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Risk analysis of turnaround reschedule planning in integrated chemical sites

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ABSTRACT

Plant maintenance turnarounds constitute a large fraction of all maintenance activities in the process industries. We consider turnaround planning problems over large networks of interconnected plants. The network interactions provide an opportunity to plan and coordinate the different turnaround activities to save on annual downtime and recover the associated revenue. We propose a stochastic optimization model to quantify the risk of loss in rescheduling maintenance turnarounds that have been previously planned and compare the proposed approach to alternative approaches incorporating different production planning strategies under uncertainty. The model also provides simultaneous hedging strategies using inventories for unplanned outages. Thus, our model offers additional flexibility to previous approaches that address long- and medium-term turnaround planning problems, and explicitly incorporates plant reliability in the planning process. Through extensive computational studies, we show that proactive planning strategies that take uncertainty over multiple time periods into account offer substantial benefits over a reactive strategy.

1. Introduction

A turnaround is a complex asset renewal project that involves one or more of inspection, repair, upgrade, or a complete overhaul of plants in a chemical site. It is a periodic large-scale maintenance activity that is integral to reliable operation of a processing plant, which undergoes wear-and-tear over time. Besides large costs in the form of materials and work resources, turnarounds typically require planned shutdown of plants longer than that required for an average maintenance routine, that incurs additional losses in revenue.

In an integrated chemical site, a large network of plants are interconnected and externally connected directly or through intermediate storage buffers. Turnarounds in an integrated chemical site are even more critical as their timing and scale disrupt normal operations beyond the associated plants. Nonetheless the tight integration also lends to an opportunity for synergistic planning of turnarounds across the network by sharing resources and materials. The constantly evolving economic climate, landscape of chemical plant technology as well as investment in new assets necessitates turnaround planning that couples production, inventory, and resource planning rather than employing a fixed turnaround schedule identified at the time of designing the chemical site.

1.1. Rescheduling turnarounds

In practice, the realities of short-term economic variability and the complexity of the logistics of a turnaround demand flexibility in the form of rescheduling turnarounds. Although the models that address turnaround planning in integrated sites can accommodate this—for example, the rolling horizon framework model by Amaran et al. (2015), they are more suited to planned preventive maintenance. Evaluation of the risk of loss due to potential unplanned outages from a financial perspective has not been addressed to our knowledge. Also, from a strategic perspective, it is valuable to

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consider rescheduling turnarounds under the following opportunities and externalities:

- *Time value of money*: Given that turnarounds are large investments, a reschedule as short as four to six months is valuable along with the additional flexibility offered for production planning. There is also a hidden long-term value as every subsequent turnaround for the associated plant can be pushed by the same time window. This, in effect, improves the turnaround frequency.
- *Market fluctuations*: Market externalities in the form of raw material, maintenance equipment, catalyst supply shortage, or rise in demand may prompt rescheduling of turnarounds. Although it may be reasonable to avoid a high-demand period for a turnaround, the opposite (planning for the turnaround in a subsequent lean-demand period) may also be undesirable. While the former affects revenue from sales, the latter involves both sales revenue and turnaround costs.
- *Availability of resources*: Turnarounds often require workforce of a few hundred personnel with varied skill sets such as welders, equipment assemblers, and supervisors. Shortage of workforce or availability of quality workforce at another time may prompt a reschedule to potentially shorten turnaround duration or improve its quality.
- *Plant performance*: Plants are continuously monitored and evaluated using key performance indicators. On account of healthy performance, it is relevant to ask if production can be continued for a short while without maintenance interruption unless it is statutory.

The schematic in Fig. 1 shows a summary of challenges in risk analysis of turnaround rescheduling, especially in integrated sites. Fig. 1 qualitatively ranks candidate factors in a risk analysis framework based on the contribution of a factor to transparency in cost–benefit, complexity of the model, and magnitude of impact or benefit due to site integration.

