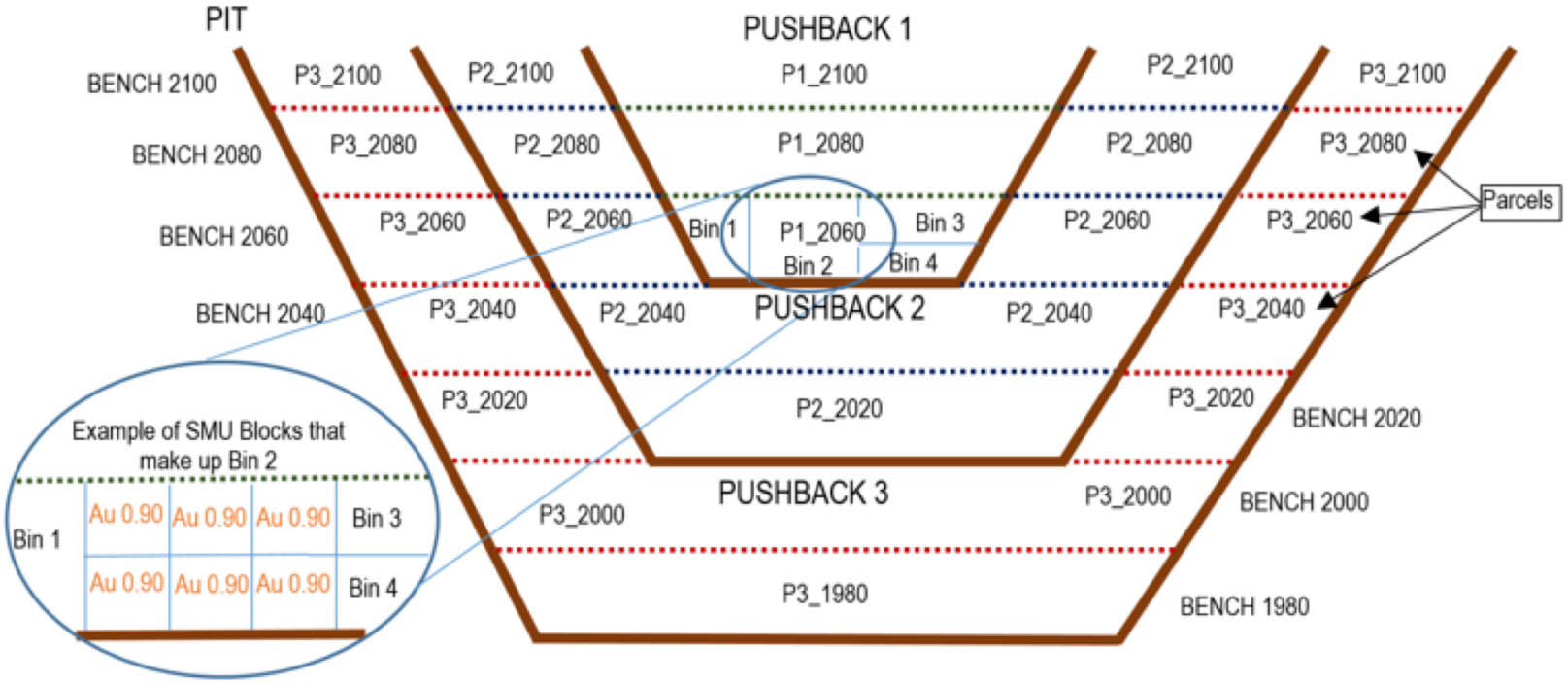
Mining Life Cycle



- Over the mining life cycle ratio of strategic to tactical planning decreases
- Whilst, cumulative business value improves over time with a decrease in the variability of business value

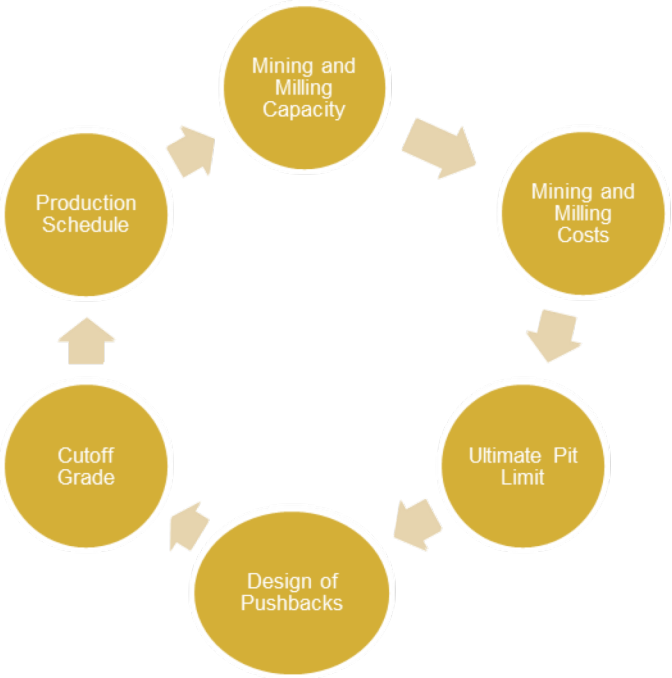
Terminology



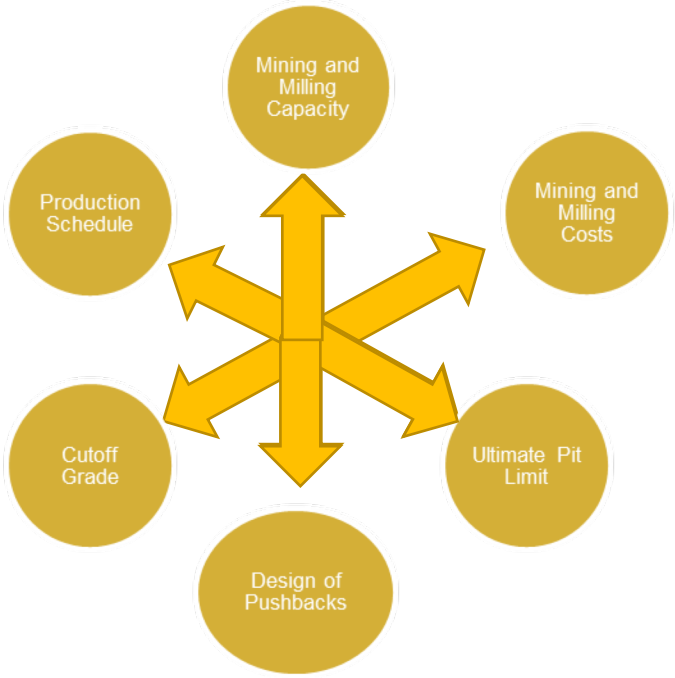


Open Pit Mine Design Process

Current Approach
(Step by Step)

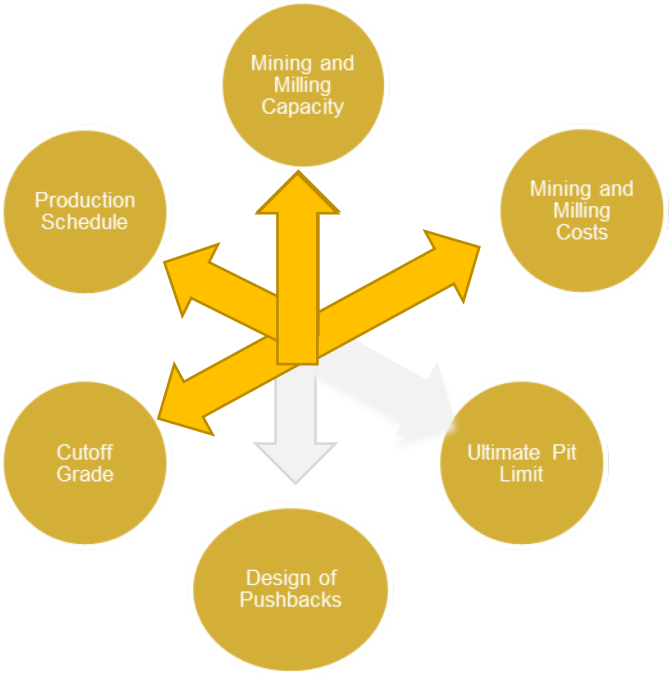


Ideal Approach
(Integrated Optimisation)

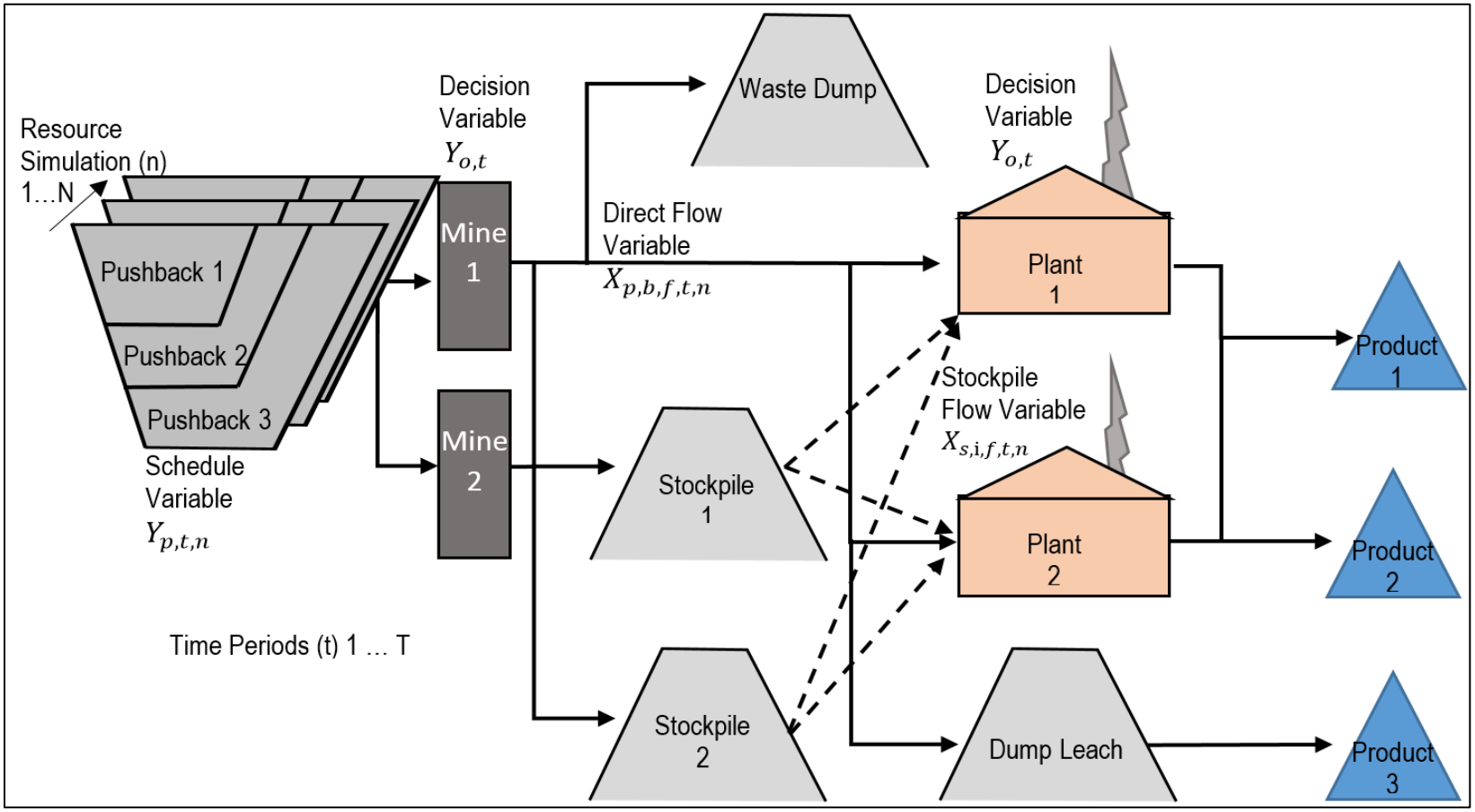


What does the model do?

