




MINE TO PLANT PRODUCTION SCHEDULING



Prof. Alessandro Navarra
Department of Industrial Engineering
Universidad Católica del Norte




Introduction

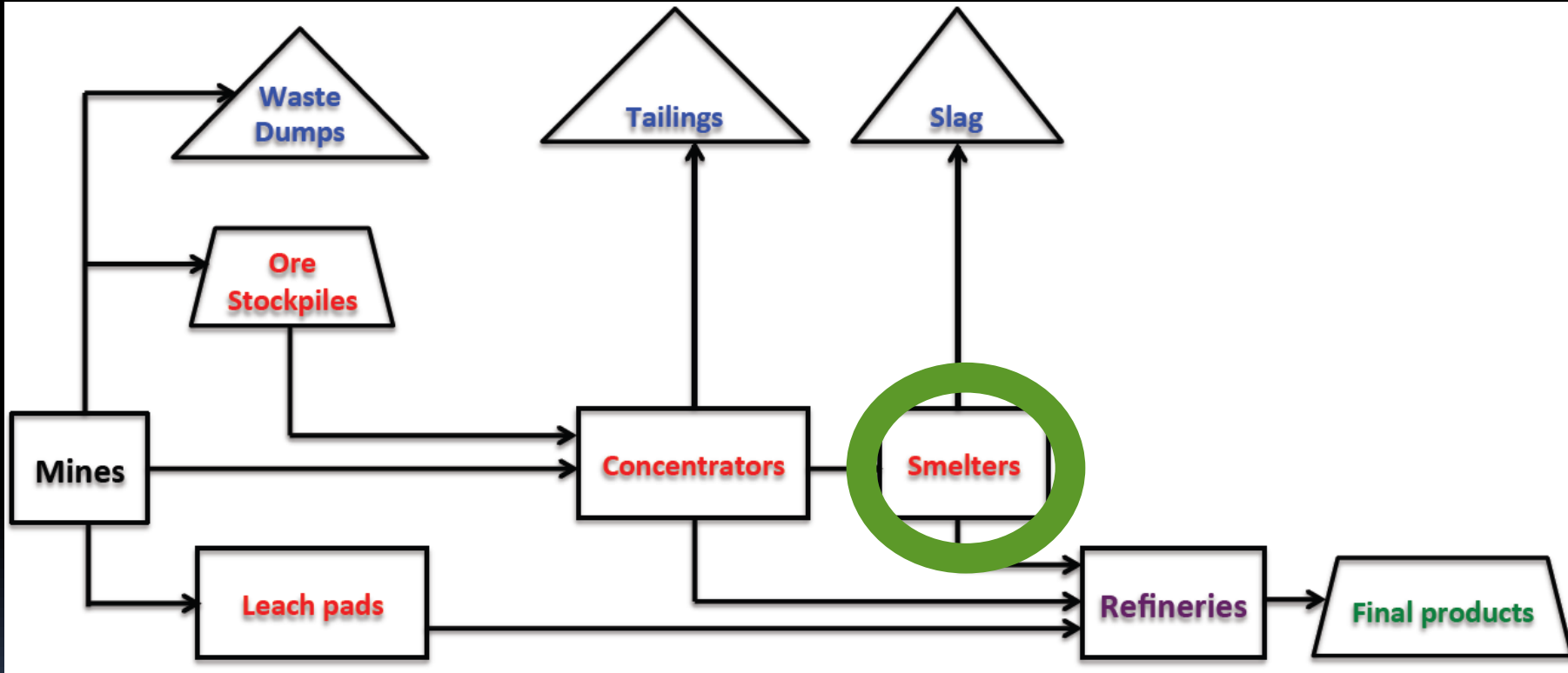
- Classical themes in industrial engineering
 - Production planning
 - Downstream logistics
 - Mineral/metallurgical extraction
 - Particular structures
 - More than just plugging numbers into models
 - Judgment and expertise to link the two
 - What to solve
 - How to solve
- 



