Planning of the maintenance outages for a set of hydroelectric turbogenerators

Pascal Côté [1] Charles Audet[2 3] Nadir Amaioua[2 3] Emmanuel Bigeon[4]
Quentin Desreumaux[5] Amina Ihaddadene[3] Youness Mir[5] Jesus Rodriguez[2 3]
Luckny Zéphyr[6]

[1]RioTinto Alcan [2]École Polytechnique de Montréal [3]GERAD

[4]École de Technologie Supérieure [5]Université de Sherbooke [6]Cornell University

August 21, 2015

Content

Context

Rio Tinto Alcan

- Many aluminium smelters over the world
- In Saguenay-Lac-St-Jean
  - 4 smelters
  - $>$1 million tons per year

Power use

Rio Tinto Alcan produces part of the required energy to operate the smelters.
In Saguenay-Lac-St-Jean, Rio Tinto Alcan uses 6 hydro-electric power plants and produces 90% of the required energy (2080MW).

Situation

Objective

Optimize the operation schedule given:

- Maintenance operations
- Precipitations models

Where the optimization criterion is the energy production

Current Situation

Each optimization input is handled by a specific group of the company.

- Precipitations are handled with optimization,
- Maintenance scheduling is done by *hand*.

⇒ Long iterative process that involves communicating maintenance schedules and availability requirements.

Problem decomposition

Energy optimization problem

$$(P) \qquad p(s) := \max_{x} \quad p_s(x) \quad \text{s.t.} \quad x \in X_s.$$

where:

- $x \in X_s$ denotes the operation variables for the scheduling s.

Solved by IPOPT

Scheduling problem

$$(S) \qquad \max_{s} \quad p(s) - m(s) \quad \text{s.t.} \quad s \in \Omega$$

where:

- $s \in \Omega$ are the scheduling variables,
- $p : \Omega \longrightarrow \mathbb{R}$ is the optimal energy production,
- $m : \Omega \longrightarrow \mathbb{R}$ is the maintenance cost relative to s.

Approaches

Approaches

2 complementary approaches:

- Direct approach (use existing solver)
- Decomposition approach (use dual solution)

Subsection 1

Direct method

Why

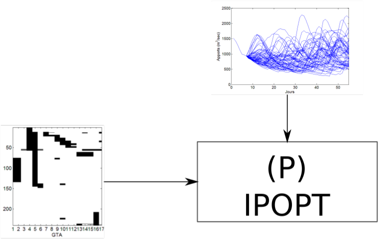
- Adapted to a proof of concept
- No complexity added

Adding maintenance constraints increases its difficulty:

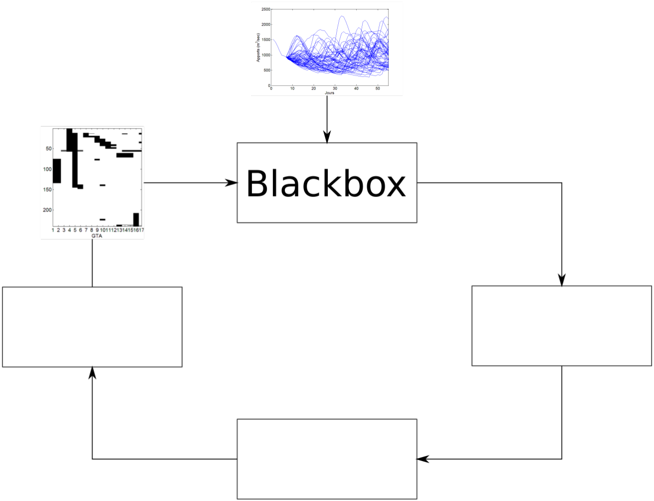
Strategic solutions:

- Encapsulation of the stochastic model by using blackbox optimization.
- Generation of a sequence of schedules.

