Heavy-Industry Optimization Modeling with Power Systems Opportunities

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Contributors

Thank you!

- Professor Daniel Bienstock, Columbia University
- Professor Andrea Brickey, South Dakota School of Mines and Technology
- Amy McBrayer, South Dakota School of Mines and Technology
- Professor Brian Thomas, Colorado School of Mines
- Many students! (see references)

•Given a set of known inputs, we wish to determine values for a set of unknowns (variables) so as to maximize or minimize a function, subject to a set of constraints.

⋆ A linear program (relatively simple):

$$\begin{aligned} \min\ & cx \\ \text{subject to}\ \ & Ax = b \\ & x \geq 0 \end{aligned}$$

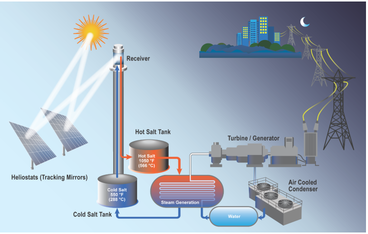
⋆ A mixed-integer, nonlinear program (relatively difficult):

$$\begin{aligned} \min\ & f(x, y) \\ \text{subject to}\ \ & g(x, y) \leq b \\ x \geq 0, y \geq 0\ \ & \text{and}\ \ \text{integer} \end{aligned}$$

Concentrated Solar Power

- The power tower technology employs a large field of mirrors, or *heliostats*, to focus the sun's light onto a receiver sitting atop a tower.
- This causes an increase in temperature of a heat transfer fluid.
- The thermal energy stored in this fluid is then converted to electrical energy, typically with a steam Rankine power cycle.
- The technology pairs with comparatively inexpensive thermal energy storage.
- A storage medium, such as a molten salt, resides in one or more tanks to be used for electricity production at a later time.
- Or, the power can be put on the grid immediately.

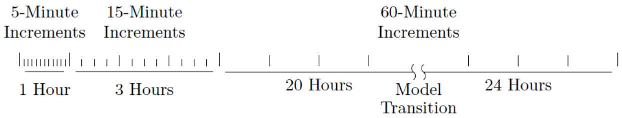
Dispatch Optimization at Hourly Fidelity



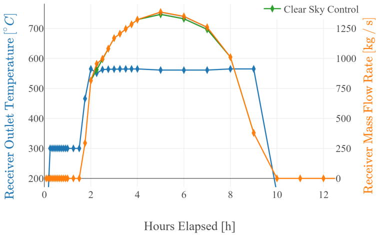
Metrics of Interest	Values from Optimized Model	Relative Improvement with respect to Heuristic
Electricity sales [$]	72,383,851	-1.48 %
Net electricity output [MW_e-hr]	627,572	-0.12 %
Turbine starts	105	86.40 %
Expected maintenance cost [$]	1,047,722	
Turbine cycles per day	1.61	24.30 %
Expected maintenance cost [$]	62,768	
Annualized maintenance costs [$]	1,110,491	85.74 %
Net revenue [$]	71,273,361	8.51 %

Annual values for a system consisting of a power cycle capable of 163 MW_e output with eight hours, or 3,142 MW_t-hr, of thermal storage and a receiver capable of 691 MW_e production, taken from: Wagner, M., W. Hamilton, A. Newman, R. Braun, J. Dent and C. Diep. "Dispatching Power at a Concentrated Solar Energy Facility," *Solar Energy*, available on-line.

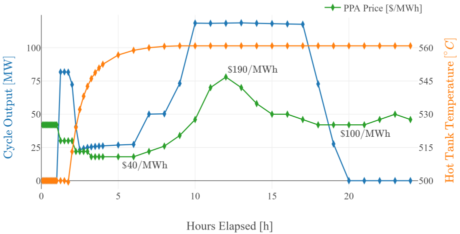
Real-Time Dispatch Optimization



Varying fidelity of time periods in a real-time dispatch 48-hour problem horizon, taken from: Cox, J., W. Hamilton, A. Newman, M. Wagner, and A. Zolan. "Real-time Dispatch Optimization for Concentrating Solar Power with Thermal Energy Storage," *Optimization and Engineering*, accepted.



Receiver dispatch solution



Power cycle dispatch solution

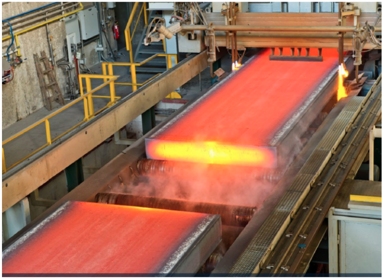
What are the opportunities for concentrated solar power to participate in day-ahead and real-time markets?

Some "answers"

- technological maturity
- market considerations
- mechanicals, e.g., ramping
- ambient conditions, e.g., solar availability
- Abiodun, K., K. Hood, J. Cox., A. Newman, and A. Zolan. "The Value of Concentrating Solar Power in the Ancillary Services Market," *Applied Energy*, **334** (2023): 120518.

