MINE TO PLANT PRODUCTION SCHEDULING

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Introduction

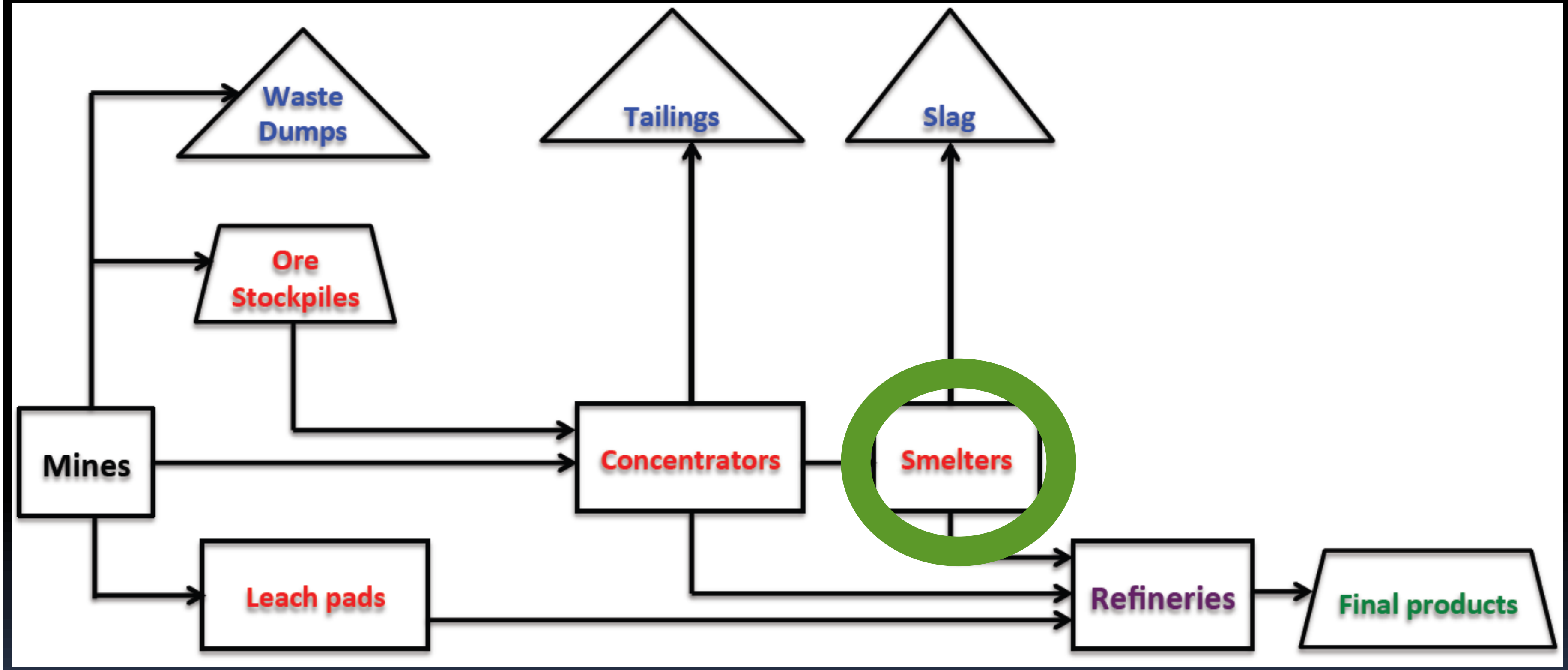
- Classical themes in industrial engineering
  - Production planning
  - Downstream logistics
- Mineral/metallurgical extraction
  - Particular structures
  - More than just plugging numbers into models
- Judgment and expertise to link the two
  - What to solve
  - How to solve

Introduction

- Part 1:
  - Strategic metallurgical production planning under geostatistical uncertainty
- Part 2:
  - Short-term smelter production scheduling

(Automatic scheduling of Altonorte operations using greedy algorithms)

Introduction



Part 1:

