Modeling for concentrator design and optimisation

Casper Steenkamp

Introduction

- Process modeling applications
  - Circuit design
  - Circuit optimisation through APC
- Ease of application
  - Complexity of model configuration
  - Large systems
  - Skilled user required
- Current modeling work
  - Milling Simulator
  - Flotation Modeling Framework

Milling Simulator

MillStar Simulator

Overview

- Dynamic simulator integrated with StarCS control platform
- Simulate nonlinear models described as ordinary differential equations
- Allow discrete process units to be connected arbitrarily to form any required process
- Ability to use model as a soft-sensor on industrial plant

MillStar Simulator

Technical Background

- Framework for easily adding new models to the simulator
  - Flexibility (only calculate states and outputs)
  - Can accurately simulate time-delays
  - Each input, output, state and parameter can have a variable number of entries (e.g. arbitrary number of size classes)
- Automatically determine solution order of process units to ensure valid results
- Internal Kalman filter
  - Use as soft sensor soft-sensor on industrial plant
  - Fitting model parameters to a plant online

MillStar Simulator

Applications – Circuit Design

- Enable rapid investigation of various flow-sheet options, such as
  - Sizing of mills, cyclones and sumps,
  - Flow-sheet changes, such as
    - Secondary sump-cyclone,
    - Pebble crusher,
    - etc
  - Operating conditions, such as mill ball loads and mill volumetric charge filling.