- Maximise Net Present Value (NPV)
- Selects optimal system configuration
- Sequences and schedules material flow



Network Layout



Objective Function

$$\sum_{\mathrm{n}=1}^{\mathrm{N}} \frac{1}{\mathrm{N}} \left(\sum_{\mathrm{t}=1}^{\mathrm{T}} \frac{1}{(1+\mathrm{r})^{\mathrm{t}}} \left[\sum_{p,b,f=1|v,d\in f}^{\mathrm{P,B}_p,\mathrm{F}} P_{v,d,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{\mathrm{S,I,F}} P_{v,d,t,n} X_{s,i,f,t,n} \right.\right.$$
$$- \sum_{p,b,f,=1|\mathrm{o}\in\mathrm{f}}^{\mathrm{P,B}_p,\mathrm{F}} V_{o,t,n} X_{p,b,f,t,n} - \sum_{s,i,f=1|s\in f}^{\mathrm{S,I,F}} V_{s,t,n} X_{s,i,f,t,n} - \sum_{\mathrm{o}=1}^{\mathrm{O}} FO_{o,t,n} Y_{o,t} - \sum_{o=1}^{\mathrm{O}} E_{o,t,n}$$
$$\left.\left. - \sum_{o=1|t\neq 1}^{\mathrm{O}} D_{o,t,n} \right] \right)$$

- Maximise the discounted

Revenue from saleable product – Variable cost of mining/processing – Fixed operating cost of design option – Capital Cost of Design Option – Disposal cost of design option

Production Constraints

Resource Constraints

$\sum_{f,t=1}^{\mathrm{F,T}} X_{p,b,\mathrm{f},t,n} \leq R_{p,b}$	for $\forall\, p,b,n$	1
$\sum_{\mathrm{b,f}=1,tt=1}^{\mathrm{B}_p,\mathrm{F},t} X_{p,b,\mathrm{f},\mathrm{tt},\mathrm{n}} \geq R_p Y_{p,t,n}$	for $\forall\, p,t,n$	2
$\sum_{b,f,tt=1}^{\mathrm{B}_p,\mathrm{F},t} X_{p',b,\mathrm{f},tt,n} \leq R_{p',n} Y_{p,t,n}$	for $\forall p,t,n$	3
$Y_{p,t-1} \leq Y_{p,t,n}$	for $\forall p,t,n$	4
$Y_{p\mid p\in PIT,t,n} \leq SR_t$	for $\forall\, PIT,t,n$	5
$\frac{1}{R_{p,b}} \sum_{f=1}^{F} X_{p,b,f,t,n} - \frac{1}{R_p} \sum_{b,f=1}^{\mathrm{B}_p,F} X_{p,b,f,t,n} \leq \gamma\%$	for $\forall\, p,b,t,n$	6
$\frac{1}{R_p} \sum_{b,f=1}^{\mathrm{B}_p,F} X_{p,b,f,t,n} - \frac{1}{R_{p,b}} \sum_{f=1}^{F} X_{p,b,f,t,n} \leq \gamma\%$	for $\forall\, p,b,t,n$	7

Production Constraints

$$\sum_{f,t=1}^{\mathrm{F,T}} X_{p,b,\mathrm{f},t,n} \leq R_{p,b} \qquad \text{for } \forall\, p,b,n \qquad 1$$

$$\sum_{\mathrm{b,f}=1,tt=1}^{\mathrm{B}_p,\mathrm{F},t} X_{p,b,\mathrm{f},\mathrm{tt},\mathrm{n}} \geq R_p Y_{p,t,n} \qquad \text{for } \forall\, p,t,n \qquad 2$$

$$\sum_{b,f,tt=1}^{\mathrm{B}_p,\mathrm{F},t} X_{p',b,\mathrm{f},tt,n} \leq R_{p',n} Y_{p,t,n} \qquad \text{for } \forall p,t,n \qquad 3$$

Sequencing Constraints

$$Y_{p,t-1} \leq Y_{p,t,n} \qquad \text{for } \forall p,t,n \qquad 4$$

$$Y_{p|p\in PIT,t,n} \leq SR_t \qquad \text{for } \forall\, PIT,t,n \qquad 5$$

$$\frac{1}{R_{p,b}} \sum_{f=1}^{F} X_{p,b,f,t,n} - \frac{1}{R_p} \sum_{b,f=1}^{\mathrm{B}_p,F} X_{p,b,f,t,n} \leq \gamma\% \qquad \text{for } \forall\, p,b,t,n \qquad 6$$

$$\frac{1}{R_p} \sum_{b,f=1}^{\mathrm{B}_p,F} X_{p,b,f,t,n} - \frac{1}{R_{p,b}} \sum_{f=1}^{F} X_{p,b,f,t,n} \leq \gamma\% \qquad \text{for } \forall\, p,b,t,n \qquad 7$$

Production Constraints

$$\sum_{f,t=1}^{F,T} X_{p,b,f,t,n} \leq R_{p,b} \qquad \text{for } \forall\, p,b,n \qquad 1$$

$$\sum_{b,f=1,tt=1}^{B_p,F,t} X_{p,b,f,tt,n} \geq R_p Y_{p,t,n} \qquad \text{for } \forall\, p,t,n \qquad 2$$

$$\sum_{b,f,tt=1}^{B_p,F,t} X_{p',b,f,tt,n} \leq R_{p',n} Y_{p,t,n} \qquad \text{for } \forall p,t,n \qquad 3$$

$$Y_{p,t-1} \leq Y_{p,t,n} \qquad \text{for } \forall p,t,n \qquad 4$$

Equal Mining of Parcels

$$Y_{p|p\in PIT,t,n} \leq SR_t \qquad \text{for } \forall\, PIT,t,n \qquad 5$$

$$\frac{1}{R_{p,b}} \sum_{f=1}^{F} X_{p,b,f,t,n} - \frac{1}{R_p} \sum_{b,f=1}^{B_p,F} X_{p,b,f,t,n} \leq \gamma\% \qquad \text{for } \forall\, p,b,t,n \qquad 6$$

$$\frac{1}{R_p} \sum_{b,f=1}^{B_p,F} X_{p,b,f,t,n} - \frac{1}{R_{p,b}} \sum_{f=1}^{F} X_{p,b,f,t,n} \leq \gamma\% \qquad \text{for } \forall\, p,b,t,n \qquad 7$$

Design Option Constraints

Capacity Constraint

$$\sum_{p,b,f=1|f\in o}^{P,B_p,F} X_{p,b,f,t,n} \leq C_{o,t,n} Y_{o,t} \quad \text{for } \forall\ o \in PRE, t, n \qquad 8$$

$$\sum_{p,b,f=1|f\in o}^{P,B_p,F} X_{p,b,f,t,n} + \sum_{s,i,f=1|f\in o}^{S,I,F} X_{s,i,f,t,n} \leq C_{o,t,n} Y_{o,t} \quad \text{for } \forall\ o \in POST, t, n \qquad 9$$

$$\sum_{p,b,f=1|f\in c,o}^{P,B_p,F} X_{p,b,f,t,n} + \sum_{s,i,f=1|f\in c,o}^{S,I,F} X_{s,i,f,t,n} \leq C_{c,o,t,n} Y_{o,t} \quad \text{for } \forall\ c, o \in POST, t, n \qquad 10$$

$$FC_{o,t,n} Y_{o,t} - FC_{o,t,n} Y_{o,t-1} \leq E_{o,t,n} \quad \text{for } \forall\ o, t, n \qquad 11$$

$$FD_{o,t,n} Y_{o,t} - FD_{o,t,n} Y_{o,t-1} \leq D_{o,t,n} \quad \text{for } \forall\ o, t, n \qquad 12$$

$$Y_{o',t} \leq Y_{o,t-1} \quad \text{for } \forall\ o, t \qquad 13$$

Design Option Constraints

$$\sum_{p,b,f=1|f\in o}^{P,B_p,F} X_{p,b,f,t,n} \leq C_{o,t,n} Y_{o,t} \qquad \text{for } \forall\ o \in PRE, t, n \qquad 8$$

$$\sum_{p,b,f=1|f\in o}^{P,B_p,F} X_{p,b,f,t,n} + \sum_{s,i,f=1|f\in o}^{S,I,F} X_{s,i,f,t,n} \leq C_{o,t,n} Y_{o,t} \qquad \text{for } \forall\ o \in POST, t, n \qquad 9$$

Financial Cost

$$\sum_{p,b,f=1|f\in c,o}^{P,B_p,F} X_{p,b,f,t,n} + \sum_{s,i,f=1|f\in c,o}^{S,I,F} X_{s,i,f,t,n} \leq C_{c,o,t,n} Y_{o,t} \qquad \text{for } \forall\ c, o \in POST, t, n \qquad 10$$

$$FC_{o,t,n} Y_{o,t} - FC_{o,t,n} Y_{o,t-1} \leq E_{o,t,n} \qquad \text{for } \forall\ o, t, n \qquad 11$$

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$$Y_{o',t} \leq Y_{o,t-1} \qquad \text{for } \forall\ o, t \qquad 13$$