Steelmaking and Casting

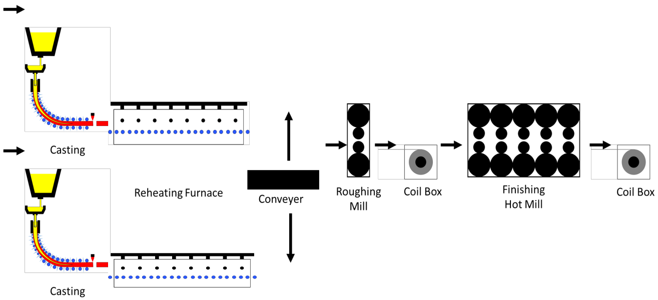
(a) Ladle of molten steel tapped from electric arc furnace [Roy, 2018]



(b) Cutting a slab from the strand exiting a continuous-caster [Primetals Technologies, 2019]

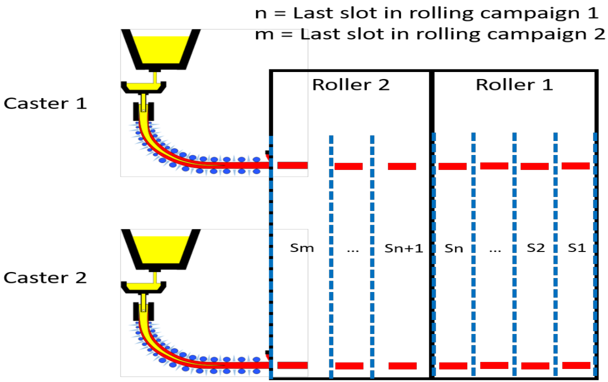
Scheduling at a Steel Mill

- Two casters operate in parallel with direct charging into the rolling mill.
- There is no capacity to hold inventory between the casting and rolling phases of production.



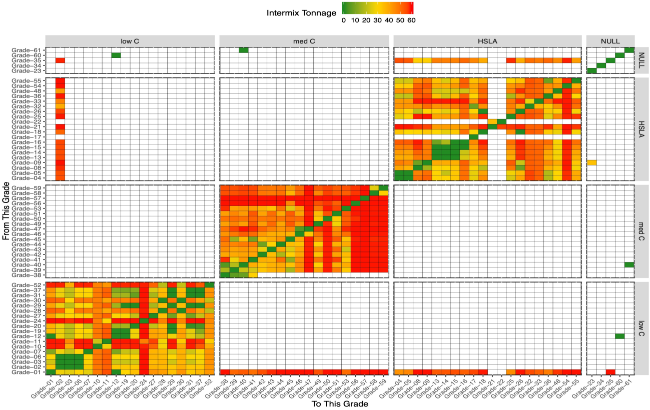
Current Operation

- A *roller* pertains to the entire set of roll stands with a capacity that is used throughout a rolling campaign.
- The casting order is divided into a *slot* for each coil.

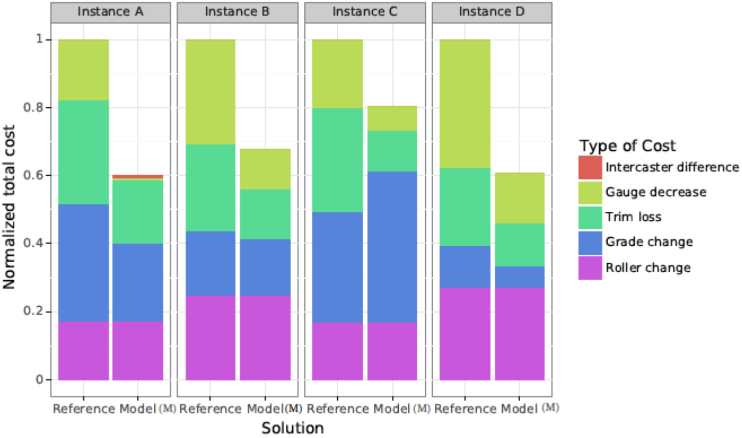


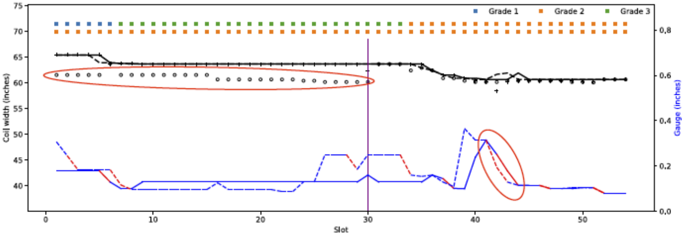
Grade Changes

- Each grade change is penalized at least minimally.
- Grade changes here are quantified in tons of intermixed steel (proportional to color).

