Maintenance Scheduling for the Hunter Valley Coal Chain

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Abstract

The Hunter Valley Coal Chain (HVCC) comprises mining companies, rail operators, railway track owners and terminal operators, together forming one of the worlds largest coal exporters. Increasing demand calls for highly efficient use of available infrastructure and resources, as well as for well-informed decisions on potential capacity expansions. In particular, the planning processes for different parts of the network have to be integrated, and this leads to complex and very large scale optimization problems.

In the talk we discuss the annual planning of preventive maintenance for railway track and terminal equipment, where the main objective is to maximize the total system capacity. The problem is naturally modeled as a dynamic network flow where the capacities of arcs are temporarily reduced due to maintenance events. We present a MIP formulation for the problem as well as heuristic approaches, and we report on computational experiments using real world data.

Key words: Maintenance scheduling, dynamic flow

The Hunter Valley Coal Chain (HVCC) constituted by 30 mines owned by 15 companies, rail and road providers, as well as port coal services operates the world's largest coal export facility. In 2008, the throughput of HVCC was about 92 million tonnes, or more than 10 per cent of the world's total trade in coal for the year. The coal export operation is responsible for around 15 billion in annual export income for Australia (Boland and Savelsbergh). A main goal of the coal chain management is to align the operations on various parts of the chain efficiently to maximize the daily capacity and to enable a long term capacity expansion.

To optimize the coal chain as a single complex system is a complicated task where a large range of aspects from coal train transportation to terminal machine operation have to be considered and coordinated. Even optimizing a single aspect of the whole system is already a hard problem. In this paper, a scheduling problem for the maintenance of different facilities of the coal chain network is investigated. This study is motivated by the observation that every year, there are series of preventive and corrective maintenance jobs carried on trains, track sections, coal reclaiming or loading machines etc. to ensure that the whole network functions properly. The system capacity is significantly restricted by maintenance that there is about 30% coal reduction due to more than $2,000$ maintenance jobs per year. Good alignment of maintenance on different parts of the infrastructure is essential for an efficient use of the system.

We model the coal chain as a network where the arcs represent the assets to be maintained. In a natural way, this leads to the study of a network flow problem where the capacity on an arc drops to zero once it's under maintenance. The objective is to schedule the maintenance jobs for a given time horizon such that the total flow is maximized.

Throughout we use the notation $[k,l]=\{k,k+1,\dots,l\}$ and $[k]=\{1,2,\dots,k\}$ for $k,l\in\mathbb{Z}$. Let (N,A,s,s') be a network with node set N, arc set A, source s and sink s', and let in addition $u_a\in\mathbb{N}$ for $a\in A$ be capacities. We consider the network over a time horizon $[T]=\{1,2,\dots,T\}$. A *maintenance job* j is specified by its associated arc $a_j\in A$, its execution time $\tau_j\in\mathbb{N}$, its release date $r_j\in[T]$, and its deadline $d_j\in[T]$. In our model, the execution of a maintenance job starting at time $t\in[r_j,d_j-\tau_j+1]$ implies that the arc a_j is not available at time t, $t+1$,..., $t+\tau_j-1]$. We consider the problem to align a given set $\mathcal{J}$ of maintenance jobs in such a way that the total throughput over the interval $[T]$ is maximized. In order to formalize the problem we introduce the following notation.

- For $a\in A$ and $t\in[T]$
  - $\phi_{at}\in\mathbb{R}_+$ is the flow on arc a over time interval t,
  - $x_{at}\in\{0,1\}$ indicates the availability of arc a at time t.
- For $j\in\mathcal{J}$ and $t\in[r_j,d_j-\tau_j+1]$, $y_{at}\in\{0,1\}$ indicates if job j starts at time t.

Our objective is to maximize the total throughput, i.e.

$$\max\ f(\boldsymbol{\phi},\boldsymbol{x},\boldsymbol{y})=\sum_{t=1}^{T}\sum_{v\,:\,a=sv\in A}\phi_{at} \tag{1}$$

subject to the following constraints.

Flow conservation constraints.

$$\sum_{u\,:\,uv\in A}\phi_{at}-\sum_{w\,:\,vw\in A}\phi_{at}=0 \qquad (v\in N\setminus\{s,s'\},\ t\in[T]), \tag{2}$$

Capacity constraints.

$$\phi_{at}\leqslant u_a x_{at} \qquad (a\in A,\ t\in[T]), \tag{3}$$

Execution constraints.

$$\sum_{t=r_j}^{d_j-\tau_j+1} y_{jt}=1 \qquad (j\in\mathcal{J}), \tag{4}$$

Outage constraints.

$$x_{at} + \sum_{t'=t-\tau_j+1}^{t} y_{jt'} \leqslant 1 \qquad (a \in A,\ j \in \mathcal{J}_a), \tag{5}$$

where $\mathcal{J}_a = \{j \in \mathcal{J} \ : \ a_j = a\}$ is the set of all jobs on arc a.

We call the problem (1)–(5) *maximum total flow with flexible arc outages* (**MaxTFFAO**). By reduction from 3-partition it is easily seen that the problem **MaxTFFAO** is strongly NP-hard, suggesting that in order to tackle instances of practical relevance efficient heuristics might be needed.

We propose a simple local search heuristics using single job movements. The approach is based on the following observations.

- For a fixed maintenance schedule the evaluation of the maximum total flow is reduced to a sequence of max flow problems in very similar networks.
- Reduced costs can be used to detect arcs on which maintenance causes bottlenecks.
- The available solutions for the maximum flow problems can be used to efficiently evaluate a large number of job movements.

We also present some computational results, indicating that our local search heuristics can perform better than just putting the MIP formulation into a general purpose solver, especially for generating quickly high quality solutions.

References

Boland, N., and M. Savelsbergh. "Optimizing the Hunter Valley coal chain." In *Managing Supply Disruptions*, edited by H. Gurnani, A. Mehrotra, and S. Ray. Springer-Verlag London Ltd. to appear.