Design Option Constraints

$$\sum_{p,b,f=1|f\in o}^{P,B_p,F} X_{p,b,f,t,n} \leq C_{o,t,n} Y_{o,t} \qquad \text{for } \forall\ o \in PRE, t, n \qquad 8$$

$$\sum_{p,b,f=1|f\in o}^{P,B_p,F} X_{p,b,f,t,n} + \sum_{s,i,f=1|f\in o}^{S,I,F} X_{s,i,f,t,n} \leq C_{o,t,n} Y_{o,t} \qquad \text{for } \forall\ o \in POST, t, n \qquad 9$$

$$\sum_{p,b,f=1|f\in c,o}^{P,B_p,F} X_{p,b,f,t,n} + \sum_{s,i,f=1|f\in c,o}^{S,I,F} X_{s,i,f,t,n} \leq C_{c,o,t,n} Y_{o,t} \qquad \text{for } \forall\ c, o \in POST, t, n \qquad 10$$

$$FC_{o,t,n} Y_{o,t} - FC_{o,t,n} Y_{o,t-1} \leq E_{o,t,n} \qquad \text{for } \forall\ o, t, n \qquad 11$$

Option Dependency

$$FD_{o,t,n} Y_{o,t} - FD_{o,t,n} Y_{o,t-1} \leq D_{o,t,n} \qquad \text{for } \forall\ o, t, n \qquad 12$$

$$Y_{o',t} \leq Y_{o,t-1} \qquad \text{for } \forall\ o, t \qquad 13$$

Stockpile Out <= In

Stockpiling Constraints

$$\sum_{f,tt=1|s,i\in f}^{F,t-1} X_{s,i,f,tt,n} \leq \sum_{p,b,f,tt=1|s,i\in f}^{P,B_p,F,t} X_{p,b,f,tt,n} \qquad \text{for } \forall\ s,i,t,n \qquad 14$$

$$\sum_{p,b,f,tt=1|s,i\in f}^{P,B_p,F,t} X_{p,b,f,tt,n} - \sum_{f,tt=1|s,i\in f}^{F,t} X_{s,i,f,tt,n} \leq C_{s,t} \qquad \text{for } \forall\ s,i,t,n \qquad 15$$

Product Constraints

$$\sum_{p,b,f=1|v,d\in f}^{P,B_p,F} REC_{v,d,p,b,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} REC_{v,d,s,i} X_{s,i,f,t,n} \leq C_{v,d} \qquad \text{for } \forall\ v,d,t,n \qquad 16$$

$$\sum_{p,b,f=1|v,d\in f}^{P,B_p,F} GL_{g,v,d} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GL_{g,v,d} X_{s,i,f,t,n} \qquad \text{for } \forall\ g,v,d,t,n \qquad 17$$

$$\leq \sum_{p,b,f=1|v,d\in f}^{P,B_p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,i,f,t,n}$$

$$\sum_{p,b,f=1|v,d\in f}^{P,B_p,F} GU_{g,v} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GU_{g,v} X_{s,i,f,t,n} \qquad \text{for } \forall\ g,v,d,t,n \qquad 18$$

$$\geq \sum_{p,b,f=1|v,d\in f}^{P,B_p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,i,f,t,n}$$

Stockpiling Constraints

Stockpile Capacity Limit

$$\sum_{f,tt=1|s,i\in f}^{F,t-1} X_{s,i,f,tt,n} \leq \sum_{p,b,f,tt=1|s,i\in f}^{P,B_p,F,t} X_{p,b,f,tt,n} \quad \text{for } \forall\ s,i,t,n \qquad 14$$

$$\sum_{p,b,f,tt=1|s,i\in f}^{P,B_p,F,t} X_{p,b,f,tt,n} - \sum_{f,tt=1|s,i\in f}^{F,t} X_{s,i,f,tt,n} \leq C_{s,t} \quad \text{for } \forall\ s,i,t,n \qquad 15$$

Product Constraints

$$\sum_{p,b,f=1|v,d\in f}^{P,B_p,F} REC_{v,d,p,b,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} REC_{v,d,s,i} X_{s,i,f,t,n} \leq C_{v,d} \quad \text{for } \forall\ v,d,t,n \qquad 16$$

$$\sum_{p,b,f=1|v,d\in f}^{P,B_p,F} GL_{g,v,d} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GL_{g,v,d} X_{s,i,f,t,n} \leq \sum_{p,b,f=1|v,d\in f}^{P,B_p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,i,f,t,n} \quad \text{for } \forall\ g,v,d,t,n \qquad 17$$

$$\sum_{p,b,f=1|v,d\in f}^{P,B_p,F} GU_{g,v} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GU_{g,v} X_{s,i,f,t,n} \geq \sum_{p,b,f=1|v,d\in f}^{P,B_p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,i,f,t,n} \quad \text{for } \forall\ g,v,d,t,n \qquad 18$$

Stockpiling Constraints

$$\sum_{f,tt=1|s,i\in f}^{F,t-1} X_{s,\mathrm{i},f,tt,n} \leq \sum_{p,b,f,tt=1|s,i\in f}^{P,\mathrm{B}p,F,t} X_{p,b,f,tt,n}$$

for $\forall\ s,i,t,n$ 14

$$\sum_{p,b,f,tt=1|s,i\in f}^{P,\mathrm{B}p,F,t} X_{p,b,f,tt,n} - \sum_{f,tt=1|s,i\in f}^{F,t} X_{s,\mathrm{i},f,tt,n} \leq C_{s,t}$$

for $\forall\ s,i,t,n$ 15

Product Capacity Limit

Product Constraints

$$\sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}p,F} REC_{v,d,p,b,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} REC_{v,d,s,\mathrm{i}} X_{s,\mathrm{i},f,t,n} \leq C_{v,d}$$

for $\forall\ v,d,t,n$ 16

$$\sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}p,F} GL_{g,v,d} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GL_{g,v,d} X_{s,\mathrm{i},f,t,n}$$

for $\forall\ g,v,d,t,n$ 17

$$\leq \sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,\mathrm{i},f,t,n}$$

$$\sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}p,F} GU_{g,v} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GU_{g,v} X_{s,\mathrm{i},f,t,n}$$

for $\forall\ g,v,d,t,n$ 18

$$\geq \sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,\mathrm{i},f,t,n}$$

Stockpiling Constraints

$$\sum_{f,tt=1|s,i\in f}^{F,t-1} X_{s,\mathrm{i},f,tt,n} \leq \sum_{p,b,f,tt=1|s,i\in f}^{P,\mathrm{B}_p,F,t} X_{p,b,f,tt,n}$$

for $\forall\ s,i,t,n$ 14

$$\sum_{p,b,f,tt=1|s,i\in f}^{P,\mathrm{B}_p,F,t} X_{p,b,f,tt,n} - \sum_{f,tt=1|s,i\in f}^{F,t} X_{s,\mathrm{i},f,tt,n} \leq C_{s,t}$$

for $\forall\ s,i,t,n$ 15

Product Constraints

Product Grade Limits

$$\sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}_p,F} REC_{v,d,p,b,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} REC_{v,d,s,\mathrm{i}} X_{s,i,f,t,n} \leq C_{v,d}$$

for $\forall\ v,d,t,n$ 16

$$\sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}_p,F} GL_{g,v,d} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GL_{g,v,d} X_{s,\mathrm{i},f,t,n}$$

for $\forall\ g,v,d,t,n$ 17

$$\leq \sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}_p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,i,f,t,n}$$

$$\sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}_p,F} GU_{g,v} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} GU_{g,v} X_{s,\mathrm{i},f,t,n}$$

for $\forall\ g,v,d,t,n$ 18

$$\geq \sum_{p,b,f=1|v,d\in f}^{P,\mathrm{B}_p,F} G_{g,p,b,f,t,n} X_{p,b,f,t,n} + \sum_{s,i,f=1|v,d\in f}^{S,I,F} G_{g,s,i,f,n} X_{s,i,f,t,n}$$

Integer Feasibility Cuts

All Options in a flow path must exist

$$Y_{o,t} - \sum_{tt=1}^{t} Y_{\hat{o},tt} \leq 0 \qquad \text{for } \forall\, o,t \qquad 19$$

$$\sum_{tt=1}^{t} Y_{p',tt,n} \leq \sum_{tt=1}^{t} Y_{p,tt,n} \qquad \text{for } \forall\, p,t,n \qquad 20$$

$$Y_{p,t,n} \leq Y_{o,t|o\in M} \qquad \text{for } \forall\, p,o,t,n \qquad 21$$

Integer Feasibility Cuts

Parcel Dependency (enforced on Binary as well as Linear Variable)

$$Y_{o,t} - \sum_{tt=1}^{t} Y_{\hat{o},tt} \leq 0 \qquad \text{for } \forall\, o,t \qquad 19$$

$$\sum_{tt=1}^{t} Y_{p',tt,n} \leq \sum_{tt=1}^{t} Y_{p,tt,n} \qquad \text{for } \forall\, p,t,n \qquad 20$$

$$Y_{p,t,n} \leq Y_{o,t|o\in M} \qquad \text{for } \forall\, p,o,t,n \qquad 21$$

Integer Feasibility Cuts

Restrict mining if no mining option has been built

$$Y_{o,t} - \sum_{tt=1}^{t} Y_{\hat{o},tt} \leq 0 \qquad \text{for } \forall\, o,t \qquad 19$$

$$\sum_{tt=1}^{t} Y_{p',tt,n} \leq \sum_{tt=1}^{t} Y_{p,tt,n} \qquad \text{for } \forall\, p,t,n \qquad 20$$