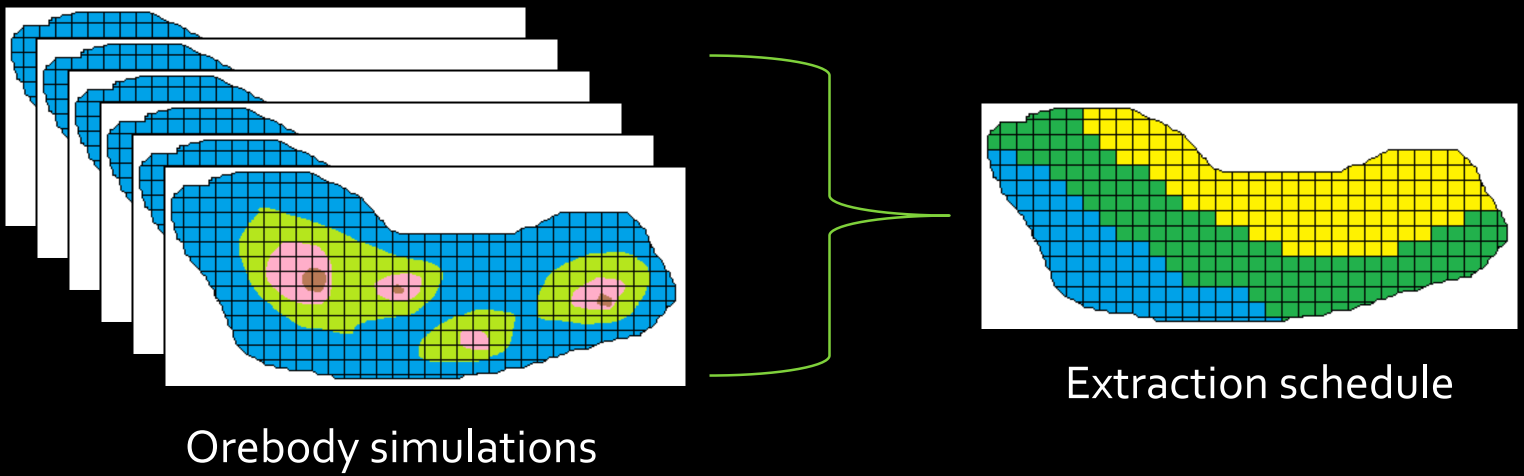
STRATEGIC METALLURGICAL PRODUCTION PLANNING UNDER GEOLOGICAL UNCERTAINTY

Overview

- Stochastic mine planning
- Centralized vs localized decision-making
- Bi-level approach to downstream optimization

Stochastic mine planning

- Capture geostatistical uncertainty
  - Repeated conditional simulations



- Constrained optimization
  - Maximize NPV ← (incomplete picture)
  - Respect constraints (capacity, blending, etc.)
- Extend scope of optimization??
  - (centralization of decision-making)

Centralized vs localized DM

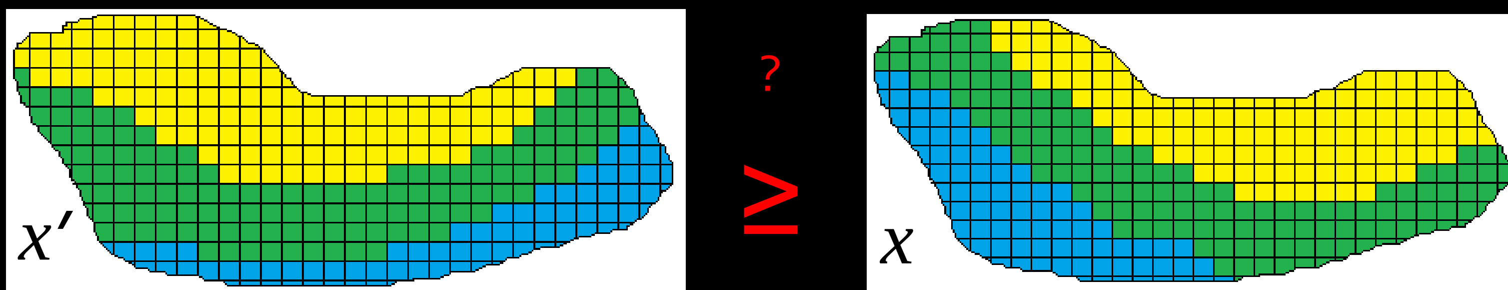
- Typical concern in industrial engineering
- Balance two perspectives
  1. Globalized solutions bring gains