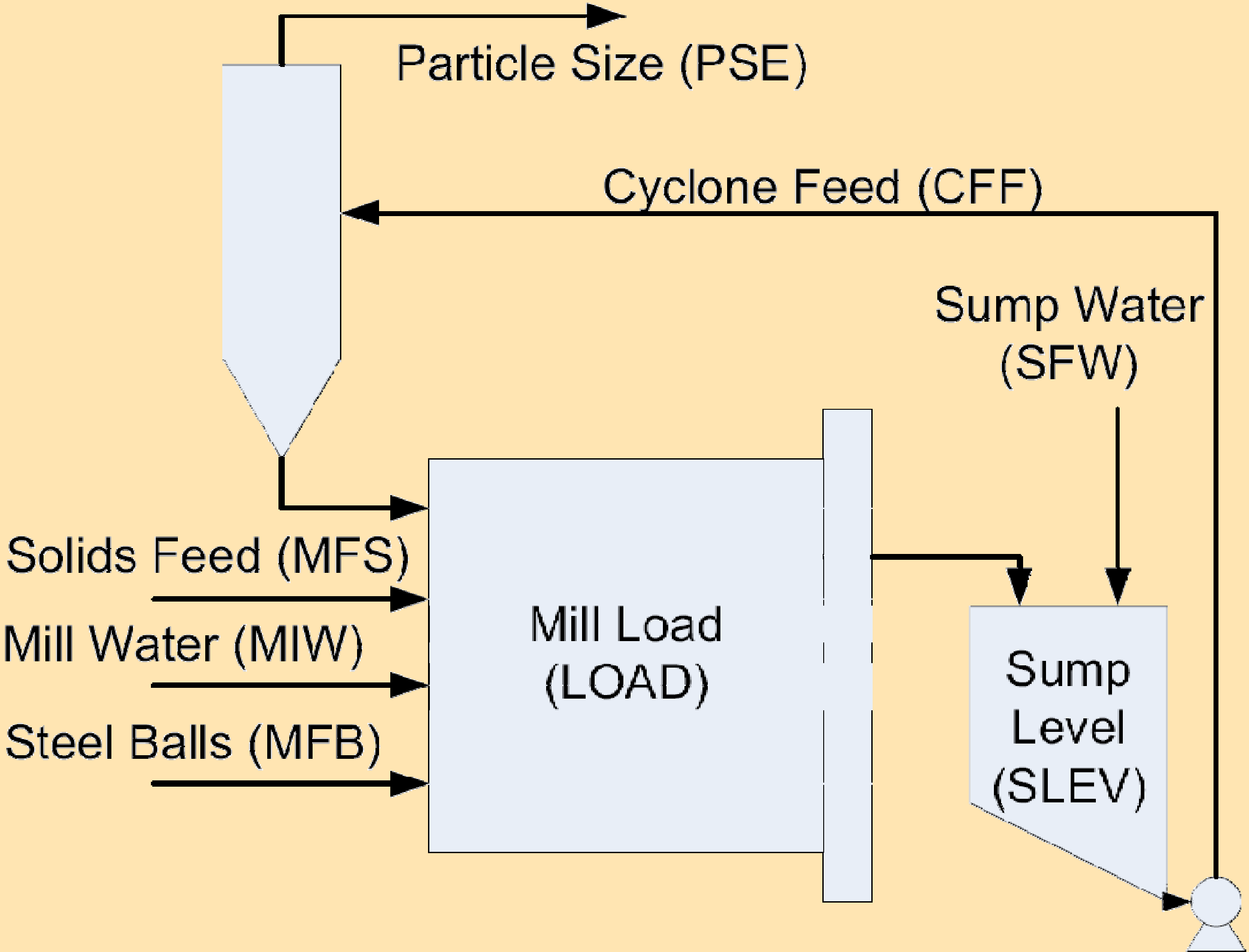
MillStar Simulator

Applications – APC Design

- APC design based on a model of a client's plant.
  - Setup controller configuration before actual controller commissioning.
  - Testing various control strategies.
  - Testing loop times for MPC control.
  - Preliminary tuning of controllers based on the model.
  - Quantifying possible performance gains.

MillStar Simulator

Example



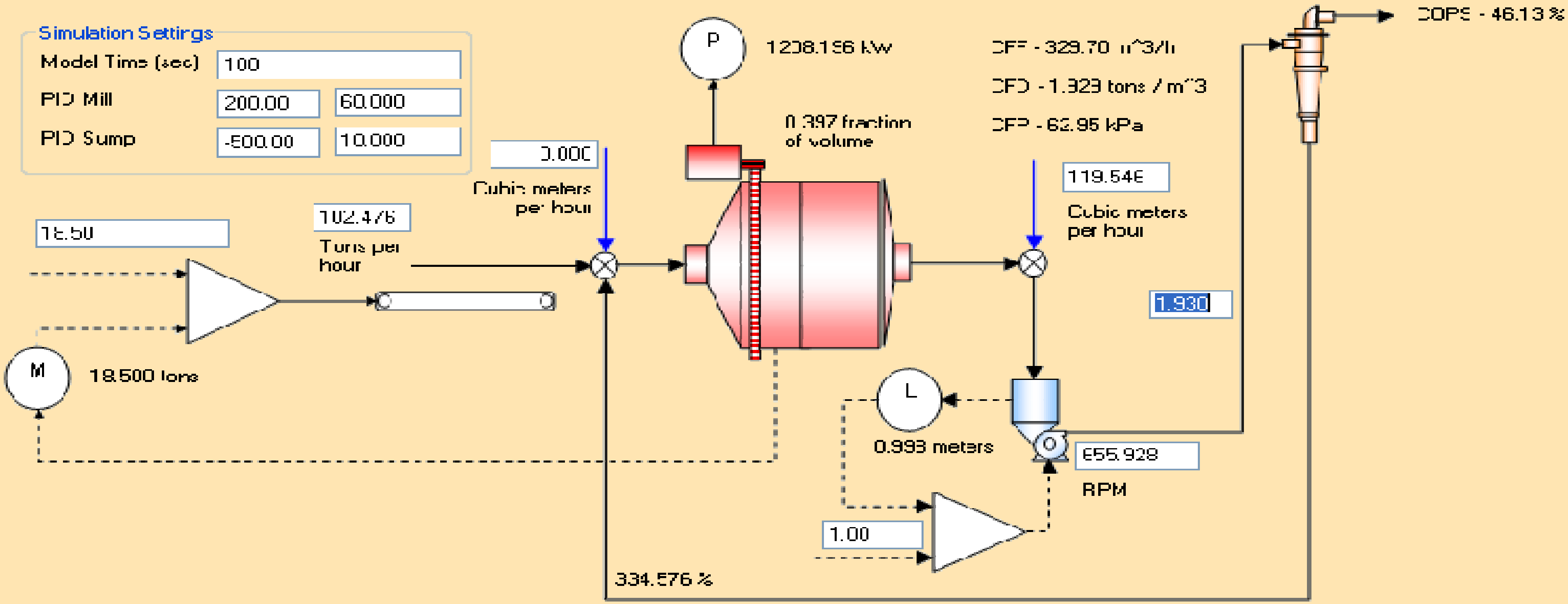
MillStar Simulator

Example

	Baseline	Target
Throughput	93 tons / hour	102 tons / hour (increase of 10%)
Ball Filling	24% of Mill volume	-
Total Charge Filling	33% of Mill Volume	-
Cyclone Overflow Volume Percentage Solids	58%	Maintain > 45%.
Grind	58% < 75 µm	Maintain at 58%