$$Y_{p,t,n} \leq Y_{o,t|o\in M} \qquad \text{for } \forall\, p,o,t,n \qquad 21$$

Performance Size Reduction Algorithms

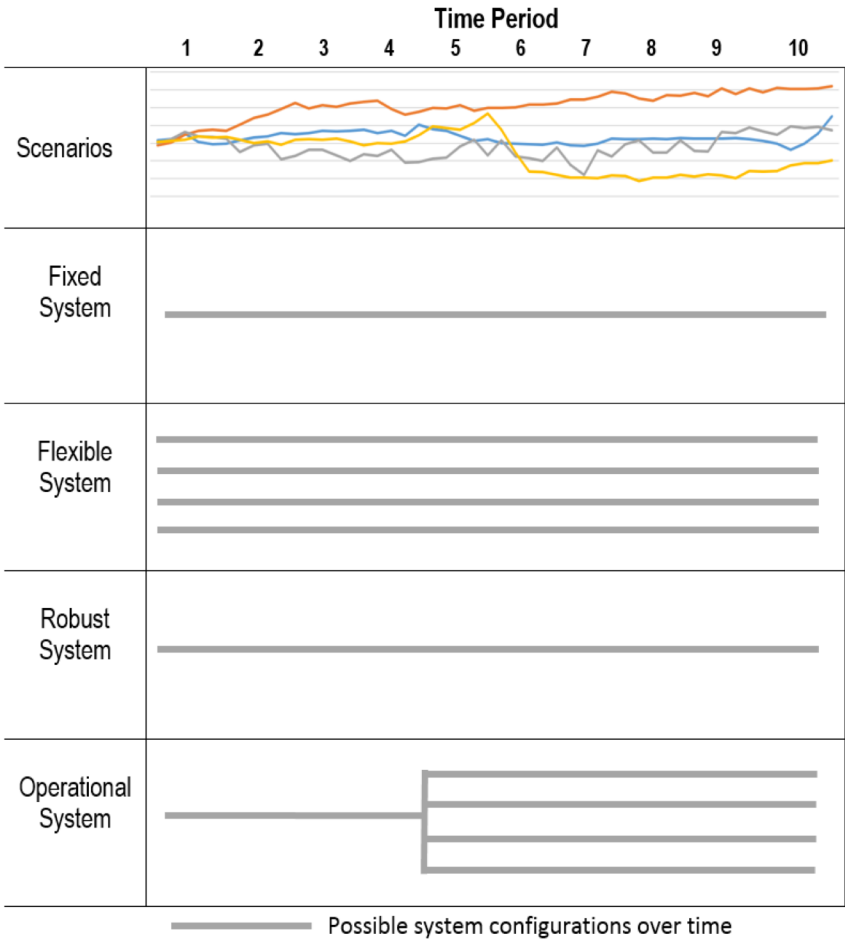
- Late start on execution of a design option due possible resource extraction being less value then the cost of the design option
- Early start on a parcel due to possible design option capacity
- Early start for a parcel due to a maximum sink rate
- Removal of flow paths with a negative marginal value

- Aggregate bins within a parcel of similar characteristics

Problem Size

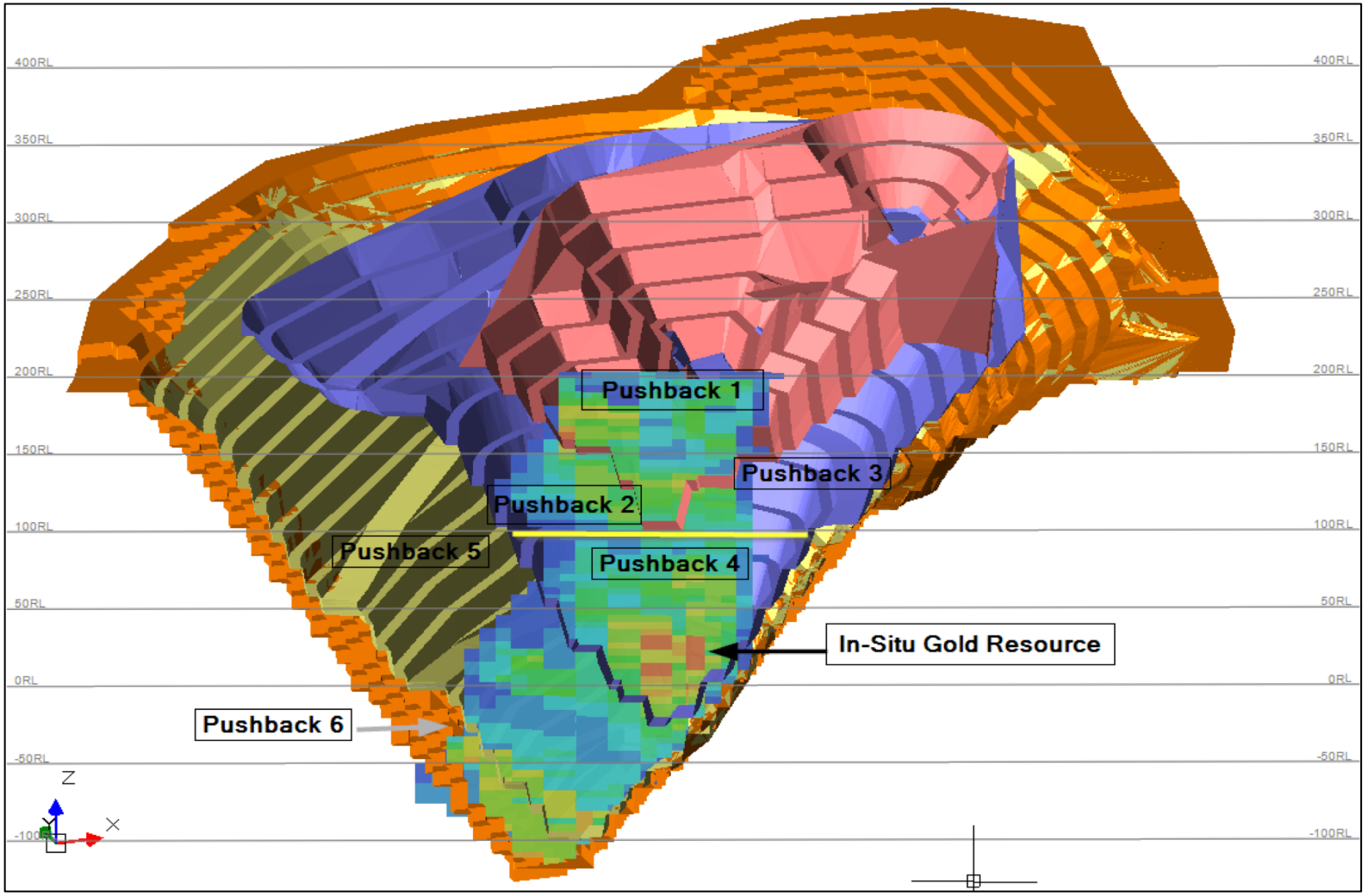
Parcels - 72 / Bins - 1446	499 binaries / 176,000 linear
Design Options - 8	56 binaries
Stockpiles – Bins - 15	1,502 linear
Time Periods - 7	

Model Modes…

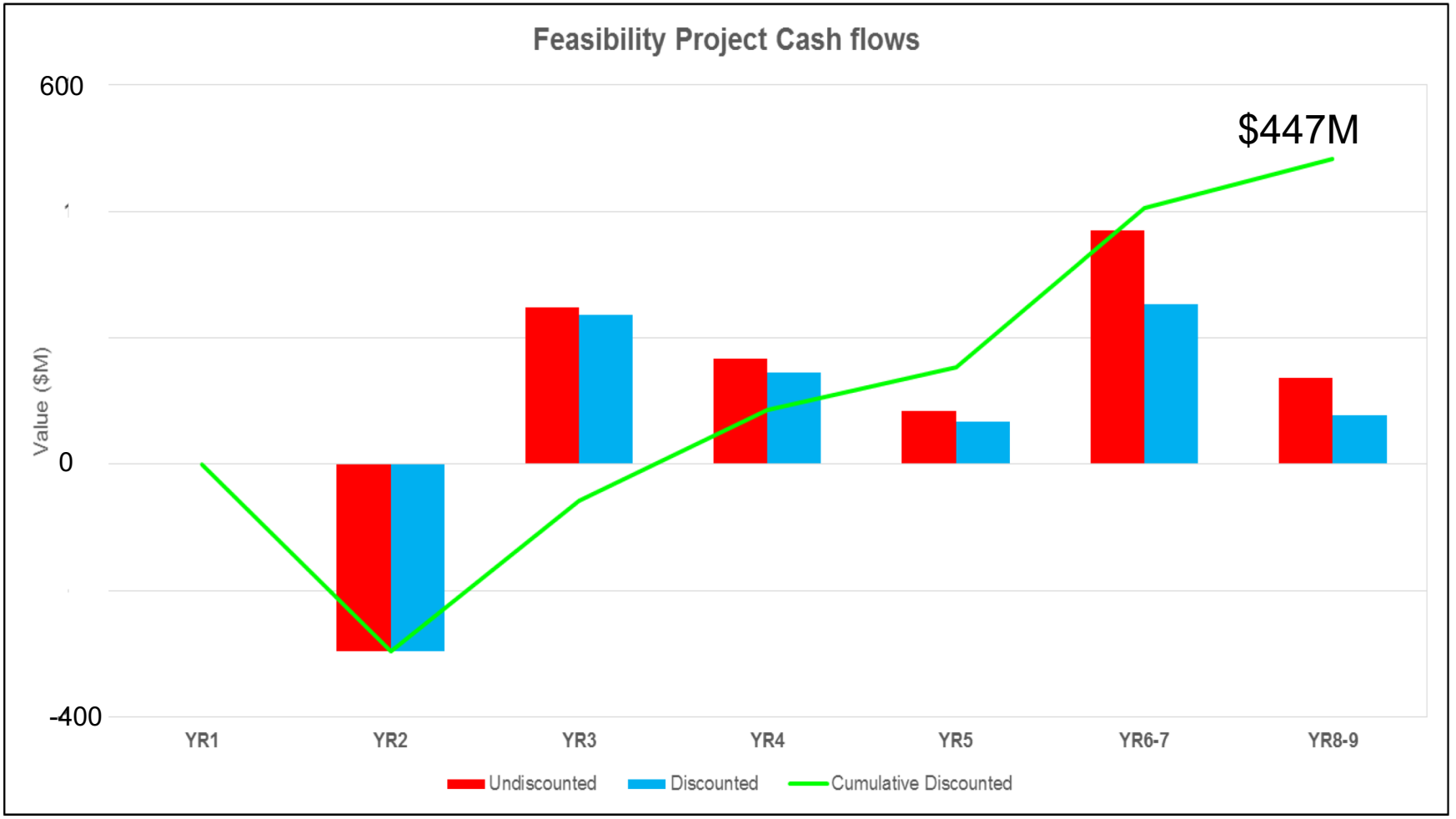


	System Configuration	Advantages	Disadvantages
Fixed System	Fixed Input by User	Clear path forward due to fixed system configuration	System configuration will not react to change
Flexible System	Optimised for each scenario	Obtains an optimal system configuration for the simulation	Assumes perfect knowledge is available to decision makers
Robust System	Optimised for all scenarios	System configuration is designed to handle change the best	Model is large thus slow to solve
Operational System	Fixed Input by User for initial periods then Optimised for each scenario	Fixed configuration and clear pathway for initial periods with flexibility maintained in back end of the schedule	Requires manual input of the initial fixed configuration which requires running of the other modes to determine the best configuration