In this work, we formulate a multistage stochastic linear programming model to evaluate the risk of rescheduling a turnaround by a fixed time window. Currently, the deterministic equivalent of the model is solved in its extensive form to show some of the features of the framework for the case of rescheduling a single turnaround in a realistic-scale site network. We also present avenues to extend the model with other first-stage decisions such as timing of the reschedule as well as integrate it with a first-stage model for risk-aware turnaround planning.

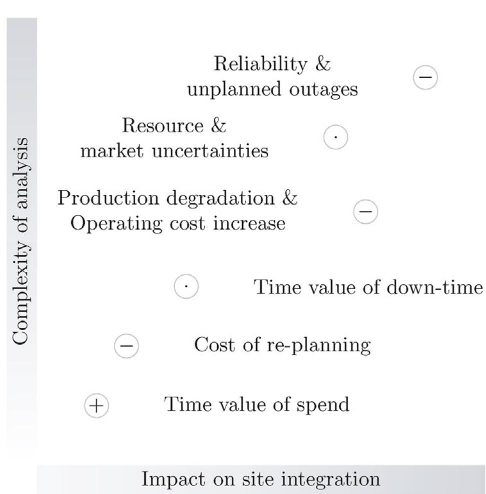

Fig. 1. Challenges in risk analysis – factors to consider and impact of the factors on model complexity, site integration, and overall profit.

The remainder of this article is organized as follows. After a brief literature review in Section 2, we present the formal problem statement along with a motivating example in Section 3. The details of the approach and the mathematical optimization model are presented in Section 4. Extensive computational results are discussed in Section 5. Concluding remarks are presented in the final Section 6.

2. Literature review

Maintenance scheduling is broadly categorized as preventive, predictive, reactive or corrective, and opportunistic maintenance. In preventive maintenance, an equipment undergoes periodic offline inspection and maintenance to reduce downtimes due to failures. Predictive maintenance is a step forward in preventive maintenance where the condition of the equipment is monitored, preferably online, to further reduce the unnecessary downtime. This is also referred to as condition-based maintenance. Corrective maintenance or break-down maintenance is largely adopted for equipments that are not critical and are of low cost. This could either be planned or unplanned depending on the history of the equipment. Opportunistic maintenance as the name suggests takes advantage of a break-down maintenance of an equipment by performing preventive maintenance on a related equipment. In terms of the strategy, some classifications of maintenance include reliability-centered maintenance and risk-based maintenance. While the focus is on maintaining high level of equipment availability in the former case, the latter involves planning of maintenance based on the risk posed by the asset. A rich source of maintenance literature falls under one of the above categories.

2.1. Maintenance scheduling problems in chemical engineering

The following are a few maintenance scheduling problems addressed in the chemical engineering literature.

Tan and Kramer (1997) develop a general maintenance framework that includes preventive, corrective and opportunistic maintenance. A Monte Carlo sampling approach is used for a discrete event simulation of the maintenance activities to obtain the overall cost implementing a given maintenance policy. The estimated cost is then minimized using a genetic algorithm framework to obtain good maintenance policies. Apart from the model framework, they also discuss economics of maintenance and reliability in chemical industry. To this end, Christer and Whitelaw (1983) estimated that the annual maintenance budget for a medium sized company in UK to be over GBP 1 million. Some early maintenance optimization models and their shortcomings are also presented in Tan and Kramer (1997).

Dedopoulos and Shah (1995a) address short-term maintenance scheduling with simultaneous production scheduling in multipurpose batch plants. They model detailed maintenance crew constraints including call out charges, resting period, and skill sets. They also discuss the effect of redundant constraints on the efficiency of a large mixed-integer linear programming (MILP) scheduling model for a lubricant design plant. The same authors investigate the idea of estimating the performance of the equipment as a function of its failure rate in a short-term scheduling horizon, and utilize this profit function in a long-term maintenance problem to obtain an optimal preventive maintenance policy (Dedopoulos and Shah, 1995b).

Sanmartí et al. (1997) study production scheduling for multipurpose batch plants under equipment failure uncertainty. The idea is to improve the reliability of performing a schedule by incorporating an uncertainty analysis prior to production planning. The