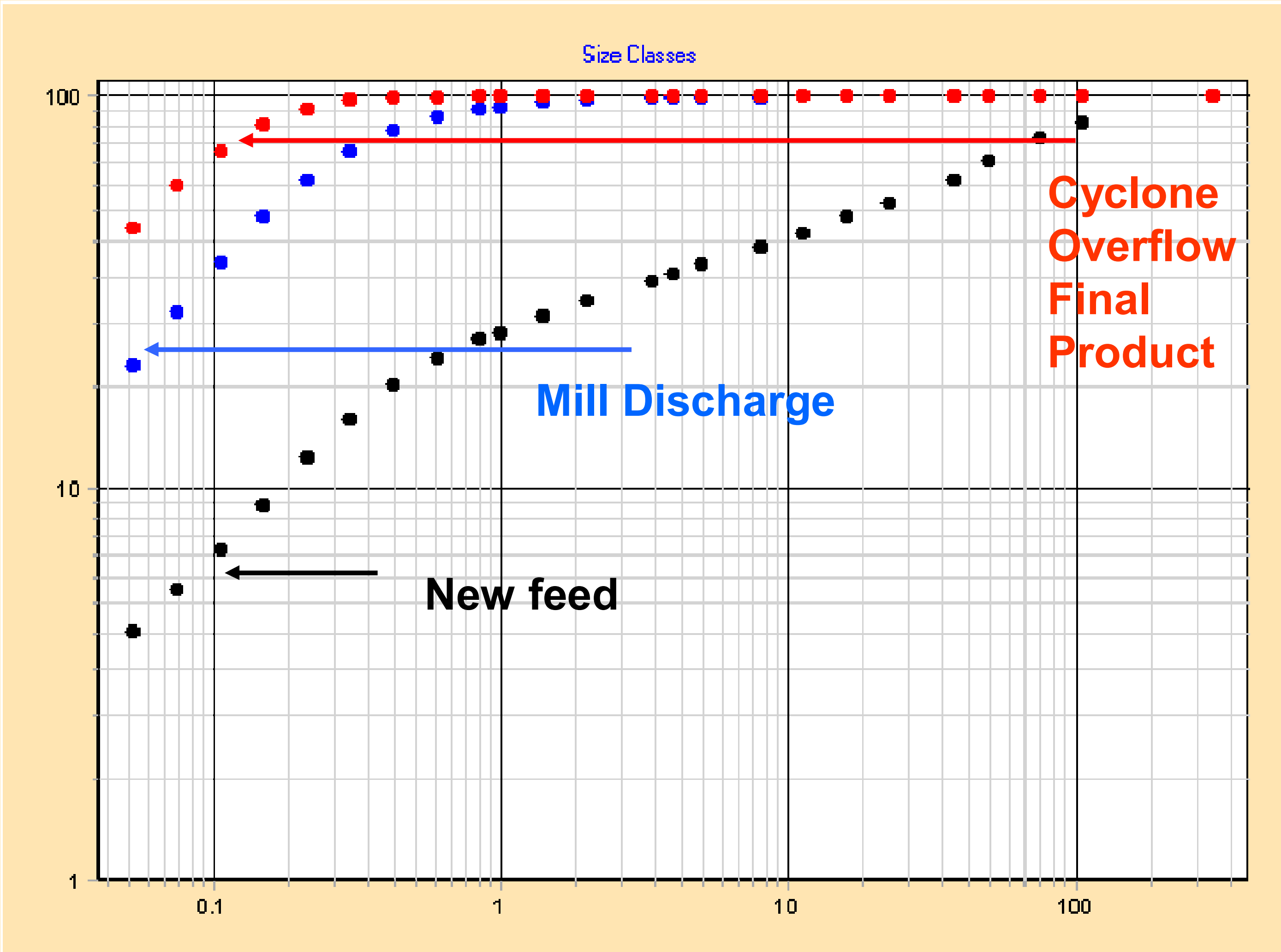
MillStar Simulator

Example



MillStar Simulator

Example



MillStar Simulator

Example

	Baseline	Target	Final
Throughput (tons / hour)	93	102 (10% increase)	102
Ball Filling (% of Mill Volume)	24%	-	30%
Total Charge Filling (% of Mill Volume)	33%	-	39.7%
Cyclone Overflow Volume Percentage Solids	58%	>= 45%	46%
Grind (% < 75 µm)	58%	>= 58%	59%