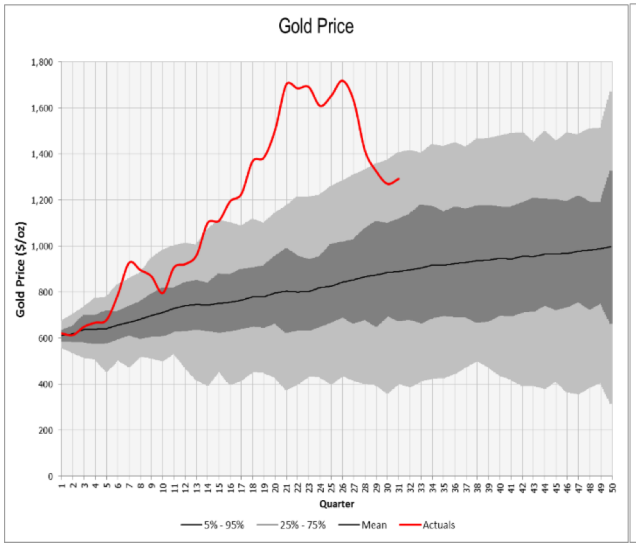
Pit and Pushback Design

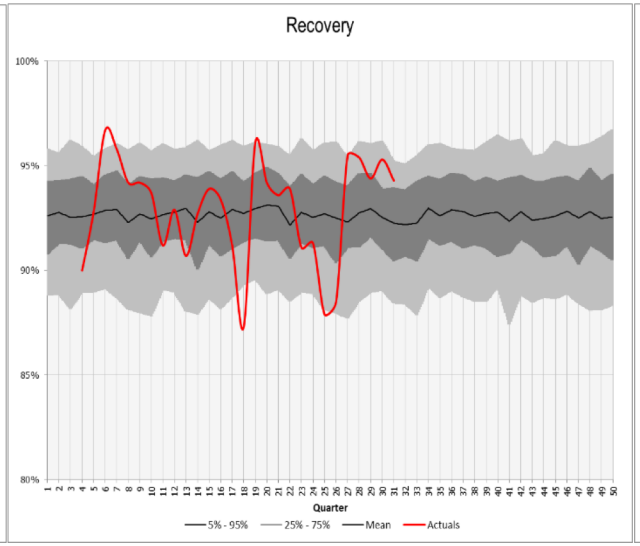


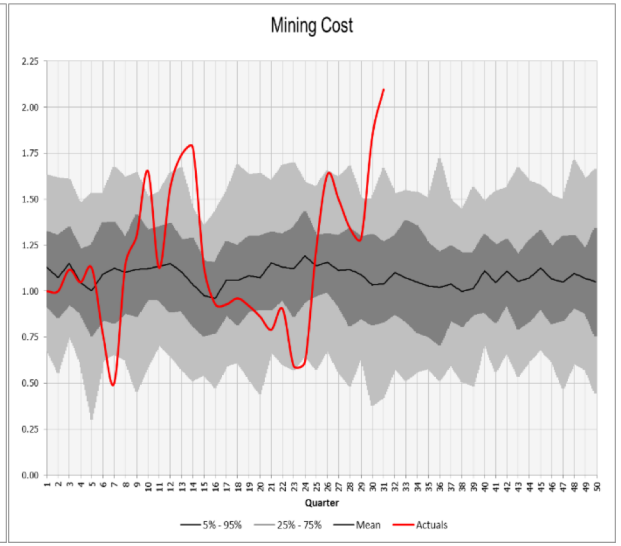
Feasibility Study

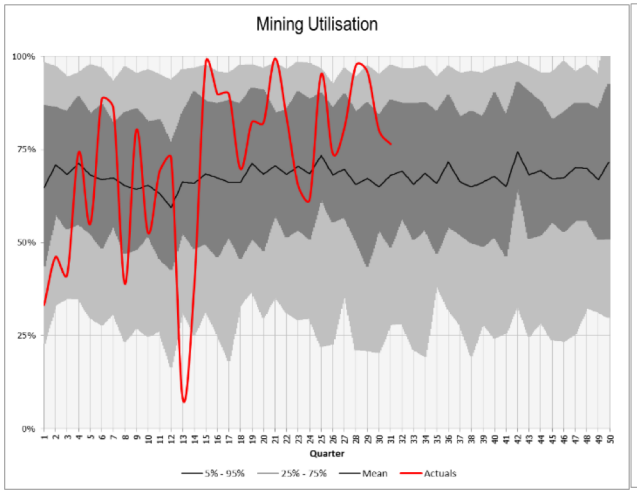


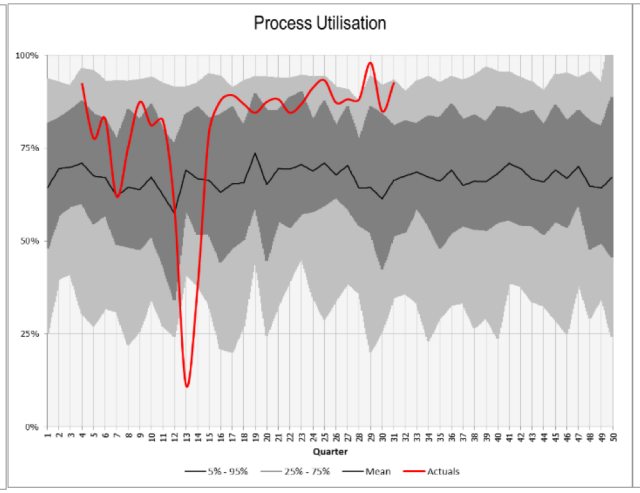
Stochastic Parameters

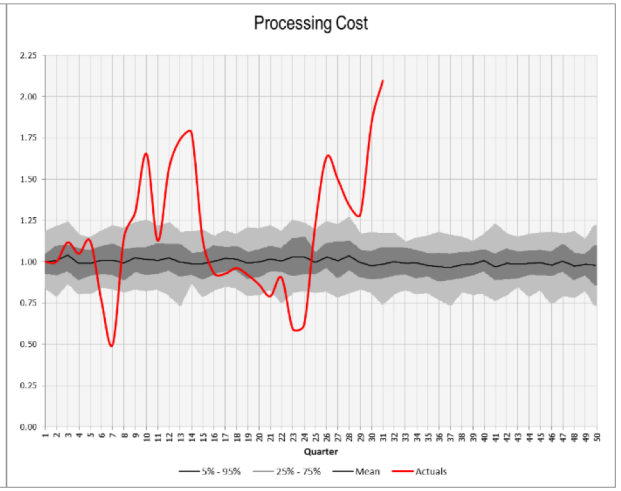




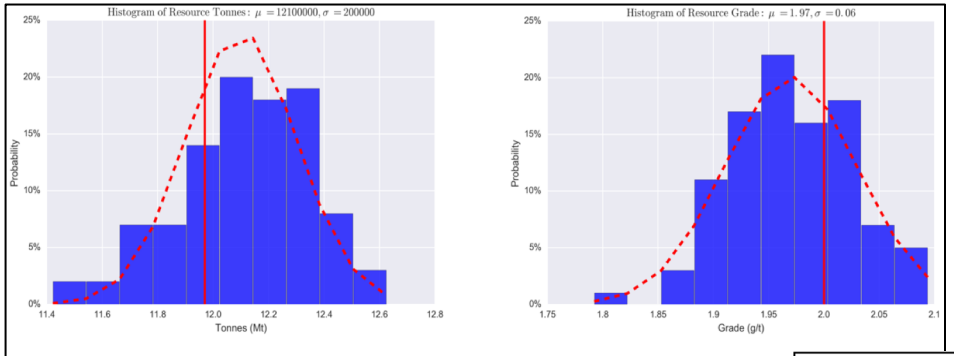