$$\max_{x}\left[f(x,y_o) \right] \leq \max_{x,y}\left[f(x,y) \right]$$

  2. Local decision-makers to react to changing circumstances ("local manageability")
  - ***Low hanging fruit***: Reengineering balance between centralization and localization
- Unmanaged variability → overengineering of downstream operations

Metaheuristics

- Current application of metaheuristics
  - Compare two potential extraction plans



  - Compare $f\,(x')$ and $f\,(x)$
  - Update data structures accordingly
  - Continue searching for improvements…
- Downstream operations may be integrated within objective function f.

Bi-level optimization

$$f(x) = \max_{y} \left[f(x,y) \right]$$

- An optimization within an optimization

- Current approach
  - $f(x)$ is NPV of x
  - $f(x')$ is NPV of x'

  } Generic allocation of dowstream resources } Overengineered (suboptimal)

- Bi-level approach
  - $f(x)$ is NPV of x, given an optimal allocation of downstream resources for $y(x)$
  - $f(x')$ is NPV of x', given optimal allocation of downstream resources for $y(x')$

Bi-level optimization

- Outer optimization
  - Vast solution space
    - (discrete block orderings)
  - Subject to geological uncertainty

Metaheuristics

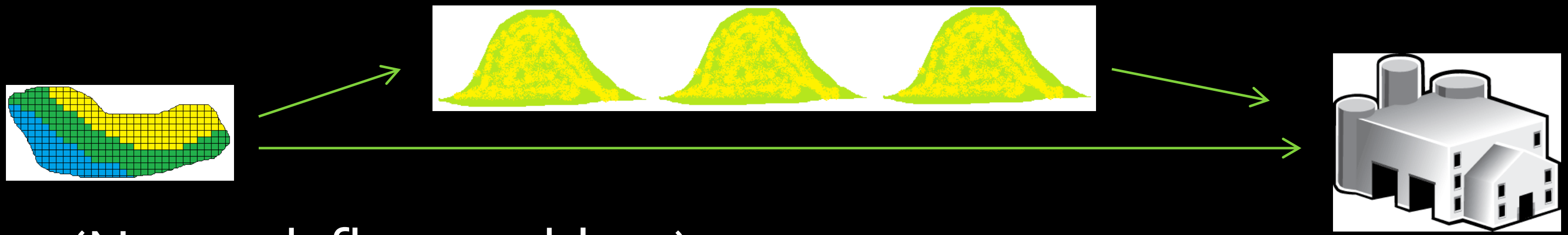
- Inner optimization
  - Continuous solution space
  - Dominated by mass flows
  - Subject to geological uncertainty

Linear program
(with embedded
flow network)

- Two proposals for bi-level formulations

Role of Linear Program

- Automate decisions for stockpiling v/s processing
  - When to <u>send material</u> to stockpiles?
  - When to <u>draw material</u> from stockpiles?
  - (Classical industrial engineering theme)



  - (Network flow problem)

- Allocation of resources
  - Divide <u>plant time</u> between several <u>modes of operation</u>
  - Divide <u>transport routes</u> between several <u>product streams</u>

- Evaluate proposed mine extraction plan (f)