Flotation Circuit Model Framework

Flotation Circuit Model Framework

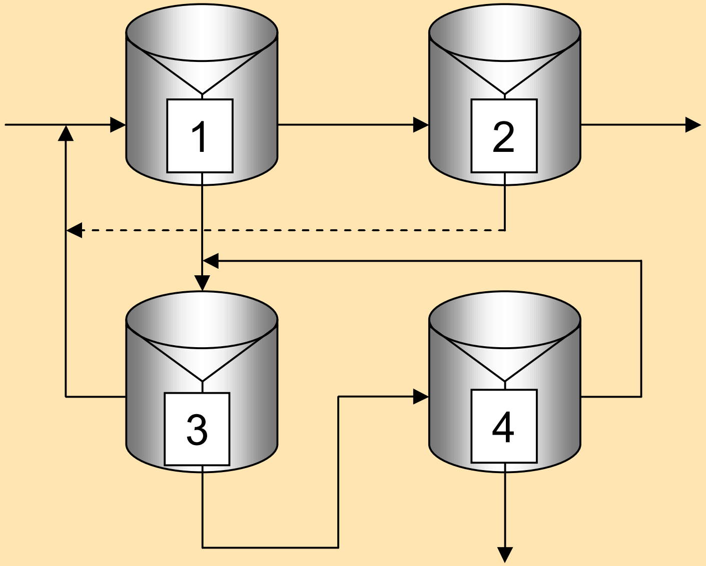
Overview

- A robust and accurate flotation circuit model will be very useful for
  - exploring flowsheet options
  - assisting in the correction of operational issues
  - comparing the performance of pilot- and full-sized plants
  - optimisation and control
  - plant design

- The framework is capable of
  - fitting rate parameters
  - solving circuit mass- and volume balances
  - simulating the behavior of a specific ore in different circuits

Flotation Circuit Model Framework

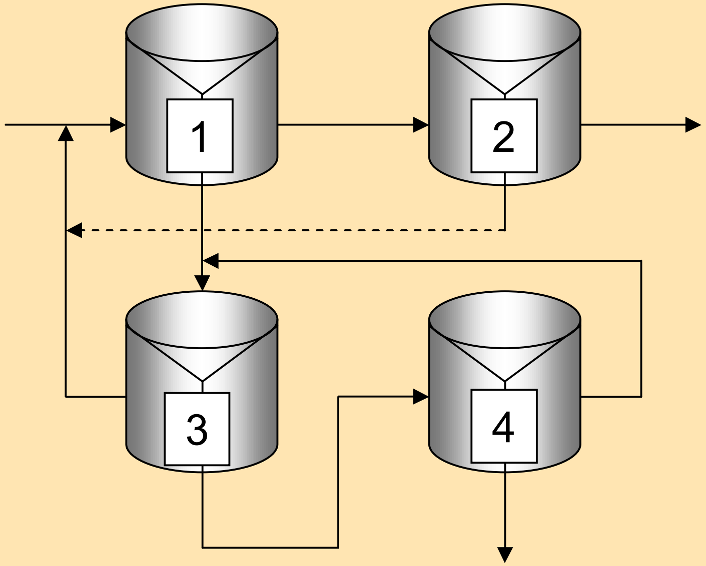
Defining the Circuit



External Feed Matrix				
	Bank 1	**Bank 2**	**Bank 3**	**Bank 4**
Specie 1	0.2	0	0	0
Specie 2	0.25	0	0	0
Specie 3	1.4	0	0	0