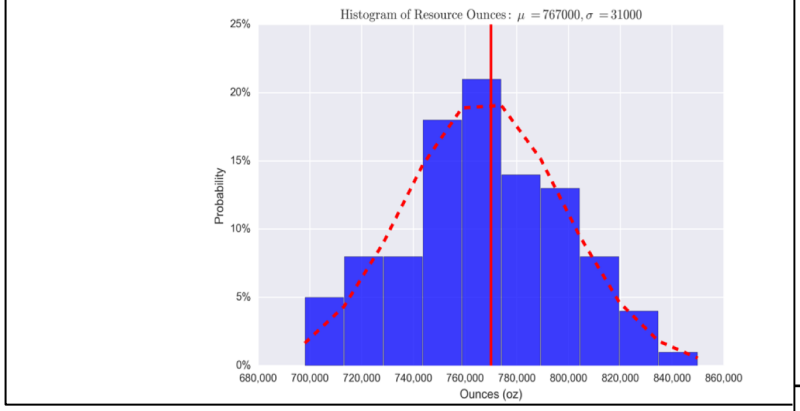


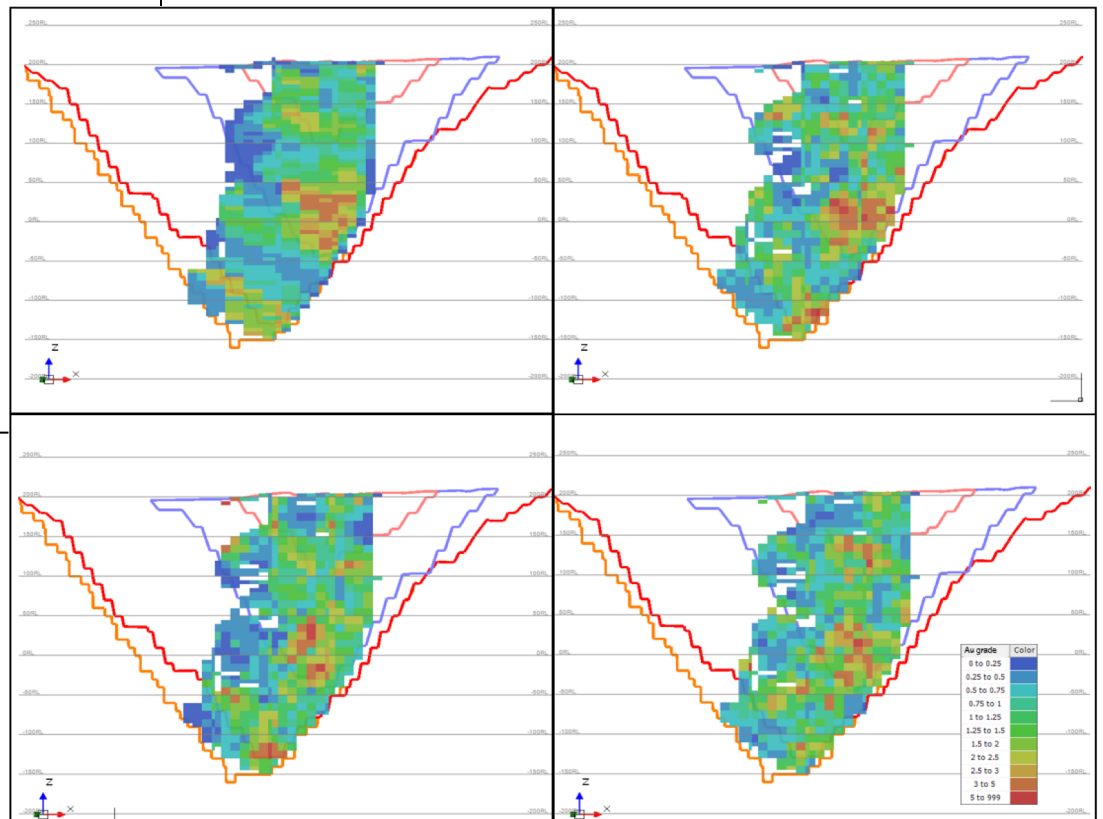




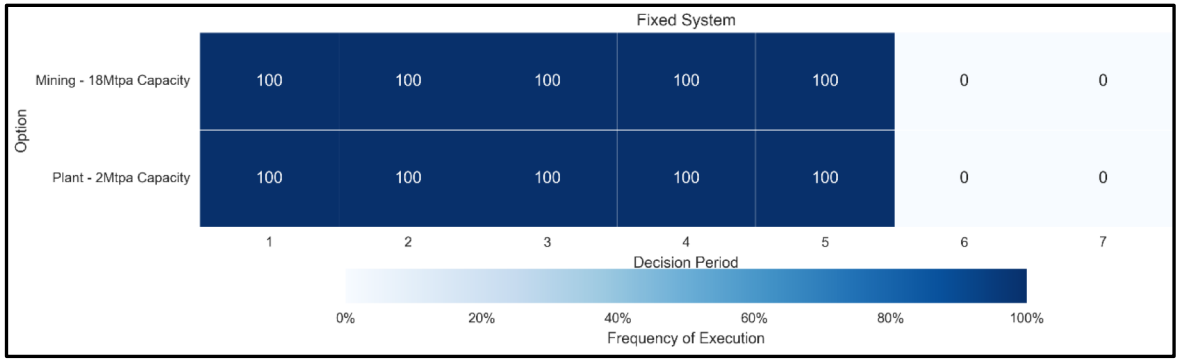
Conditionally Simulated Models





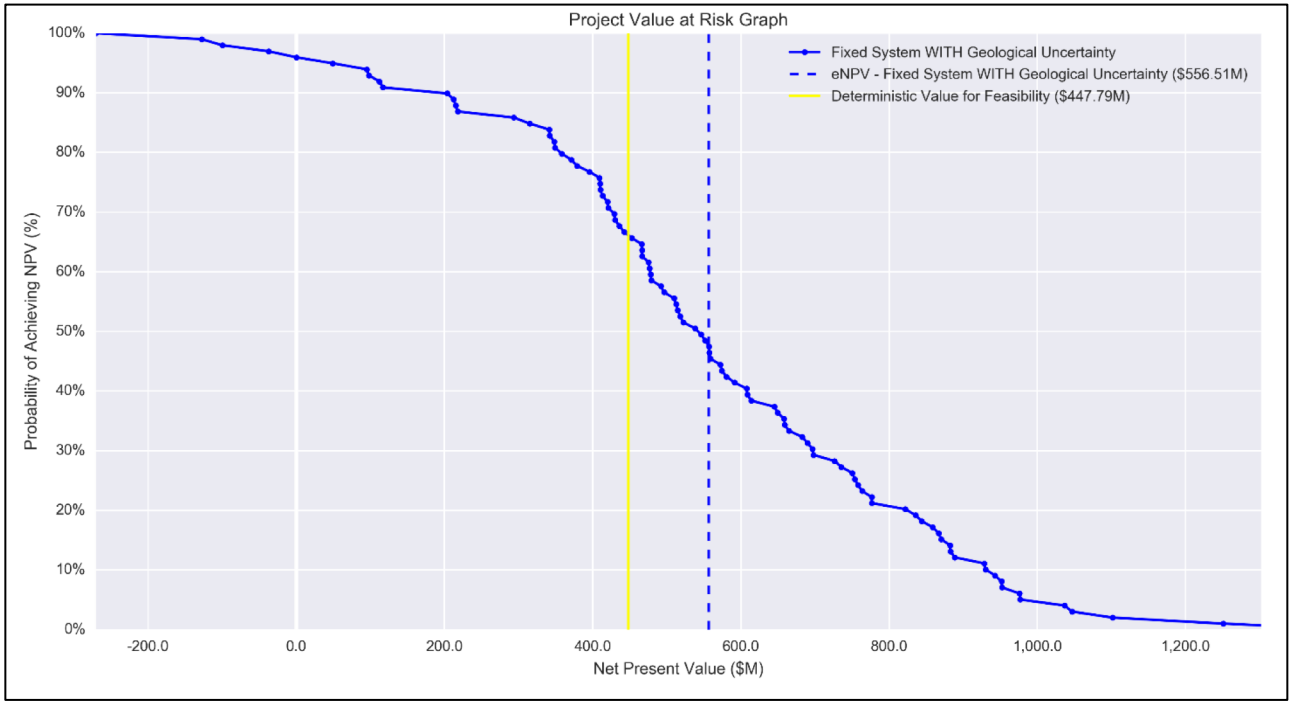


Fixed System

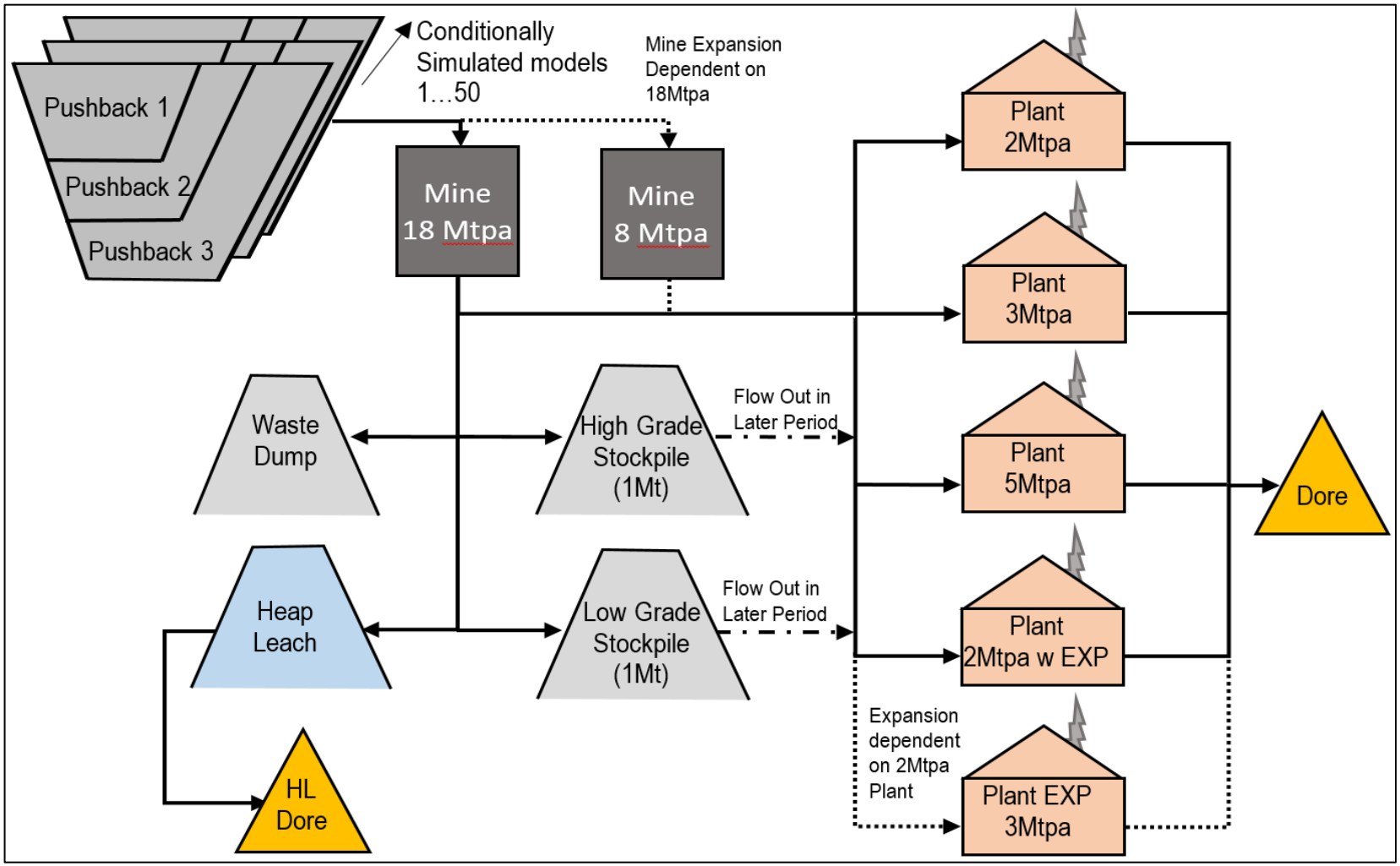


- Feasibility Configuration
  - Mining 18 Mtpa
  - Plant 2 Mtpa
- Optimised Schedule