Second Proposal

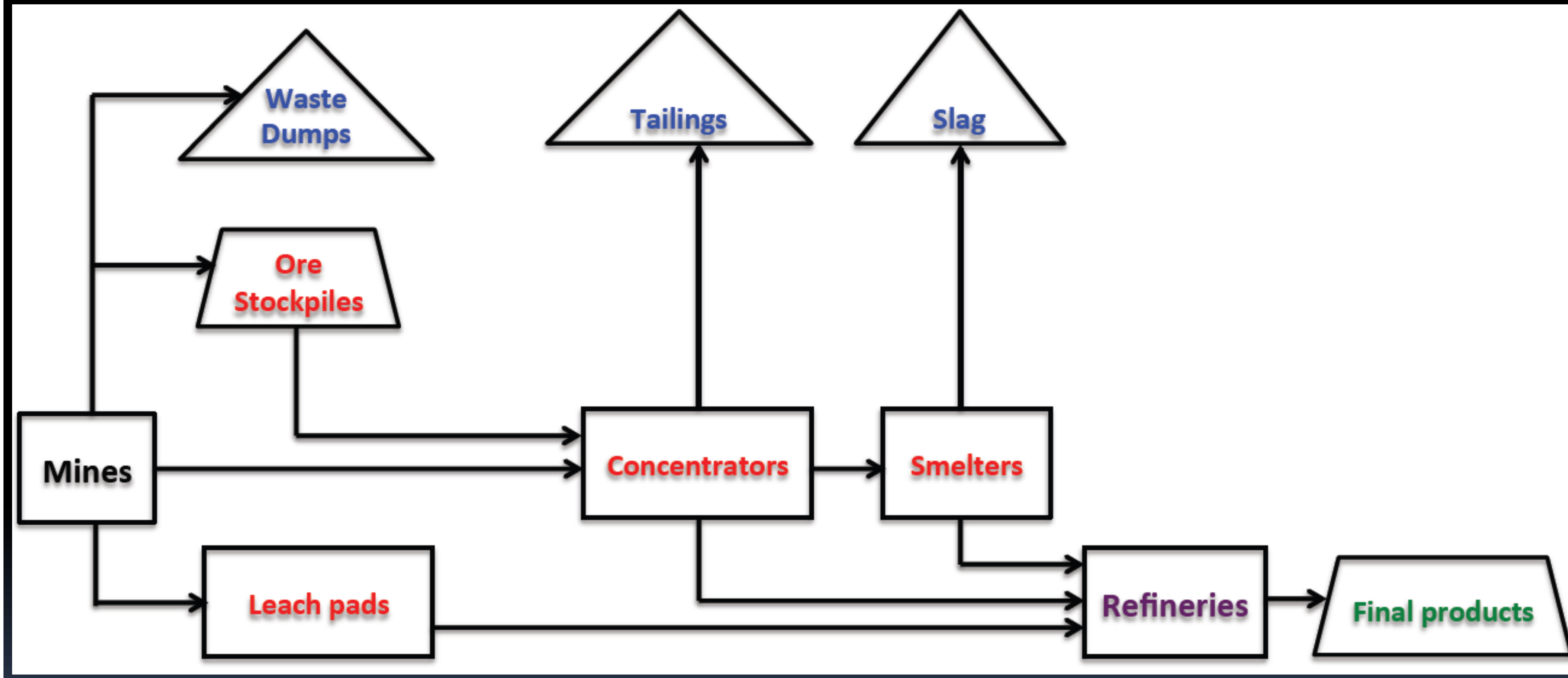
Preprocessing

- Generate set of orebody simulations
- Generate initial mine plan
- Evaluate initial mine plan using LP ← (inner optimization)

Loop

- Modify mine plan according to metaheuristic
- Evaluate mine plan using LP ← (inner optimization)
- Update data structures accordingly

Postprocessing


Waste
Dumps
Tailings
Slag
Ore
Stockpiles
Mines
Concentrators
Smelters
Leach pads
Refineries
Final products

Closing remarks

- Mine-to-plant production scheduling is an “easy” problem, except for the supply source
- This should be reflected in the computational approach
- Resist the urge to over-centralize decision-making, given the geological uncertainty

Automatic Scheduling of Altonorte Operations Using Greedy Algorithms

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Oscar Mendoza
Altonorte Smelter, Glencore-Xstrata