Flotation Circuit Model Framework

Defining the Circuit

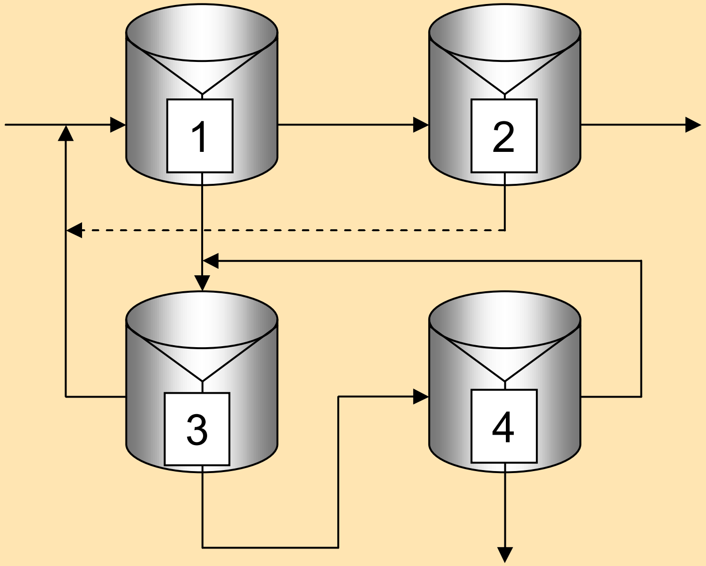


Tailings Config Matrix

		FROM			
		Bank 1	**Bank 2**	**Bank 3**	**Bank 4**
TO	**Bank 1**	0	0	1	0
	Bank 2	1	0	0	0
	Bank 3	0	0	0	1
	Bank 4	0	0	0	0

Flotation Circuit Model Framework

Defining the Circuit



Concentrate Config Matrix

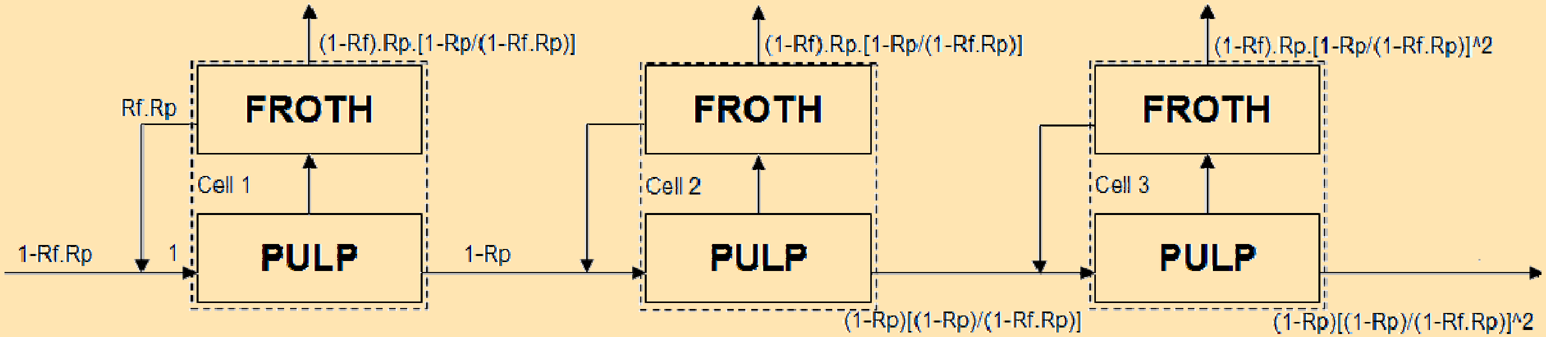
		FROM			
		Bank 1	**Bank 2**	**Bank 3**	**Bank 4**
TO	**Bank 1**	0	1	0	0
	Bank 2	0	0	0	0
	Bank 3	1	0	0	0
	Bank 4	0	0	1	0

Flotation Circuit Model Framework

Models

- True Flotation
  - First order (pulp/froth) flotation model
  - Derived for multiple cells per bank