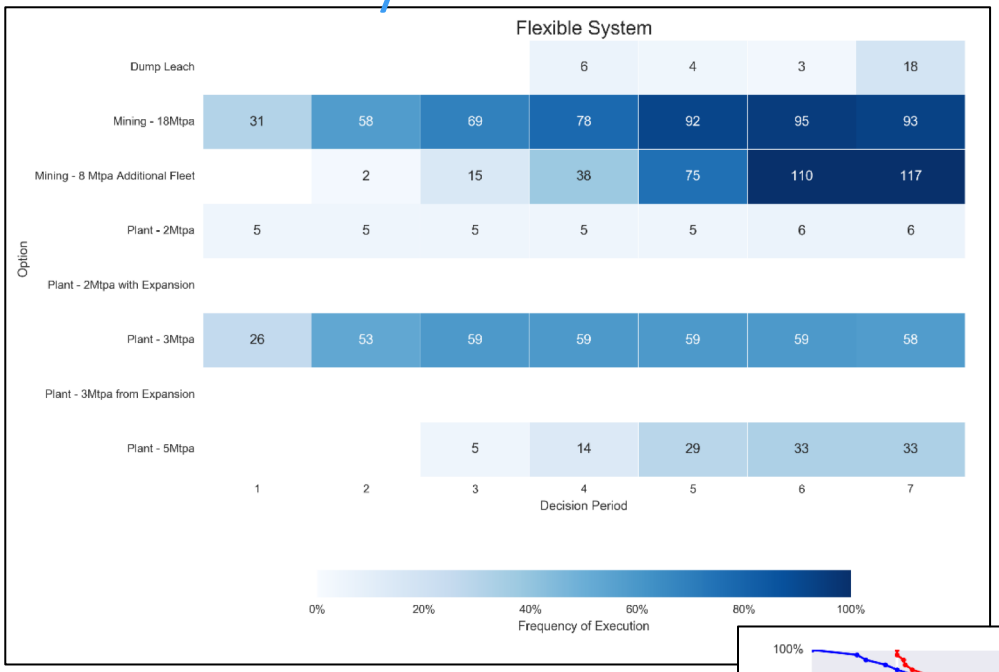
- Feasibility System Configuration with variability from uncertainty
- ENPV - $556M



Options

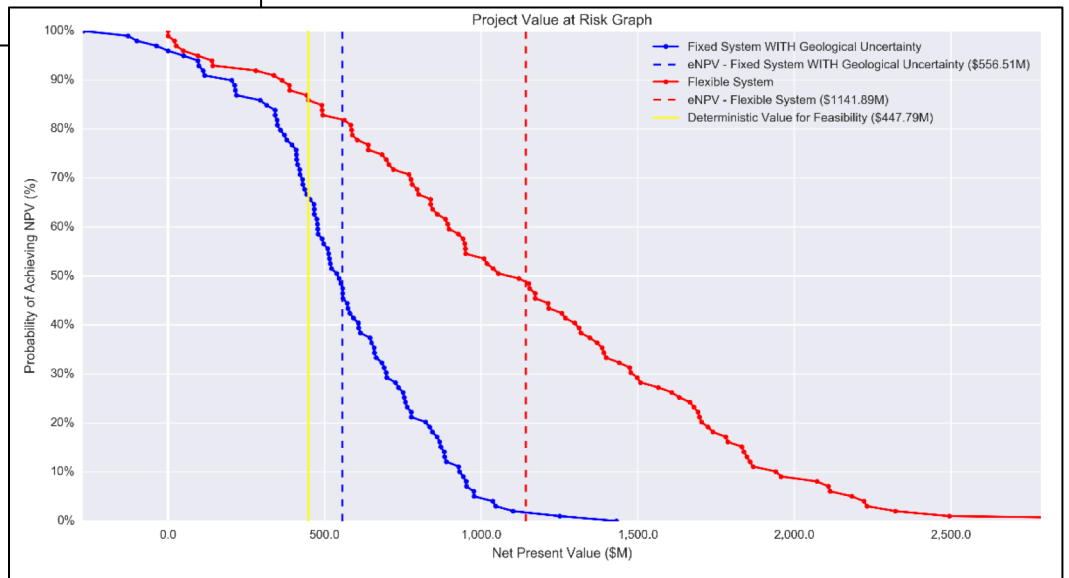

Pushback 1
Pushback 2
Pushback 3
Conditionally Simulated models 1…50
Mine Expansion Dependent on 18Mtpa
Mine 18 Mtpa
Mine 8 Mtpa
Plant 2Mtpa
Plant 3Mtpa
Plant 5Mtpa
Plant 2Mtpa w EXP
Plant EXP 3Mtpa
Dore
Waste Dump
High Grade Stockpile (1Mt)
Flow Out in Later Period
Heap Leach
Low Grade Stockpile (1Mt)
Flow Out in Later Period
HL Dore
Expansion dependent on 2Mtpa Plant

Flexible System

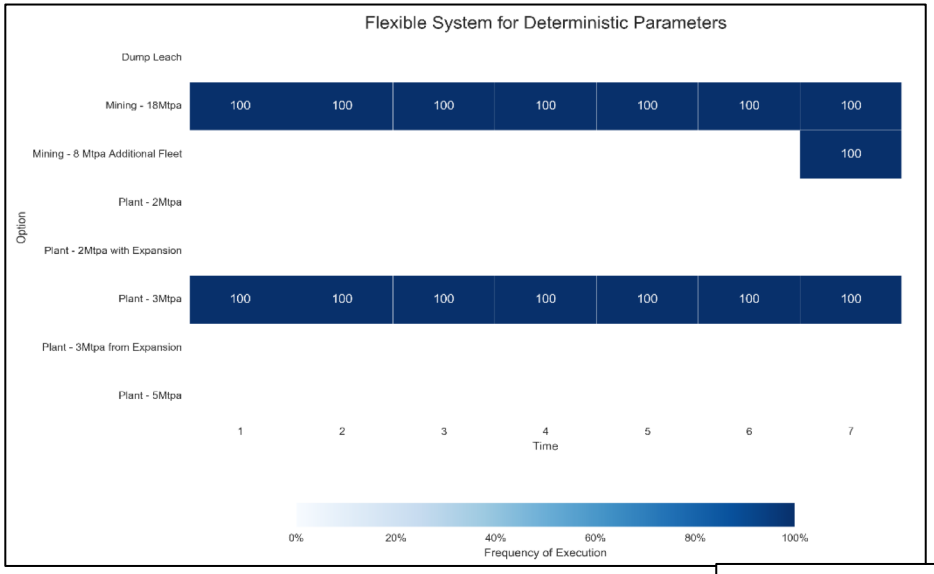


- Flexible system configuration generates optimal configuration for each period
- Mining – 8Mtpa has FoE higher than 100% as it executes multiple times in some cases
- Recommends:
  - Mining 18Mtpa (p1-7)
  - Mining Expansion (p5-7)
  - Plant 3Mtpa (p2-p7)

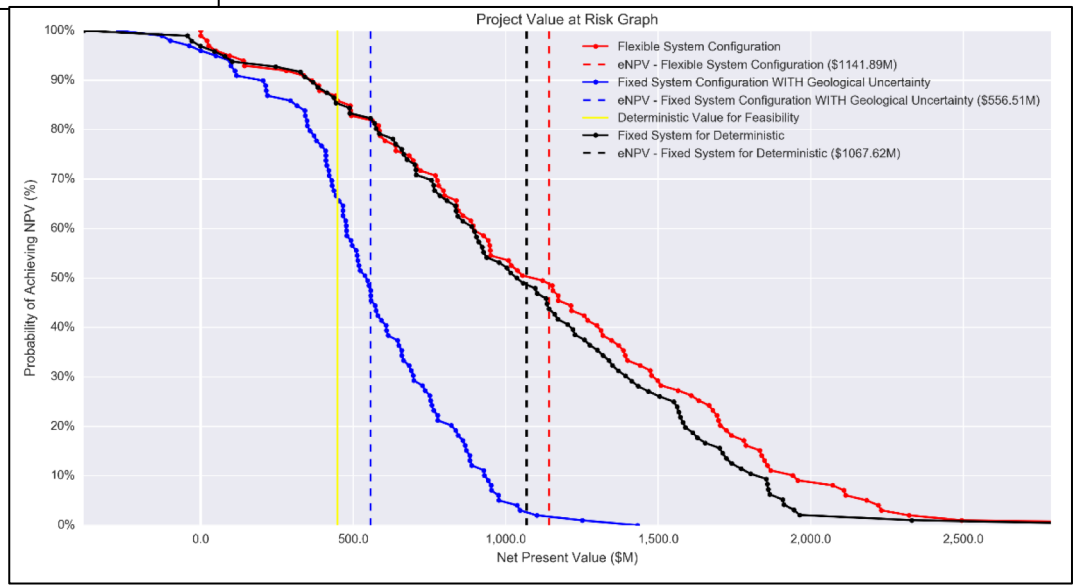
- Flexible System Configuration value distribution
- ENPV - $1142M



Flexible System for Deterministic

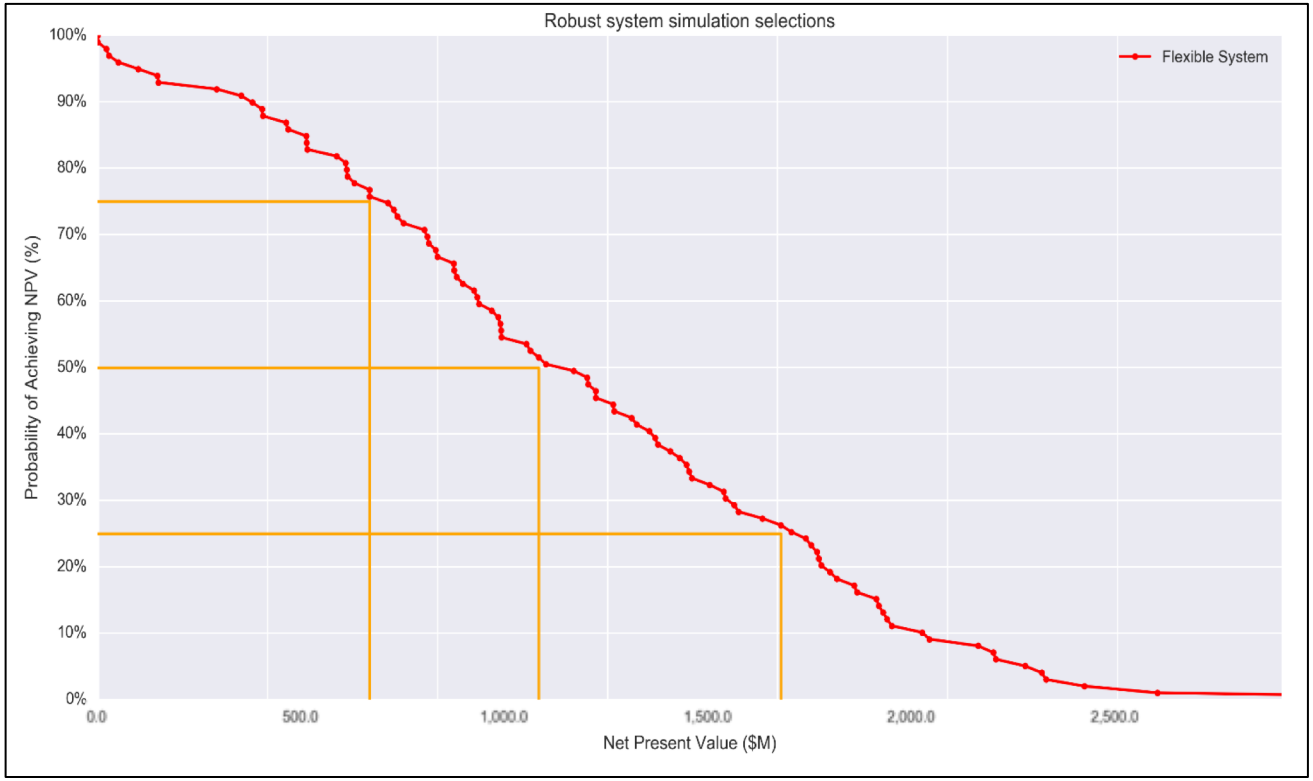


- Include Design Options in optimisation process to determine System Configuration simultaneously with mine schedule

