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Multi-item capacitated lot-sizing problem in a flow-shop system with energy consideration

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Abstract: This paper discusses a multi-item capacitated lot-sizing and scheduling problem in a flow-shop system with energy consideration. A mixed integer linear programming is formulated. The planning horizon is defined by a set of periods where each one is characterized by a length, an electricity price, a maximal allowed power and an external demand. Since the capacitated lot-sizing problems are NP-hard, a fix-and-relax heuristic is developed. To evaluate the effectiveness of the proposed heuristic, computational experiments are presented and numerical results are discussed and analyzed. The obtained results are promising.

Keywords: capacitated lot-sizing and scheduling, flow-shop, energy, fix-and-relax.

1. INTRODUCTION

Lot-sizing and scheduling are the incontournable tasks to provide the production planning and control system. Lot-sizing deals with determining the quantity to produce of each product at each period, while scheduling is to determine the production sequence in which the products are manufactured on a machine (Fandel and Stammen-Hegene (2006)).

Sustainability in manufacturing systems is an important requirement due to several causes as environmental concerns and rising in energy prices. This article focuses on manufacturing systems taking into account ecological aspects (energy consumption, greenhouse gas emission...). For scheduling problem, Mouzon and Yildirim (2008) proposed a mathematical model that minimizes total tardiness of jobs and total energy consumption on a single machine. Liu et al. (2014) considered a generalized case with several machines. Fang et al. (2011a) proposed a mathematical programming model of the flow shop scheduling problem that considers peak power load, energy consumption, and associated carbon footprint. A two machines flow-shop system is considered in the work of Mansouri et al. (2016). A mixed integer linear multi-objective model is developed to find the Pareto frontier comprised of makespan and total energy consumption. For a flow line production system, Wang and Li (2013) proposed two zero-one non linear programming models . The first one aims to minimize the energy consumption and the second one aims to minimize the energy cost, while maintaining an amount of average cumulative production not lower than the required level. An energy aware scheduling algorithm based on a mixed integer programming formulation is presented by Bruzzone et al. (2012). This algorithm modifies the original timetable to reduce the shop floor peak's power. To reduce the power demand during the peak periods, Fernandez et al. (2013) proposed a "just for peak" buffer inventory model. Some works as Luo et al. (2013), Tan and Liu (2014) and Bego et al. (2014) considered the variation of the price of electricity according to periods. Fang et al. (2011b) presented a multi-objective mixed integer prgramming model for a flow-shop scheduling problem. The objective is to determine the optimal schedule that minimizes the makespan, the carbon footprint and the peak power consumption. A case study for a hybrid flow-shop system is considered for Xu et al. (2014) where the objective aims to reduce the power demand for the scheduling problem. Gahm et al. (2016) developed a research framework for energy-efficient scheduling in manufacturing systems and classified the related studied problems in the literature.

For lot-sizing problems taking into account the ecological aspects, Absi et al. (2013) presented four different alternatives (periodic, cumulative, global and rolling) carbon emission constraint in the single item lot-sizing problems. Heck and Schmidt (2010) considered the power usage, carbon dioxide emission and water consumption in their lot-size study. To limit the carbon emission, Yu et al. (2013) integrated a carbon emission constraint per period, in the proposed lot-sizing problem.

As far as the lot-sizing problem in a flow-shop system is considered in the present paper, an overview of the recent works dealing with this type of problems are presented. Babaei et al. (2014) proposed a multi-level and multi-period capacitated lot-sizing and scheduling problem with sequence-dependent setups, setup carry over and backlogging in flow-shop system. A mixed-integer programming

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model for a lot-sizing and scheduling problem with availability constraints where the objective is to minimize the production, storage and sequence-dependent setup costs, was presented in the paper of Ramezanian et al. (2013) paper. Mortezaei and Zulkifli (2013) proposed a mixed-integer programming model for lot-sizing problem in flow-shop system with objective to minimize production, holding and makespan costs. The minimization of setup, holding and overtime costs was the objective of the proposed mixed-integer model for the multi-level capacitated lot-sizing problem developed by Sahling et al. (2009). Mohammadi et al. (2010) presented a multi-product multi-level capacitated lot-sizing and scheduling problem with sequence-dependent setups where the objective aims to minimize the sequence-dependent setup costs, storage and production costs. These papers do not consider the ecological aspect in their problem models. Masmoudi et al. (2015b) and Masmoudi et al. (2015a) proposed a single item capacitated lot-sizing problem in flow-shop system with energy consideration. They proposed a mixed-integer programming model where the objective is to minimize the production costs in terms of electrical, setup, holding and power costs.