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



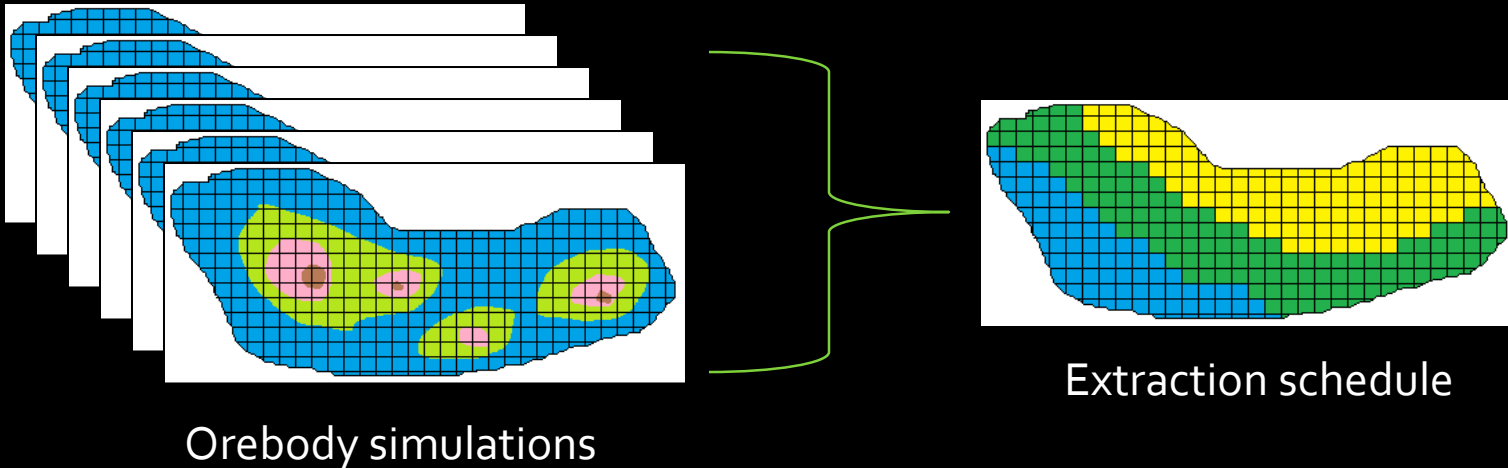


Overview

- 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

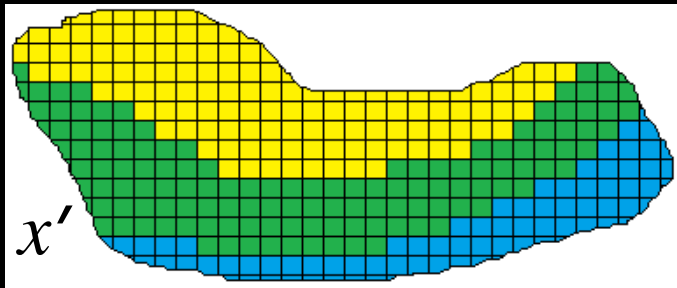
$$\max_x \left[f(x, y_o) \right] \leq \max_{x,y} \left[f(x, y) \right]$$

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

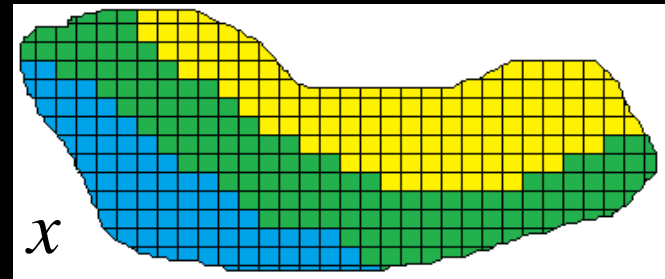
Metaheuristics

- Current application of metaheuristics
 - Compare two potential extraction plans



?

\geq



- 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 downstream 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

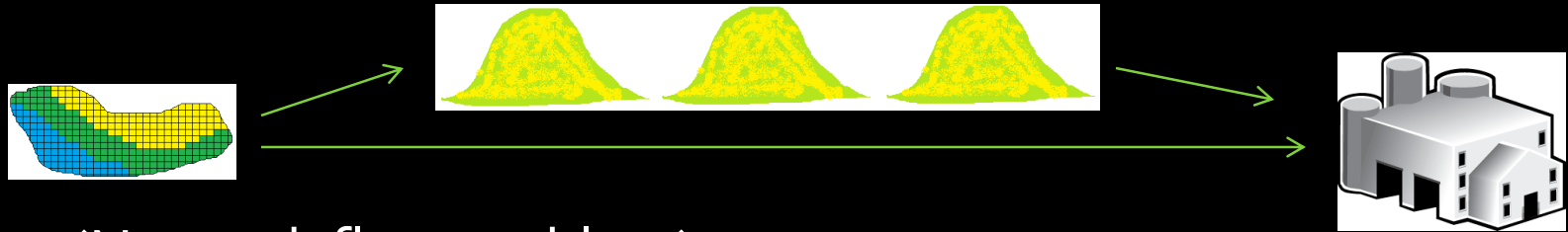
- Outer optimization
 - Vast solution space
 - (discrete block orderings)
 - Subject to geological uncertainty