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Agenda

- Introduction
- Altonorte Operations
- Greedy Programming
- Extensions/Future Work

Introduction

- Common for smelters to use manual daily scheduling techniques

- Two problems:
  1. Suboptimality (w.r.t. any particular objective)
  2. Limits accuracy of simulation → decicion-making

- Altonorte has taken a first step
  - On par with Chuquicamata (Pradenas et al., 2006)
  - (we have developed more sophisticated algorithms, but not yet implemented)

Altonorte Operations

- **Level of Noranda Reactor : continuous**
- **Discrete PSC batches**

Semi-Discrete Dynamics

- **The Peirce-Smith Converter Problem**
  - **Scientific Basis for OR of Cu and Ni smelting**

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Altonorte Operations

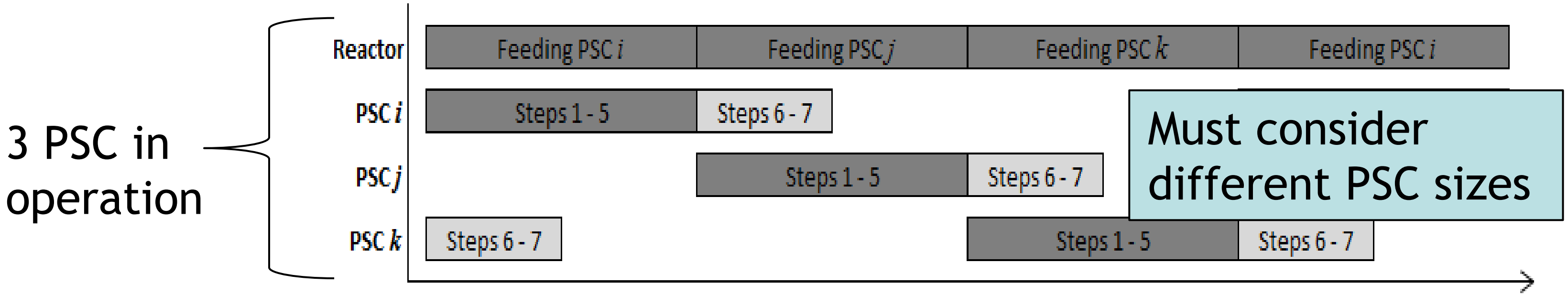
- **PSC at Altonorte**
  - **Seven step cycle**
    1. **Initial charging** (4 to 7 ladles, depending on which converter)
    2. **Blow**
    3. **Charge an additional ladle**
    4. **Blow**
    5. **Charge an additional ladle**
    6. **Final blow**
    7. **Final skim and discharge**
  - **High matte grade (~73%), so Cu-Blow dominates**
  - **Different sizes of converters**

Altonorte Operations

- **PSC at Altonorte**
  - **Coordination with Noranda Reactor**
  - **Merge steps**

    1-5: Initial charge, blow, charge additional ladle, blow, charge additional ladle