In this paper, a generalized case with multi-item capacitated lot-sizing problem in flow-shop system with energy consideration is studied. According to Goldman (2010), there exist two types of demand response programs: price driven and event driven. For the first one, the price of electricity varies according to periods. Therefore the manufacturers plan and organize their activities in a way to minimize the cost of electricity. Time Of Use (TOU), Real-Time Pricing and Critical Peak Pricing represent some examples for this type of program. For the event driven program, in order to response to specific triggering events (as weather conditions and systems economics), rewards will be allocated to manufacturers who reduce their energy consumption. Therefore, these possible programs and the international context emphasize the growing interest of the energetic issues in the manufacturing systems. Then we can easily imagine that in the few coming years, different possible offers of energy suppliers can be considered. For example, by providing to manufacturers options and alternatives depending on different types of energy resources (solar, wind, nuclear, fossil...) with a flexibility in engagement and energy supply contracts. They are in a generic way characterized by price of electricity, duration and maximal power with the possibility to vary according to periods. The study developed in this paper is within this context, where the problem aims to provide the production planning taking into account prices and constraints of these energy contracts.

The outline of this paper is organized as follows. Section 2 introduces a detailed description of the problem and its underlying assumptions. Section 3 explains the fix-and-relax heuristic. Section 4 reports the numerical experiments and finally the last section presents the conclusions and future researches.

2. PROBLEM DESCRIPTION

As mentioned previously, a multi-item capacitated lot-sizing problem in flow-shop system with energy consideration is studied. The manufacturing system is composed of M reliable machines separated by M buffers with infinite capacity as illustrated in figure 1. In this section, the assumptions and a mixed integer programming model are detailed and described.

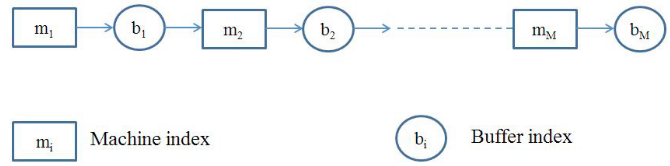

Fig. 1. A typical manufacturing system with M machines and M buffers

2.1 Assumptions

The main assumptions for the problem of multi-item capacitated lot-sizing problem in flow-shop system with energy consideration are summarized as follows:

- Several items are produced in a flow-shop structure.
- Lot-sizing and scheduling decisions are made simultaneously.
- The capacity of each machine is constrained.
- The demands are known in advance.
- The demands are satisfied at each period.
- The first machine is never starved and the last one is never blocked.
- There is no lead time between the different production levels.
- Vertical interaction: A machine m cannot begin to produce a quantity $x_{j,m,t}$ of product j in period t if this quantity is not available at the previous buffer stock.
- The machine cannot process more than one product simultaneously.
- For each machine, several setups are allowed at each period.
- The power required by the system is related to the power of machines running in parallel (overlap between machines). It should not exceed a defined maximal power.

2.2 Mathematical model

The following notations are used in the proposed mixed integer programming model.

indices :
j, i : Product index.
m, r : Machine index.
t : Period index.

Parameters :
N : Number of different products.
M : Number of machines.
T : Number of periods.
ϕ_m : Power of machine m.
Co_t : Price of electricity during period t.
$p_{j,m}$: Processing time for machine m to produce one unit of product j.
h_j : Holding cost per unit of product j.
$w_{i,j,m}$: Sequence-dependent setup cost of switching from product i to product j on machine m.
$ST_{i,j,m}$: Sequence-dependent setup time of switching from