$$\text{Bank Recovery} = 1 - \left(\frac{(1 - R_P)}{1 - R_P R_F} \right)^n$$

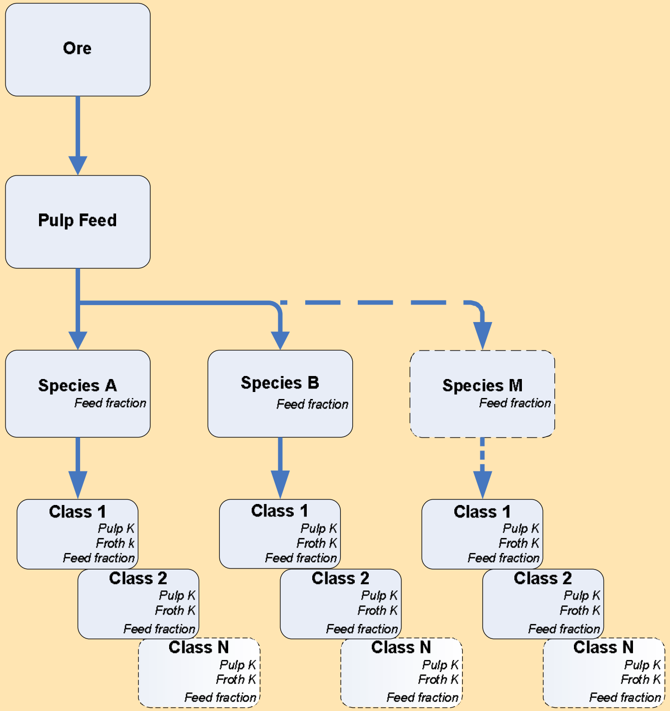


- Entrainment
  - Moys entrainment model
  - Derived for multiple cells per bank

Flotation Circuit Model Framework

Regression

- Inputs
  - 1 Circuit mass balance
  - 2 Layout
  - 3 Sizing
  - 4 Flow Rates
  - 5 Ore composition
  - 6 Operating conditions



- Parameters are regressed by running the algorithm on experimental pilot-plant data
- Recovery calculated from rate parameters and mass balance is solved

Flotation Circuit Model Framework

Applications – Circuit Design

- Circuit Simulation
- The regressed parameters can be used to simulate:
  - the same circuit, with different operational parameters
  - a differently configured circuit
- Intermediate step in a double pilot plant run
- Quantify the implications of small design alterations