    6-7: Final blow, skim, discharge



  - **After Step 5, reactor is free to charge another converter**

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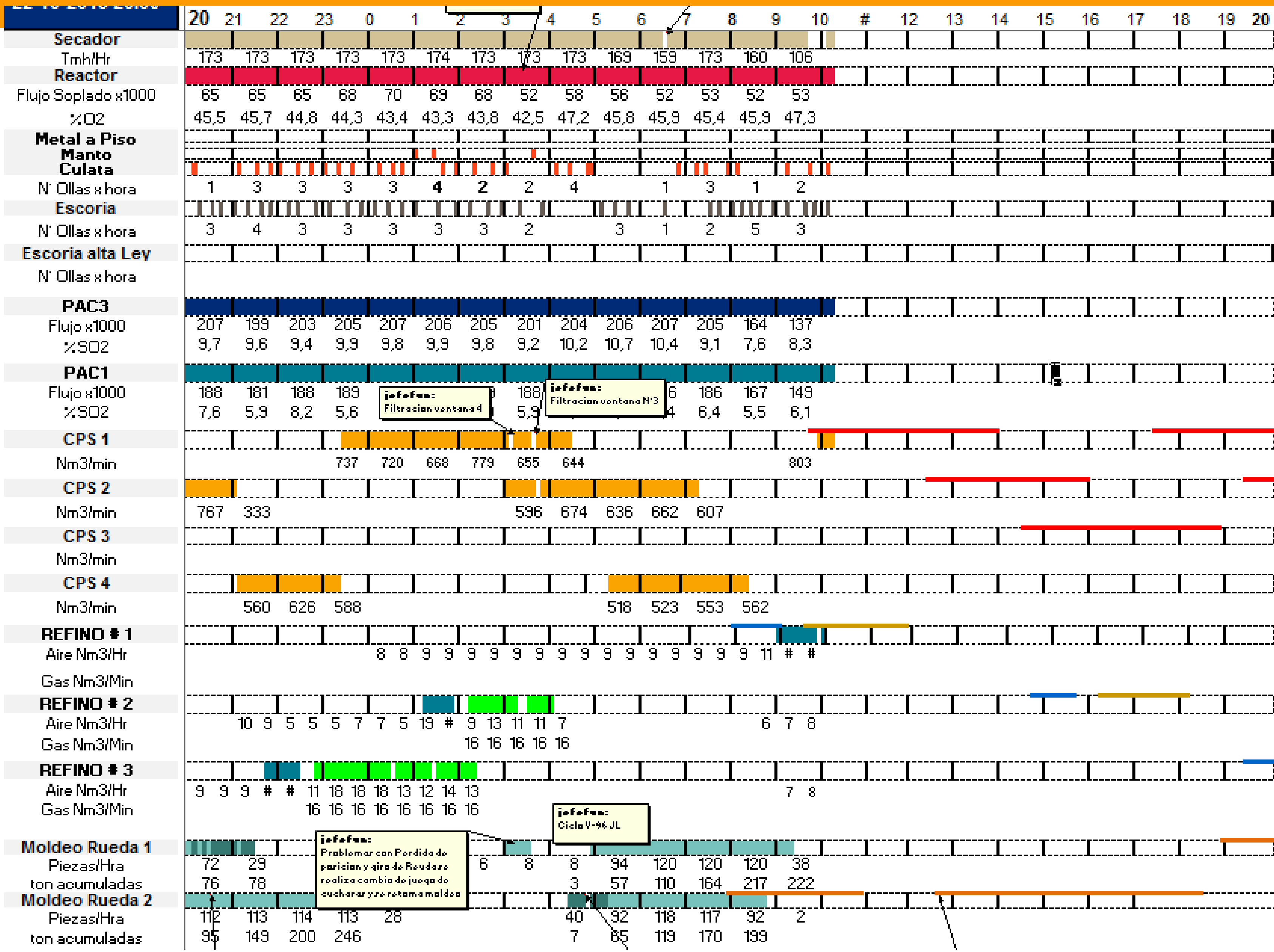
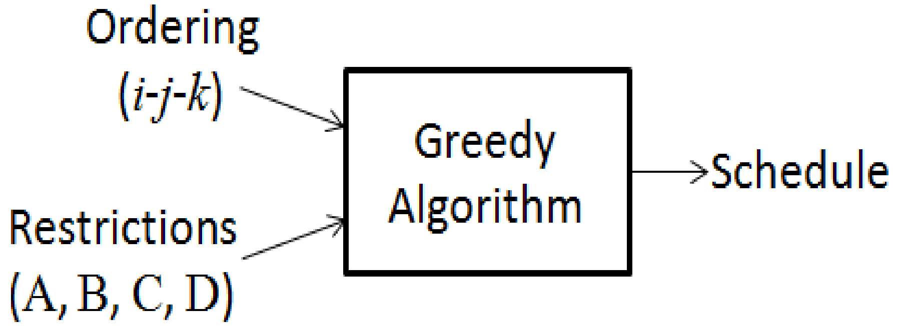
Altonorte Operations