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 send material to stockpiles?
 - When to draw material from stockpiles?
 - (Classical industrial engineering theme)



- (Network flow problem)
- Allocation of resources
 - Divide plant time between several modes of operation
 - Divide transport routes between several product streams
- Evaluate proposed mine extraction plan (f)

Second Proposal

Preprocessing

- Generate set of orebody simulations

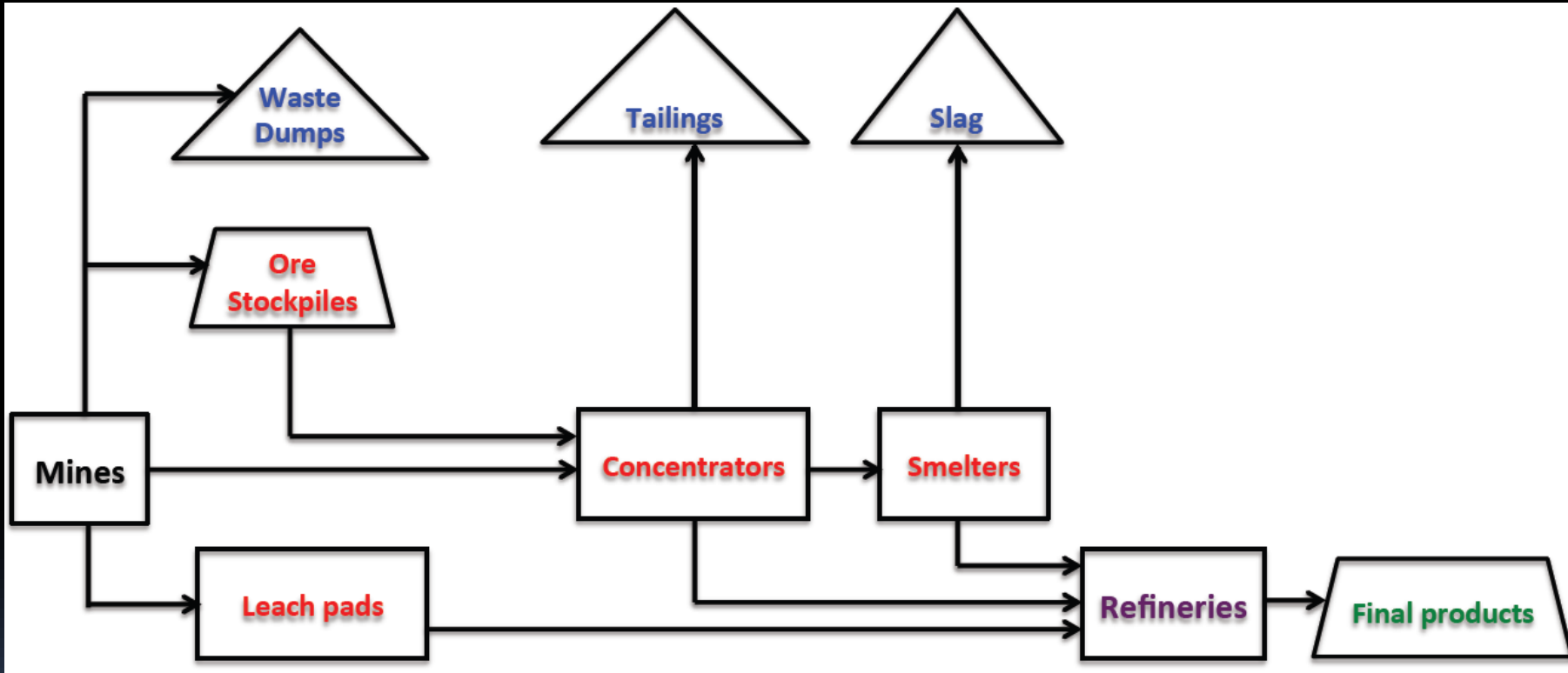


- Generate initial mine plan
- Evaluate initial mine plan using LP ← (inner optimization)

Loop


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

Postprocessing





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

Prof. Alessandro Navarra
Universidad Católica del Norte

Oscar Mendoza
Altonorte Smelter, Glencore-Xstrata



Universidad Católica del Norte
ver más allá

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 → decision-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**