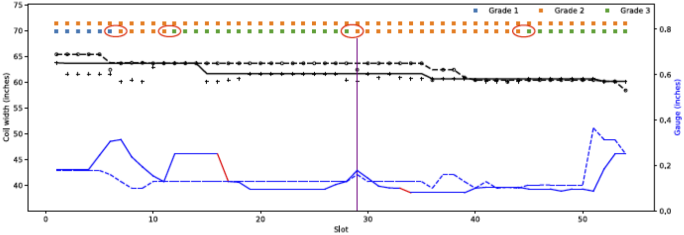


We focus on a comparison of *Model* (**M**) relative to the heuristic (*Reference*) that the mill has started using.





(a) *Reference* solution



(b) *Model* (M) solution

Taken from: Torres, N., G. Greivel, J. Betz, E. Moreno, A. Newman, and B. Thomas. "Optimizing Steel Coil Production Schedules under Continuous Casting and Hot Rolling," *Submitted*, 2022.

Steel Mill Power Systems Questions

How can steel companies ensure that their power needs are cost-effectively met?

Some "answers"

- market considerations
- mechanics, e.g., set ups
- favorable pricing contracts

Hard Rock Underground Mining

- Used when ore is located sufficiently deep below the earth's surface
- Consists of selective mining methods
- Associated with design and scheduling decisions that have large monetary implications

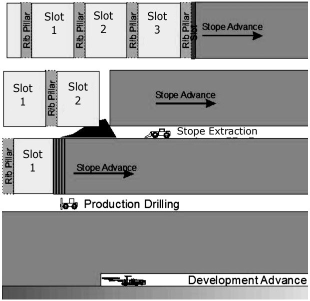


Figure: Sublevel Stoping Underground Mine Design

Cutoff Grade

- **Definition**: the minimum ratio of metal to host rock, i.e., gold ounces per tonne (oz/t), that is to be processed into a salable good
- All material extracted from stopes is at or above a pre-determined cutoff grade unless it is removed to access high-value stopes.
- A low cutoff grade yields more ore tonnage, a longer mine life, and more overall metal production, but at the cost of additional development meters.
- A high cutoff grade implies a shorter mine life that may not justify the large capital cost of starting a mine.

Central Zone: Comparison Versus Company Schedule

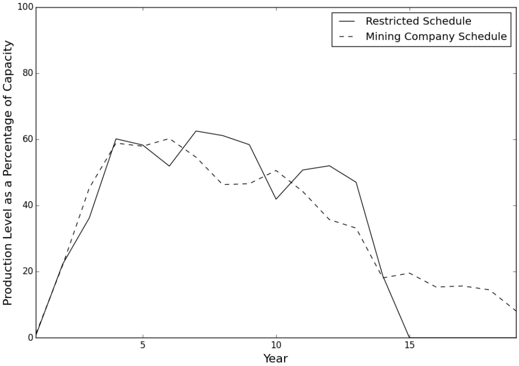
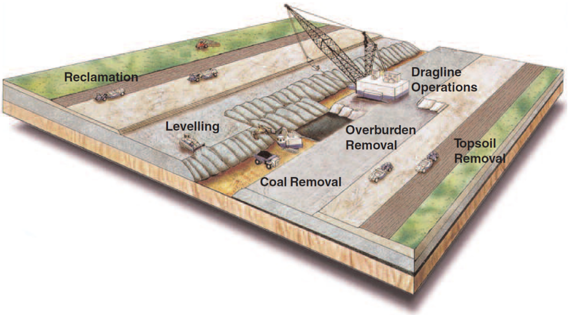


Figure: Both schedules follow a vary similar trend in the first five years of production. However, ours (the restricted schedule) has a higher and more consistent level of production, which is desirable.

Taken from: King, B. and A. Newman. "Optimizing the Cutoff Grade for an Underground Mine," *Interfaces*, 48(4):357–371, 2018.

Soft Rock Surface Mining

Area mine life-cycle beginning with initial topsoil removal and ending with final reclamation



Equipment Involved

Figure: (a) Truck and shovel excavating overburden; (b) Dragline excavating overburden above truck and shovel loading. Photos courtesy of Wyoming Mining Association and Amy McBrayer, respectively

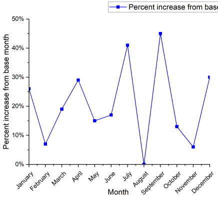
Mining Power Systems Questions

How can the mining industry ensure that it has access to a low-cost, resilient power network?

- electric equipment use for a large percentage of mine production
- potential to shift production away from periods of high electric demand
- production scheduling flexibility with respect to power demand

Some "answers"...

Case Study: Powder River Basin



- Incorporate a demand factor (based on the monthly variation in power prices) into a medium-term production scheduling model at daily fidelity to determine the impacts of seasonal electricity price variations for a two-year horizon.
- Integrate demand charges and potential for renewable energy into a model at a fifteen-minute fidelity for a three-day horizon.
- Both models contain the same resource constraints, precedence constraints, and blending constraints.

Results are currently being generated... ☺