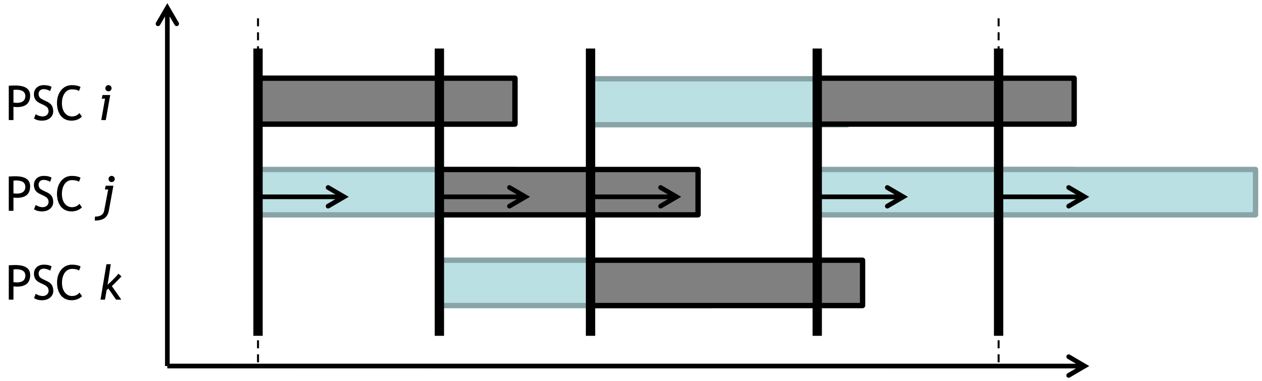


Greedy Programming

- **Integrated into combinatorial search**
  - **Find converter sequence that maximizes <u>number of converted ladles</u> in schedule**
- **Consider the following restrictions:**
  - **A) Initial conditions**
  - **B) Availability of converter**
  - **C) Availability of reactor** (consider production rate of reactor)
  - **D) Offgas handling system**



Greedy Programming



- **Given an ordering (*i*-*j*-*k*),**
  - **cursor advances from left to right**
  - **places the next cycle as <u>early as possible</u> (while respecting restrictions)**

"Greedy" → cursor only looks forward

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Greedy Programming

- **Mathematical formalism:**
  - **Consider ordering (*i-j-k*)**
  - **Consider the four restrictions A, B, C, D**

t_1 = starting time of <u>first cycle</u> of the new schedule

$= \max\{ t_1^A, t_1^B, t_1^C, t_1^D \}$

where t_1^A = earliest starting time for first cycle not to violate A

t_1^B = earliest starting time for first cycle not to violate B

t_1^C = earliest starting time for first cycle not to violate C

t_1^D = earliest starting time for first cycle not to violate D

Result: t_1 is the earliest time which satisfies all four conditions

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Greedy Programming

- **Mathematical formalism:**
  - **Similarly,**

t_2 = starting time of <u>second cycle</u> of the new schedule

$= \max\{ t_2^A, t_2^B, t_2^C, t_2^D \}$

  - **Calculation of** (t_2^B, t_2^C, t_2^D) **takes into account the first cycle**

(thus <u>second cycle</u> does not conflict with <u>first cycle</u>)

  - **More generally,**

t_l = starting time of l^{th} cycle of the new schedule

$= \max\{ t_l^A, t_l^B, t_l^C, t_l^D \}$

  - **Calculation of** (t_l^B, t_l^C, t_l^D) **takes into account the previous cycles,** $1,2,3,\ldots(l-1)$

(thus l^{th} **cycle does not conflict with <u>previous cycles</u>)**

Extensions/Future Work

- Paper also describes the management of Refining/Casting

- More advanced algorithms
  - Alternate objectives (modes of operation)
    - Convert as much matte as possible
    - Reduce a certain class of WIP
    - Use as little energy as possible, etc.

- Operations Research of Cu Smelting