Computers and Chemical Engineering 33 (2009) 2091–2105

Contents lists available at ScienceDirect

Computers and Chemical Engineering

journal homepage: www.elsevier.com/locate/compchemeng

Centralized–decentralized optimization for refinery scheduling

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ARTICLE INFO

Article history:
Received 6 November 2008
Received in revised form 14 May 2009
Accepted 3 June 2009
Available online 11 June 2009

Keywords:
Refinery
Scheduling
Optimization
Centralized
Decentralized

ABSTRACT

This paper presents a novel decomposition strategy for solving large scale refinery scheduling problems. Instead of formulating one huge and unsolvable MILP or MINLP for centralized problem, we propose a general decomposition scheme that generates smaller sub-systems that can be solved to global optimality. The original problem is decomposed at intermediate storage tanks such that inlet and outlet streams of the tank belong to the different sub-systems. Following the decomposition, each decentralized problem is solved to optimality and the solution to the original problem is obtained by integrating the optimal schedule of each sub-systems. Different case studies of refinery scheduling are presented to illustrate the applicability and effectiveness of the proposed decentralized strategy. The conditions under which these two types of optimization strategies (centralized and decentralized) give the same optimal result are discussed.

1. Introduction

Production scheduling defines which products should be produced and which products should be consumed in each time instant over a given small time horizon; hence, it defines which run-mode to use and when to perform changeovers in order to meet the market needs and satisfy the demand. Large-scale scheduling problems arise frequently in oil refineries where the main objective is to assign sequence of tasks to processing units within certain time frame such that demand of each product is satisfied before its due date. As the scale of the production problem increases, the mathematical complexity of the corresponding scheduling problem increases exponentially. Decomposition of the initial system into sub-systems which are easier to be solved, is a natural way to deal with this type of optimization problems.

There are relatively few papers that have addressed planning and scheduling problems using centralized and decentralized optimization strategies providing a comparison of these two approaches. Kelly and Zyngier (2008) presented a procedure to find a suitable way to decompose large decision-making problems and compared different decentralized approaches using hierarchical decomposition heuristics. The focus of their work was to find globally feasible solutions to large decentralized and distributed decision-making problems when a centralized approach is not possible. Saharidis, Dallery, and Karaesmen (2006) and Saharidis, Kouikoglou, and Dallery (2009) studied the problem of production planning in deterministic and stochastic environments and compared centralized and decentralized optimization for an enterprise consisting of two production plants in series producing many different outputs with subcontracting options. Chen and Chen (2005) studied a joint replenishment arrangement with a two-echelon supply chain with one supplier and one buyer, facing a deterministic demand and selling a number of products in the marketplace. They proposed both centralized and decentralized decision policies to analyze the interplay and to investigate the joint effects of two-echelon coordination and multi-product replenishment on the reduction of total costs. The cost differences between these policies show that the centralized policy significantly outperforms the decentralized policy. Gnoni, Iavagnilio, Mossa, Mummolo, and Leva (2003) present a case study from the automotive industry dealing with the lot sizing and scheduling decisions in a multi-site manufacturing system. They use a hybrid approach which combines mixed-integer linear programming model and simulation to test local and global production strategies. Their results show that local optimization strategy allows a cost reduction of about 19% compared to the reference actual annual production plan, where as the global strategy leads to a further cost reduction of 3.5% and a better overall economic performance. Harjunkoski and Grossmann (2001) presented a decomposition scheme for solving large scheduling problems for steel production which splits the original problem into sub-systems using the special features of steel making. Their proposed approach cannot guarantee global optimality, but comparison with theoretical estimates indicates that the method produces solutions within 1–3% of the global optimum. Bassett, Pekny, and Reklaitis (1996) presented resource decomposition method to reduce problem complexity by dividing the scheduling problem into sub-sections based on its process recipes. They showed that the overall solution time using resource

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doi:10.1016/j.compchemeng.2009.06.010

Nomenclature

Indices
- j production units
- jst storage tanks
- i tasks
- n event points
- s states
- k kth sub-system in decentralized system
- K total number of sub-systems in decentralized system