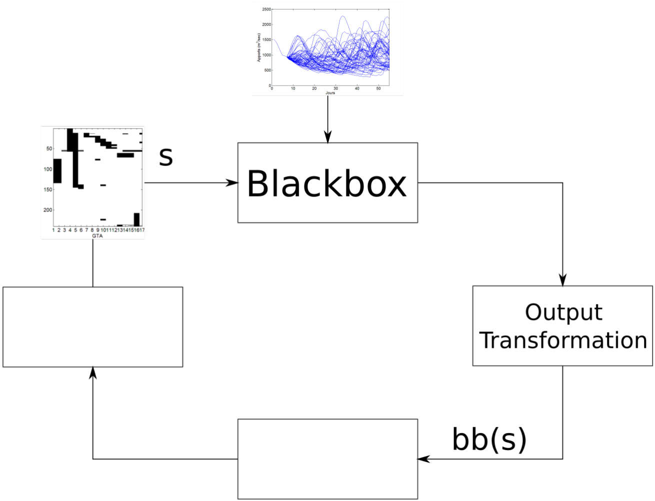
Blackbox optimization



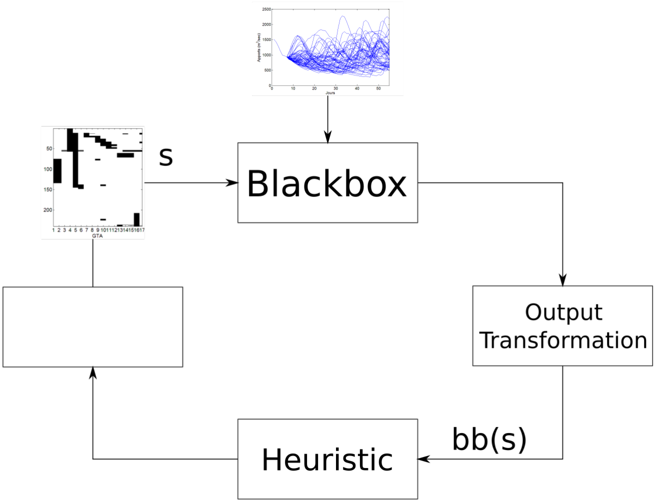
Blackbox optimization



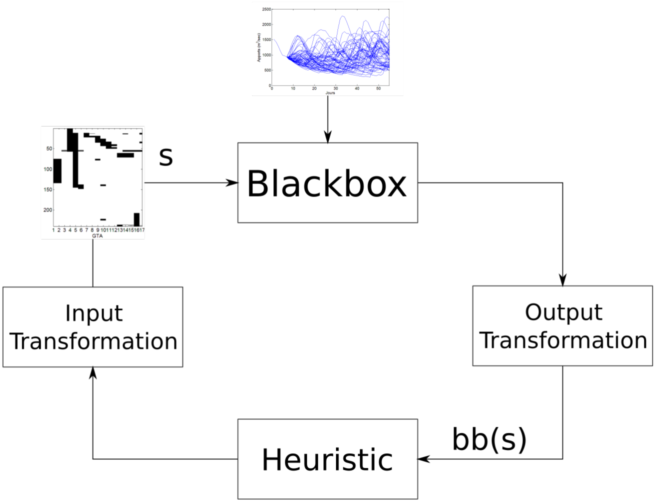
Blackbox optimization



Blackbox optimization



Blackbox optimization



Heuristic used

Heuristic

Simple neighbourhood of the initial schedule

- Maintenance can be moved one day earlier or one day later

Heuristic used

Definitions

Let $\mathcal{I}$ be the set of interventions, Ω the set of possible maintenance schedules. For $s \in \Omega$ we define:

- s_{d_j-1}, the maintenance schedule that is identical to s except for the intervention j that starts a day earlier.
- s_{d_j+1}, the maintenance schedule that is identical to s except for the intervention j that starts a day later.

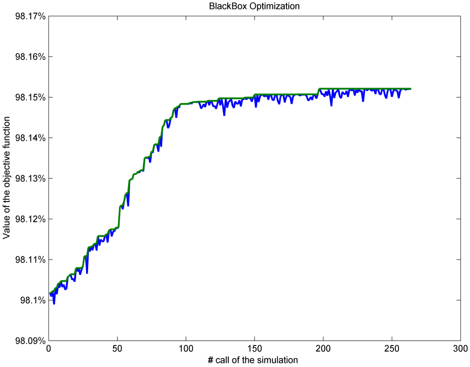
Algorithm

for $j \in \mathcal{I}$ **do**

$$S \leftarrow \begin{cases} S_{d_j-1} & \text{if } bb(S) < bb(S_{d_j-1}) \\ S_{d_j+1} & \text{else if } bb(S) < bb(S_{d_j+1}) \\ S & \text{in any other cases} \end{cases}$$

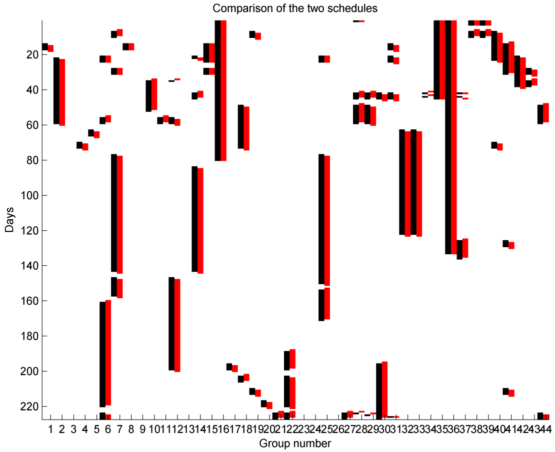
end for

Results and discussion



- Run at Rio Tinto Alcan overnight
- 100% corresponds to an empty maintenance schedule
- Monetary gain: 420000$