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

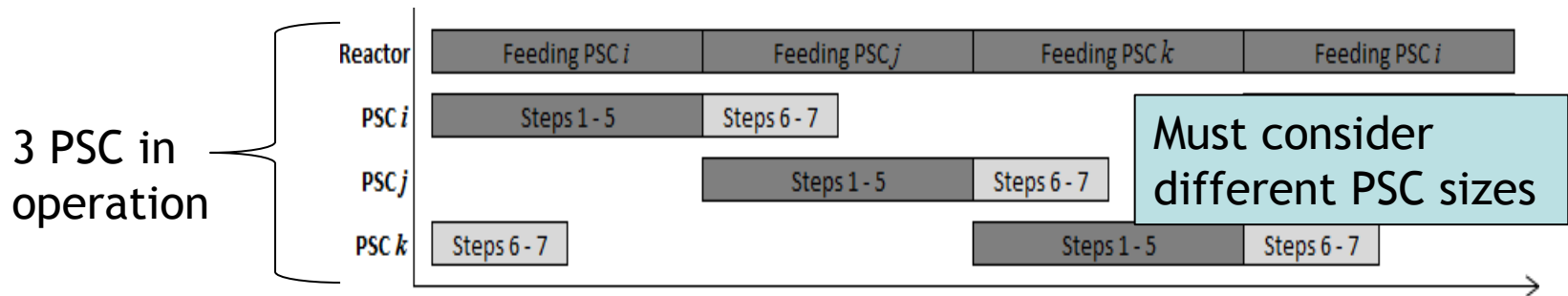
- **PSC at Altonorte**

- **Coordination with Noranda Reactor**

- **Merge steps**

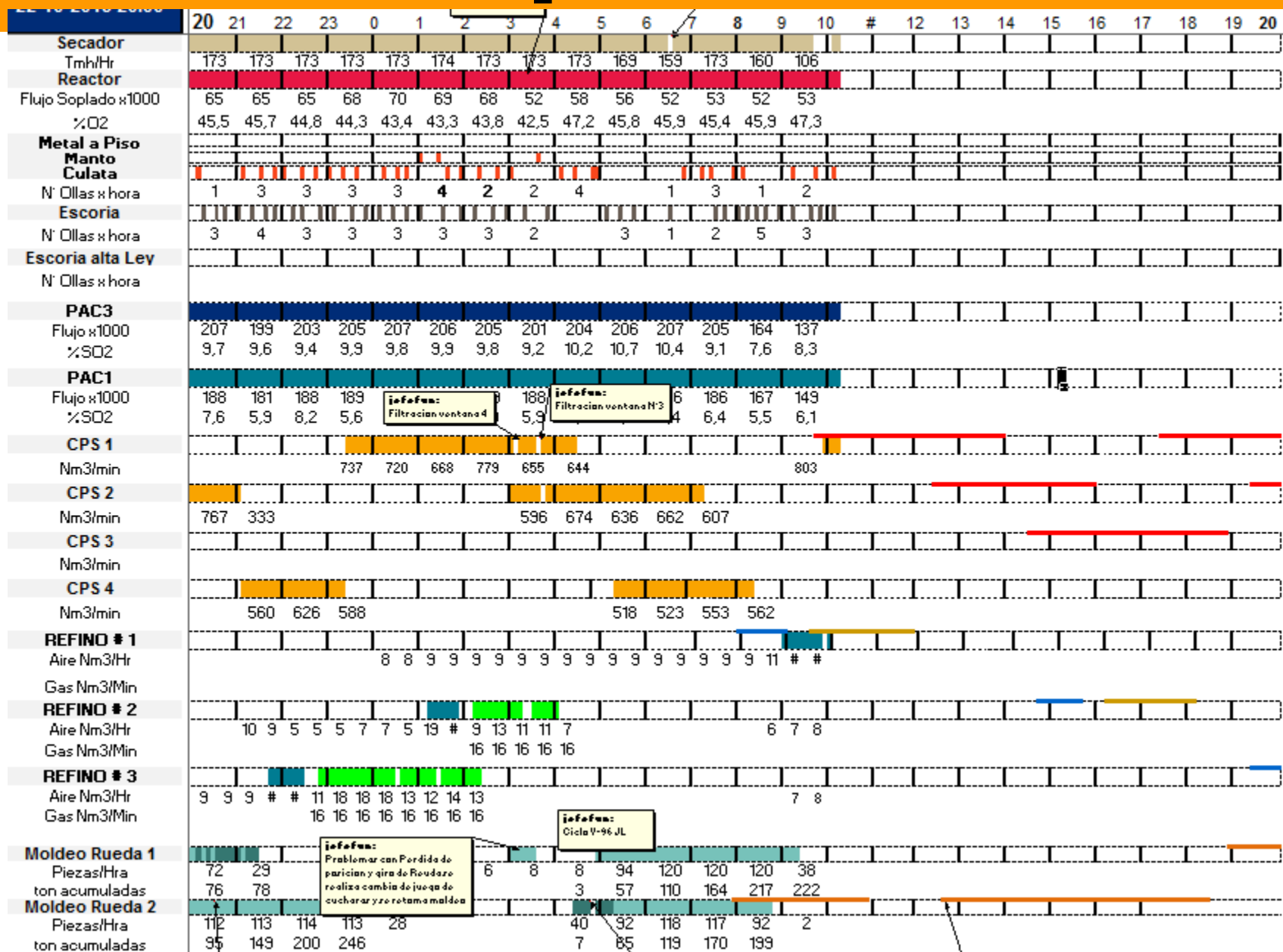
- 1-5: Initial charge, blow, charge additional ladle, blow, charge additional ladle**