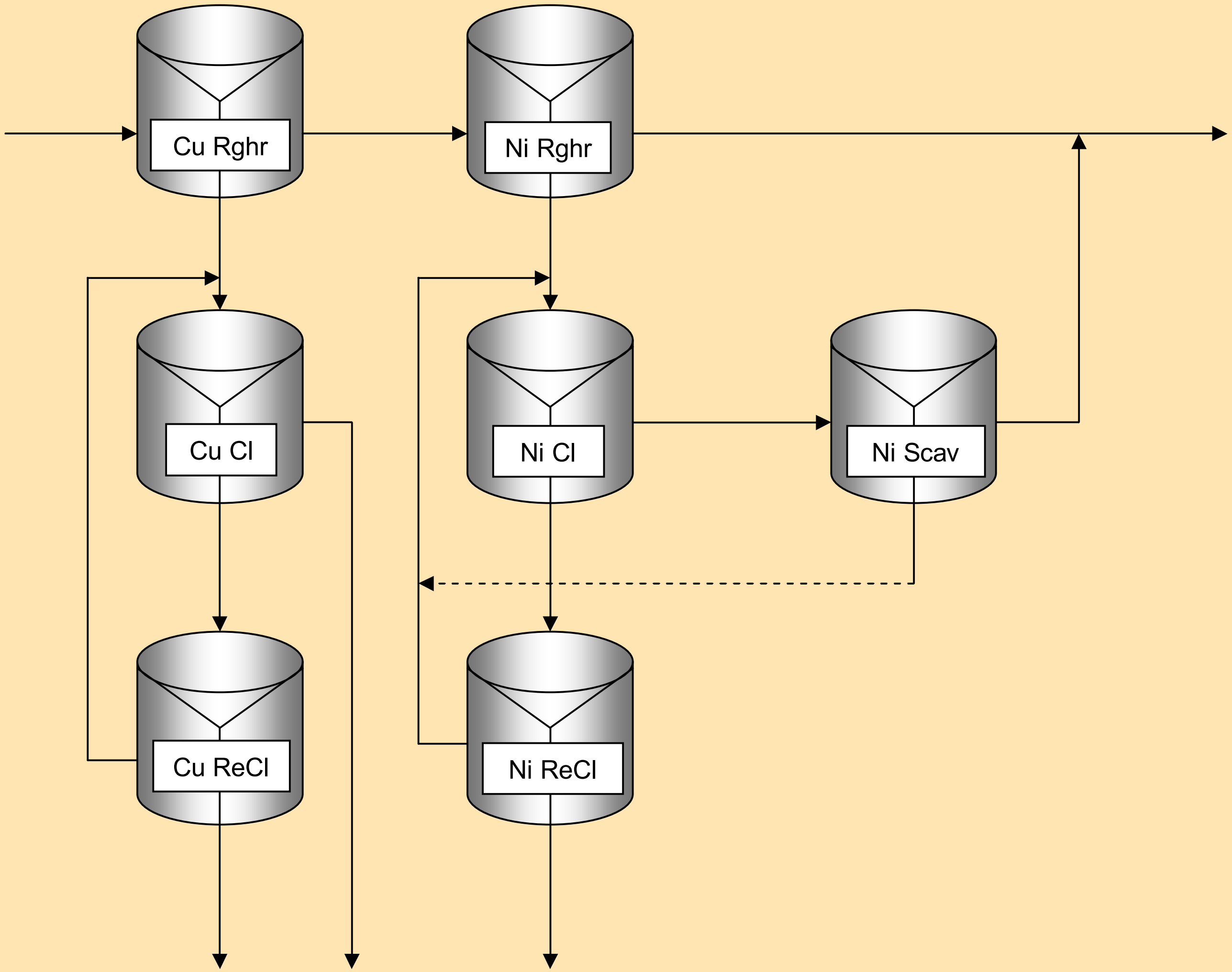
Flotation Circuit Model Framework

Applications – APC Design

- Quantify the implications of small changes in operational parameters
  - Determine effect on residence time, recirculating loads
- Soft-sensor
  - Use the model to provide more regular online grade measurements
  - Provide an indicative value if an online instrument should fail