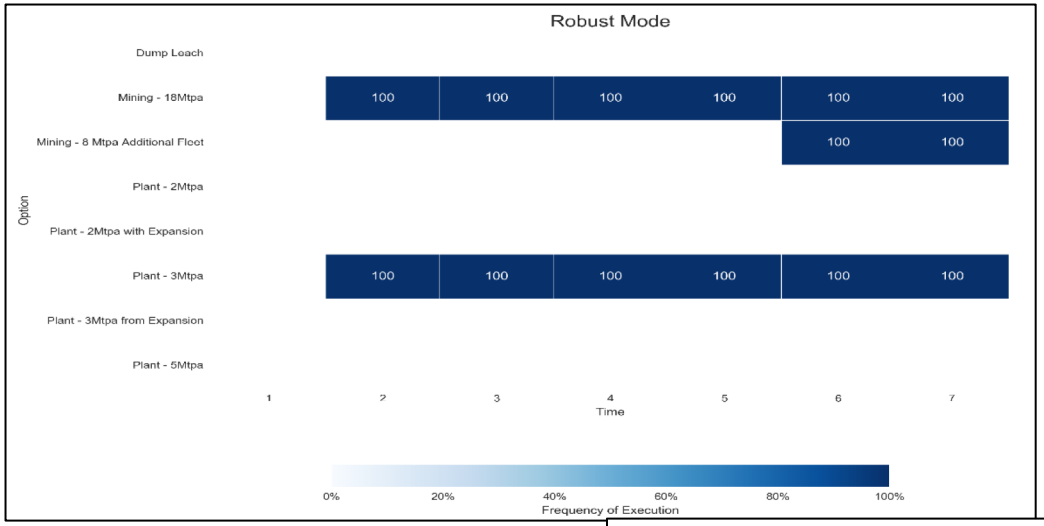


- With the proposed ‘fixed’ system configuration determine distribution of value by examining performance under uncertainty
- Significant increase in ENPV to $1067M compared to feasibility of $556M

Robust System

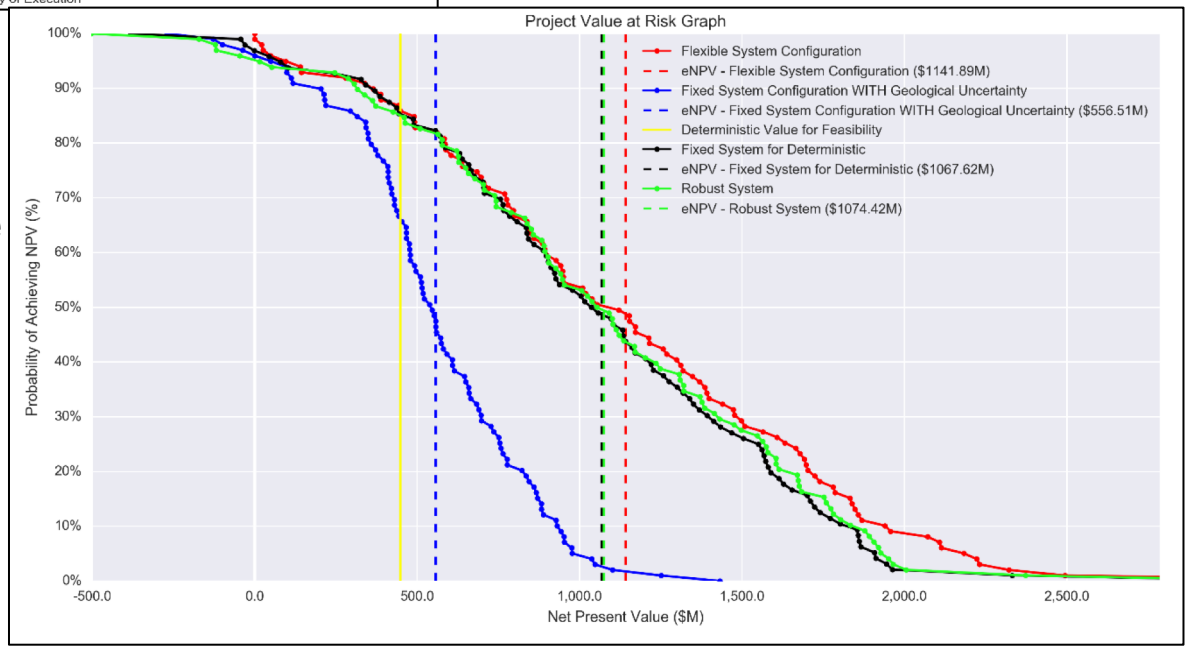


Robust System

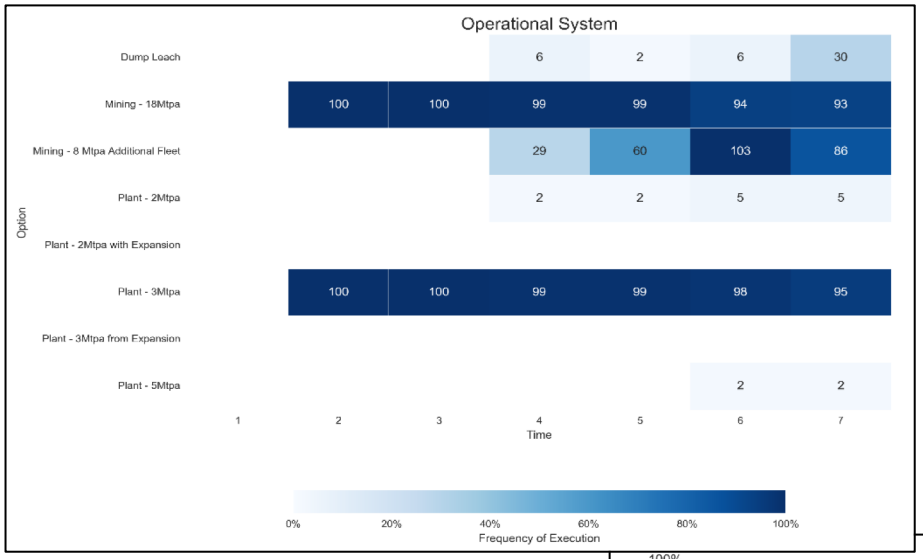


- Single system configuration that handles 3 simulations the best
- Delay of operation commencement by 1 year (allow uncertainty to resolve)

- Increase in ENPV to $1074M
- Greater losses but more upside potential

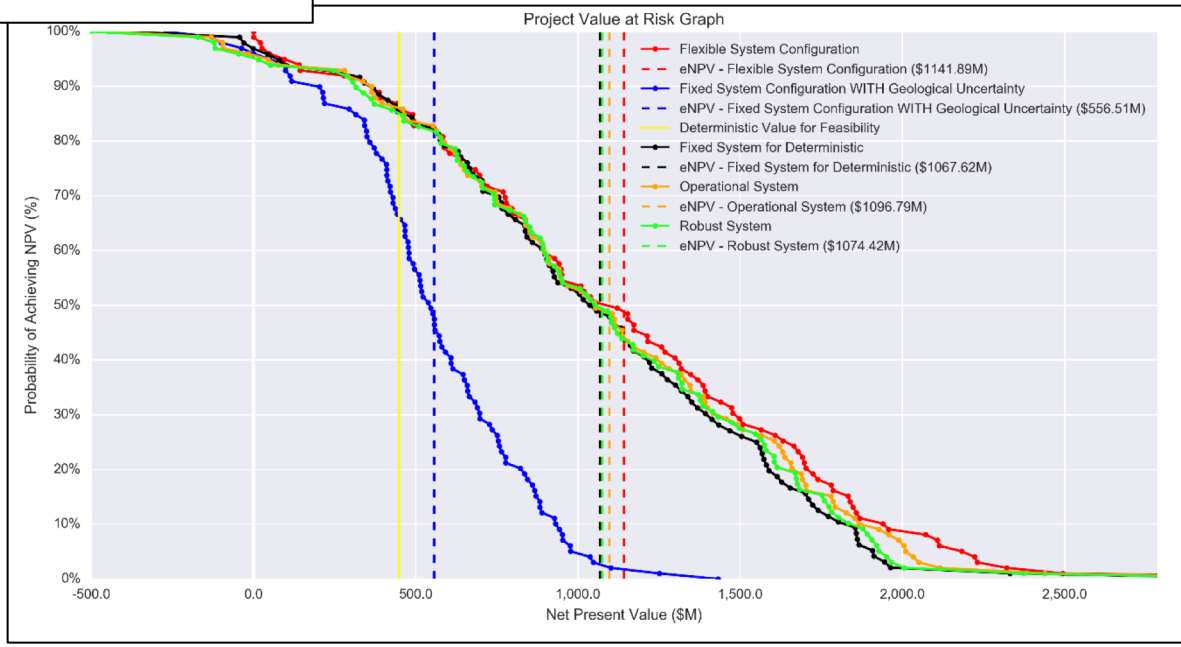


Operational System



- Fixed System Configuration for Decision Periods 1 – 3
- Flexible System Configuration in later Decision Periods

- Increase in ENPV to $1096M
- Operational system configuration allows a robust decision to be made in initial periods with flexibility maintained in later periods



Summary

Name	Expected Project Value ($M)
Feasibility Study	447
Feasibility Sched	556
Fixed System	1067
Robust System	1074
Operational System	1096
Flexible system	1142

- Fully Flexible system configuration is unrealistic as it assume perfect information
- Operational system configuration is the best due to inclusion of flexibility in later year

Take Away's

- Significant Increase in Expected Project Value by including Design Options in the optimisation process and simultaneously optimising
- Inclusion of Uncertainty in analysis process justifies including flexibility in the design