Short Term Scheduling in Open-Pit Mines with Multiple Objectives
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Contribution

STP-SOLVE is a tool for the short term scheduling of an open-pit mine, in which several objectives, of varying priority, characterise solution quality. Current technology applies greedy heuristics, with little optimisation. To construct a schedule in which equipment is sufficiently utilised, while the grade of production meets a desired target, often requires hundreds of runs of these heuristics followed by parameter adjustment. Our tool generates multiple short term schedules, meeting a range of common objectives without the need for parameter adjustment.

Modelling the Mine

We model a mine in terms of a set of blocks $B$ – geological regions containing multiple types of material (e.g., high grade, low grade, and waste). A short term schedule identifies which blocks are to be mined in each period of the planning horizon, and where each block is to be sent (e.g., a stockpile, processing plant, or waste dump).

Mining precedences constrain the order in which blocks can be extracted. Each block $b \in B$ is linked to a set of block sets $A_b$, at least one of which must be entirely extracted before $b$ can be accessed.

We capture detailed mining operations, supporting:
- Multiple types of truck and dig unit constrained by cycle times and capacities;
- Multiple plants and processing options (wet and dry);
- Multiple stockpiles;
- Blending constraints on produced ore and material fed to stockpiles and plants;
- Rules constraining the flow of material across the mine.

Optimisation Scenarios

STP-SOLVE allows a planner to build optimisation scenarios – sequences of objectives ordered from highest to lowest priority. Existing work focuses on a narrow range of objectives: the maximisation of net present value (over long term horizons); the minimisation of costs; and the formation of correctly blended products. We support a diverse range of relevant additional objectives, including:

- Maximising utilisation of trucks and dig units;
- Mining waste consistently across the schedule;
- Maintaining stockpiles at desired sizes; and
- Minimising the extraction of specific regions.

For each scenario built by the planner, we generate multiple schedules using a split-and-branch technique within a rolling horizon-based scheduling algorithm.

Rolling Horizon-Based Search

STP-SOLVE splits a horizon of $T$ periods into $N$ aggregates of increasing size. A schedule is generated by solving a series of $N$-period MIPs – one for each period $t$.

An optimise-and-prune approach is used to optimise with respect to a sequence of prioritised objectives $\hat{O}$.

for each period $t \in \{1, \ldots, T\}$ do

for each $o \in \hat{O}$ do

Solve $N$-period MIP with objective $o$

Prune from feasible solution space inferior schedules

Fix the activities of period $t$

Split-and-Branch

A split and branch factor, $\alpha_s \geq 1$ and $\alpha_o \geq 1$, characterise the number of schedules generated by STP-SOLVE. We mark $\alpha_s$ periods in our horizon, starting with $t = 1$, as split points – SP – evenly distributing them across the horizon (as shown in Figure 4). STP-SOLVE maintains an initially empty set of schedules in progress, $X$.

$X \leftarrow \emptyset$

$\emptyset \leftarrow \emptyset$

> Keep track of mine states

for each $t' \in \{1, \ldots, T\}$ do

for each $g \in X$ do

Optimise and prune to schedule period $t'$

if $t' \in SP$ then

Add $\alpha_o - 1$ new schedules and mine states to $\hat{X}$ and $\hat{\emptyset}$ using CPLEX's Populate

Update mine state $\delta_t \in \hat{\emptyset}$

Visualisation

STP-SOLVE visualises generated schedules in tables, charts, and maps. Profiles of the grade of production in each schedule are shown in charts for easy comparison.

Deployment

STP-SOLVE will be undergoing a full deployment trial in 2015-16 at two of our industry partner’s mines.

References