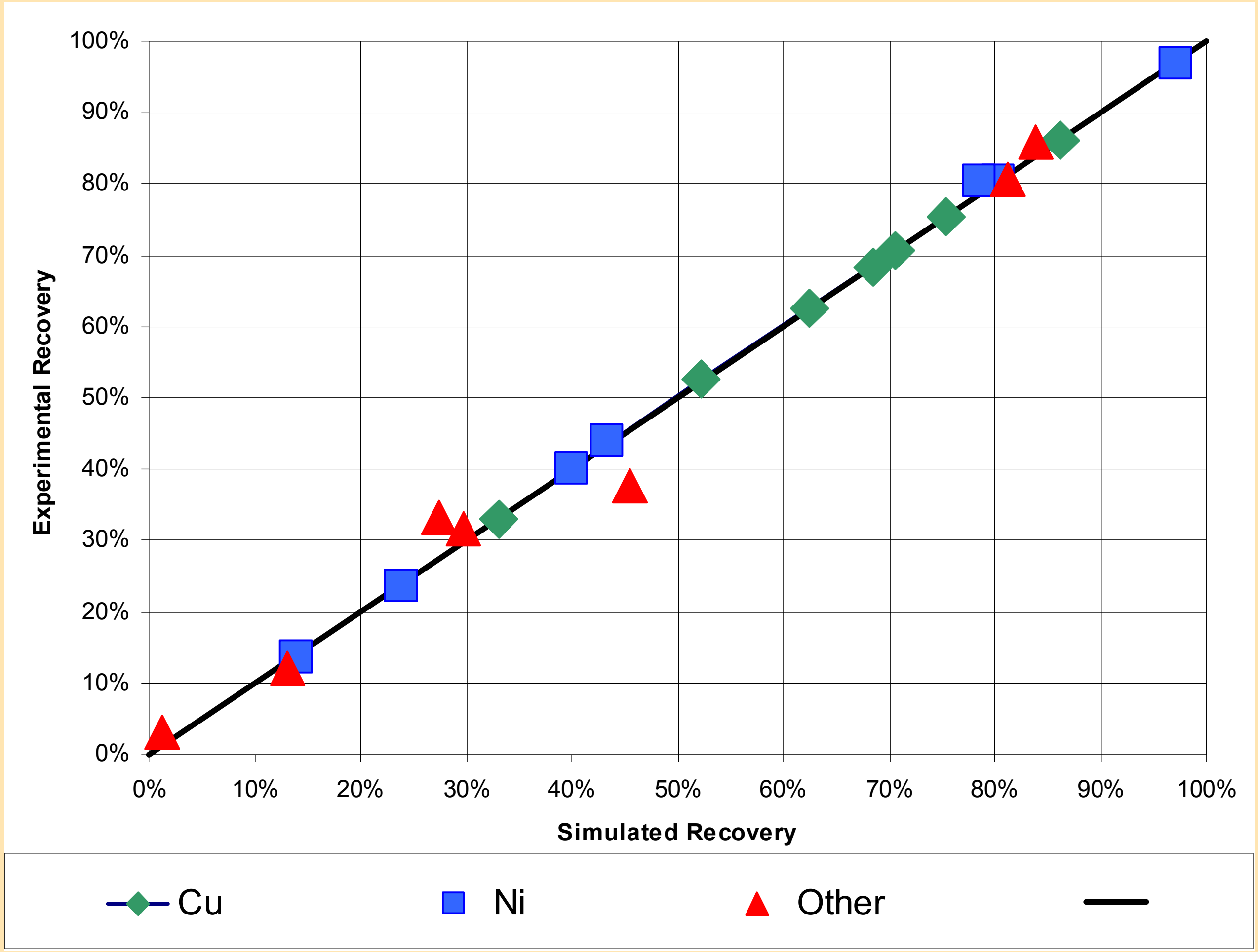
Flotation Circuit Model Framework

Example: Cu-Ni



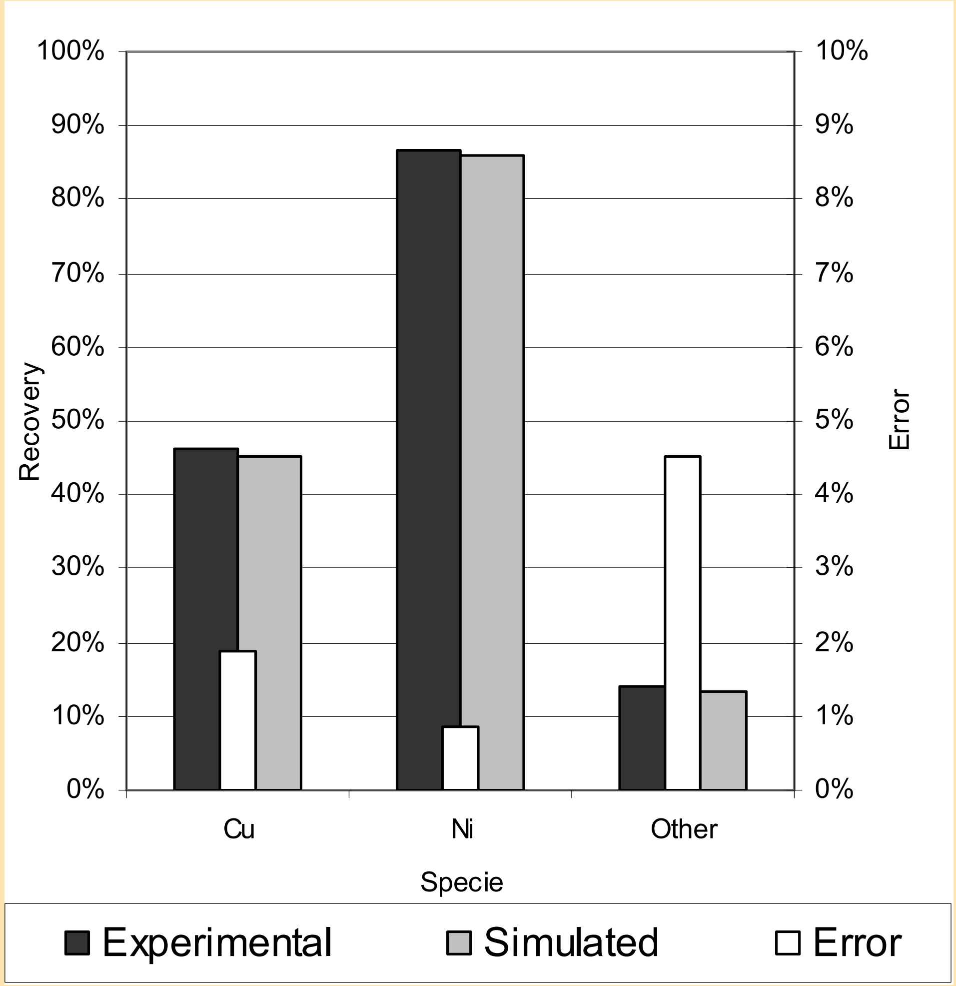
Flotation Circuit Model Framework

Example: Cu-Ni



Flotation Circuit Model Framework

Example: Cu-Ni



Flotation Circuit Model Framework

Example: Cu-Ni

SIMULATED SCENARIOS			
	RECOVERY		
SCENARIO	**Cu**	**Ni**	**Other**
No Change	**[45.23]**	**[85.92]**	**[13.25]**
Cu-Rougher Volume increase by 10%	1.7%	0.4%	0.1%
Cu-Cleaner tails back to Cu-Rougher feed	-13.6%	-50.3%	0.6%
Reduce feed flow rate by 10%	11.1%	3.7%	2.0%
Increase feed flow rate by 10%	-10.9%	-4.7%	-2.6%
Extra Ni cleaning stage (30L, 1 cell)	0.0%	-6.9%	-10.8%

Conclusions

- Model frameworks and simulators
  - Useful for design and optimisation
- Future work
  - Milling Simulator
    - GUI
  - Flotation Circuit Modeling Framework
    - Model refinements
    - GUI

Questions