Sets
- j production units
- jst storage tanks
- S states
- N event point within the time horizon
- $j(i)$ units which are suitable for performing task i
- $i(j)$ tasks which can be performed in unit j
- $Iseq(i')$ i' produces state s that will be consumed by task i
- $Jstprod(jst)$ units that consume material s stored in tank jst
- $Jprodst(jst)$ units that produce material s stored in tank jst
- $Junitp(s)$ units that can produce material s
- $Junitp(s,k)$ units in sub-system k that can produce material s
- $Junitc(s)$ units that consume material s
- $Junitc(s,k)$ units in sub-system k that can consume material s
- $Jseq(j')$ units that follow unit j' (no storage in between)
- $Jst(s)$ tanks that can store material s
- $Jst(s,k)$ tanks in sub-system k that can store material s
- $JSTprodst(j)$ tanks that follow unit j
- $JSTstprod(j)$ tanks that are followed by unit j

Parameters
- $R^{\min}(i,j)$ minimum rate of material processed by task i required to start production unit j
- $R^{\max}(i,j)$ maximum rate of material processed by task i in unit j
- $P_{\min}(s)$ the possible maximum rate of production of material (s)
- $P^{k}_{\max}(s)$ the maximum rate of production of intermediate final product s in sub-system k
- $C^{k}_{\max}(s)$ the maximum rate of consumption of intermediate final product s in sub-system k
- $V^{\max}(jst)$ maximum available storage capacity of storage tank jst
- $\rho^{p}(s,i)$ proportion of state s produced by task i, $\rho^{p}(s,i) \geq 0$
- $\rho^{c}(s,i)$ proportion of state s consumed by task i, $\rho^{c}(s,i) \geq 0$
- $d(s)$ demand of the final product s at the end of the time horizon
- $r(s,n)$ demand of intermediate state s at event point n
- $r'(s,n)$ adjusted demand of intermediate state s at event point n
- $stin(jst)$ amount of state s that is present at the beginning of the time horizon
- UH available time horizon

Variables
- $wv(i, j, n)$ binary variable that assign the starting of task i in unit j at event point n
- $iter$ binary variable that assign the number of iterations between sub-systems
- $b(i,j,n)$ amount of material undertaking task i in unit j at event point n
- $st(jst,n)$ amount of state s present in storage tank jst at event point n
- inflow1(jst,n) flow of raw material to storage tank jst event point n
- outflow1(jst,n) flow of final product from storage tank jst at event point n
- inflow2(s,j,n) flow of raw material s to production unit j at point n
- outflow2(s,j,n) flow of product material s from unit j at point n
- inflow(j,jst,n) flow of material from unit j to storage tank jst event point n
- outflow(jst,j,n) flow of material from storage tank jst to unit j at point n
- in(j,jst,n) binary variable that assign the starting of material flow into storage tank jst from unit j at point n
- out(jst,j,n) binary variable that assign the starting of material flow out of storage tank jst to unit j at point n
- unitflow(s,j,j',n) flow of state s from unit j to consecutive unit j' for consumption at point n
- $st(jst,n)$ amount of material in tank jst at event point n
- $Ts(i,j,n)$ time that task i starts in unit j at event point n
- $Tf(i,j,n)$ time that task i finishes in unit j at event point n
- $Tss(i,jst,n)$ time that material starts to flow from unit j to storage tank jst
- $Tsf(i,jst,n)$ time that material finishes to flow from unit j to tank jst at event point n
- $Tss(jst,j,n)$ time that material starts to flow from tank jst to unit j at event point n
- $Tsf(jst,j,n)$ time that material finishes to flow from tank jst to unit j at event point n
- H time horizon

decomposition is significantly lower than the time needed to solve the global problem. However, their proposed resource decomposition method did not involve any feedback mechanism to incorporate "raw material" availability between sub-problems.

In this work, the problem of refinery scheduling optimization is addressed with centralized and decentralized decision making process. The paper is organized as follows. Section 2 describes general structure of problem studied in this paper. Section 3 defines the mathematical formulation of the problem, whereas the decomposition approach is presented in Section 4. Section 5 presents a real case study provided by Honeywell Hi-Spec Solutions and provides comparative results for centralized and decentralized optimization of the system. Finally Section 6 draws conclusions indicating perspectives for future research.

2. Problem definition

In general there are two decision levels in refinery process operations—the planning and the scheduling level. The planning level determines the volume of raw materials needed for the upcoming months (typically 12 months), and the type of final products and the estimated quantities to be ordered, depending on demand forecasts. After determining the yearly plan in the second level we have to determine the optimal production scheduling. The scheduling level determines the detailed schedule of each CDU and other production unit for a shorter period (typically 10 days) by taking into account the operational constraints of the system under study. Once the plan is known (the quantities and the types of final products ordered as well as the arrival of raw materials), managers must schedule the production of each unit based on the