Results and discussion

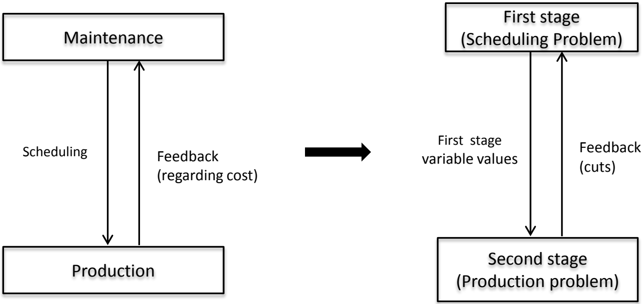


- Monetary gain: 420000$

Subsection 2

Decomposition approach

General description



Objectives

- Modelling scheduling and production problems simultaneously
- Connecting these two problems in a correct way
- Minimizing the scheduling and production costs simultaneously (thus eliminating a decision process with many iterations between the maintenance and production departments)
- Finding a solution approach to the proposed model

Notation

Parameters

- Maintenance Group
- Production Group

Decision Variables

- Maintenance Group
- Production Group

Overall Problem: constraint

$$s_{t+1} = s_t - Bu_t - Cy_t + \tilde{Q}_t, \quad (1)$$

$$x_t^+ - x_t^- + \sum_{i \in P} h_i(u_{it}, s_{it}, s_{i,t+1}, sch_{it}) = L_t, \quad (2)$$

$$x_t^+ \leq C_t^+, \quad x_t^- \leq C_t^-, \quad (3)$$

$$\underline{u} \leq u_t \leq \overline{u}, \quad (4)$$

$$\underline{s}_{t+1} \leq s_{t+1} \leq \overline{s}_{t+1}, \quad (5)$$

$$t\delta_{jg}^t + D_j^g \leq LT_j^g, \quad ET_j^g \leq t \leq LT_j^g - D_j^g, \quad g \in G. \quad (6)$$

,

$$\sum_{g \in G} \sum_{t'=t-D_j^g}^{t} \delta_{jg}^{t'} Req_{kj}^g \leq AV_{kj}^t + \sum_{g \in G} \sum_{j \in MT} Ext_{gj}^t, \quad 1 \leq t \leq T, \quad (7)$$

$$\sum_{j \in MT} \sum_{k \in G_k} (1 - \sum_{t'=t-D_j^k}^{t} t' \delta_{jk}^{t'}) \geq NG_i, i \in P, \quad (8)$$

Overall Problem: objective function

$$\min_{u_t, s_t, y_t, \delta_t, Ext} \left\{ \mathbb{E}_{\tilde{Q}_t} \left[\sum_{t=1}^{T} (f_t(sch_t) + m_t(sch_t)) \right] \right\}$$

$$\text{s.t. } (1) - (8)$$

Decomposing of the model

P1 (Production problem)

$$\min_{u_t(sch_t^*), s_t(sch_t^*), y_t(sch_t^*)} \left\{ \mathbb{E}_{\tilde{Q}_t} \left[\sum_{t=1}^{T} f_t(sch_t^*) \right] \right\}$$

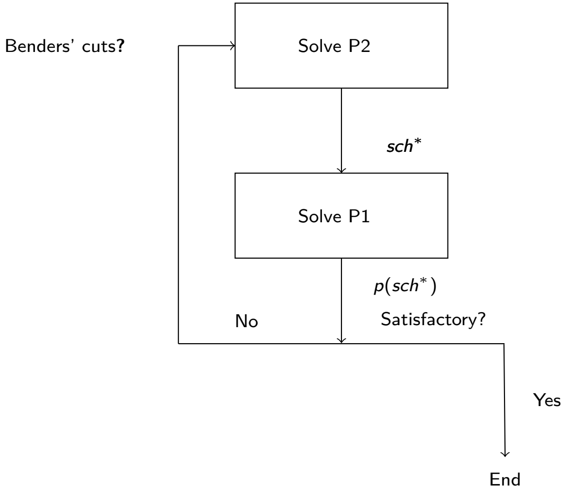
$$\text{s.t. } (1) - (6)$$

P2 (Scheduling problem):

$$\min_{\delta_t, Ext} \{ m_t(sch_t) \}$$

$$\text{s.t. } (7) - (8)$$

Benders Algorithm



- Take into account the true scheduling constraints including work force and overtime issues.
- Use a broader neighbourhood strategy and a more sophisticated optimization solver such as Nomad.
- Use a surrogate of function $p(s)$ derived by restricting the number of historical scenarios.
- Apply a warm start on the IPOPT solver.

- Apply the Benders' decomposition technique to solve the scheduling and production problem.
- Improve the modelling of the problem by including more realistic constraints in the scheduling subproblem.
- Develop an optimization algorithm to solve the master problem efficiently.
- Use the nonlinear model of RTA for the production subproblem instead of the current linear approximation.