- 6-7: Final blow, skim, discharge**



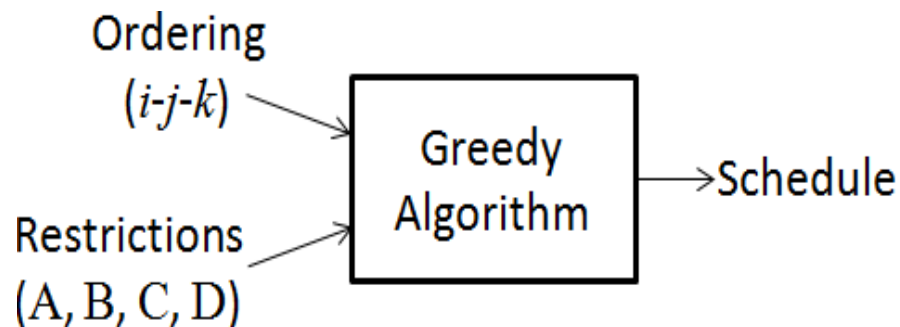
- **After Step 5, reactor is free to charge another converter**

Altonorte Operations

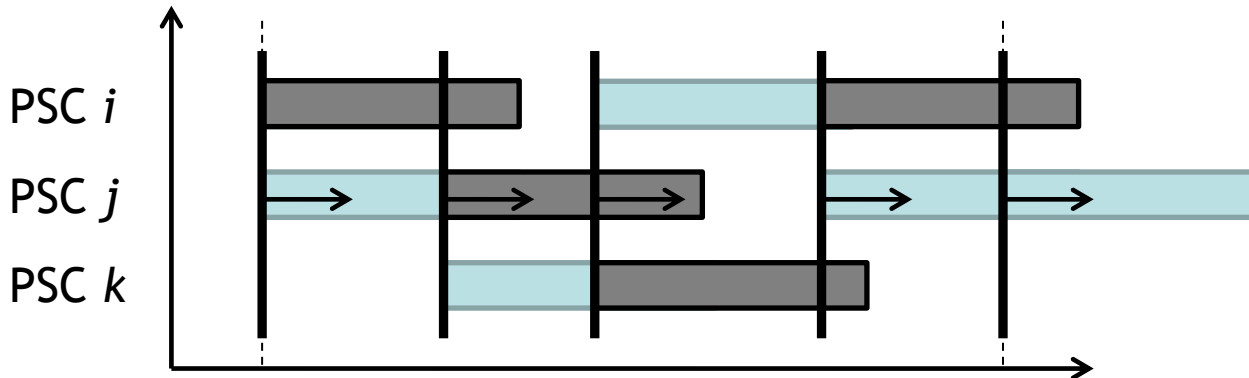


Greedy Programming

- **Integrated into combinatorial search**
 - **Find converter sequence that maximizes number of converted ladles 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 early as possible (while respecting restrictions)**
- “Greedy”** → **cursor only looks forward**

Greedy Programming

- **Mathematical formalism:**

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

$$\begin{aligned} t_1 &= \text{starting time of first cycle of the new schedule} \\ &= \max\{ t_1^A, t_1^B, t_1^C, t_1^D \} \end{aligned}$$

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



Greedy Programming

- **Mathematical formalism:**

- **Similarly,**

$$\begin{aligned} t_2 &= \text{starting time of } \underline{\text{second cycle}} \text{ of the new schedule} \\ &= \max\{ t_2^A, t_2^B, t_2^C, t_2^D \} \end{aligned}$$

- **Calculation of (t_2^B, t_2^C, t_2^D) takes into account the first cycle**
(thus second cycle does not conflict with first cycle)

- **More generally,**

$$\begin{aligned} t_l &= \text{starting time of } l^{\text{th}} \text{ cycle of the new schedule} \\ &= \max\{ t_l^A, t_l^B, t_l^C, t_l^D \} \end{aligned}$$

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

(thus l^{th} cycle does not conflict with previous cycles)



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**

