Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 48-3 (2015) 727–732

Lot-sizing in flow-shop with energy consideration for sustainable manufacturing systems

Oussama Masmoudi* Alice Yalaoui* Yassine Ouazene* Hicham Chehade*

* *ICD, LOSI, Troyes University of Technology, UMR 6281, CNRS, Troyes, France (e-mail: oussama.masmoudi, alice.yalaoui, yassine.ouazene, hicham.chehade)@utt.fr*

Abstract: This paper presents a capacitated lot-sizing problem in flow-shop system with energy consideration. The planning horizon is defined by a set of periods. Each period is characterized by demand, duration, electricity cost and maximum peak power. Both non-linear and linear mixed integer programming are proposed to solve the problem with the objective of minimizing the production costs. The costs are considered as the sum of electrical, holding, setup and power demand costs. Computational experiments are presented and the numerical results are discussed and analyzed to evaluate the efficiency of those methods.

Keywords: Lot-sizing, flow-shop, sustainable manufacturing, peak power, production planning

1. INTRODUCTION

The aim of a lot-sizing problem is to determine the amount of products to realize at each period of a given horizon to satisfy demand while minimizing total costs. In this paper, the Capacitated Single Item Lot-Sizing Problem (CSILSP) in a flow-shop system is considered.

Nowadays, the consideration of the ecological aspects in manufacturing systems is essential for the protection of the planet. To reduce the environmental impacts, several alternatives could be presented as reduction of greenhouse gas emissions, energy consumption and water consumption. According to Mouzon et al. (2007), the expansion of research to minimize the energy consumption is due to the increase of the price of electricity and the intensification of the global warming.

As far as scheduling problems are concerned, Mouzon and Yildirim (2008) and Yildirim and Mouzon (2012) proposed a mathematical model which minimizes total tardiness of jobs and total energy consumption on a single machine. A generalized case, which has the same objective, has been developed by Liu et al. (2014) who considered a set of machines. Two zero-one non-linear programming models for a system production were presented by Wang and Li (2013) for the total electricity consumption minimization and for the total electricity cost minimizations, while maintaining an amount of average cumulative production that is not lower than the required level. Starting from an advanced planning and scheduling system, the energy aware scheduling method modifies the original timetable to reduce the shop floor peak's power. This method was proposed by Bruzzone et al. (2012). A mixed-integer programming problem aims to minimize total tardiness and makespan while respecting the power's peak demand of the manufacturing system. Fernandez et al. (2013) developed a "just for peak" buffer inventory to reduce power demand during the peak periods without affecting the throughput of the manufacturing systems. Luo et al. (2013) and Bego et al. (2014) also considered the energy aspect during the production by taking into account changes in the cost of electricity from one period to another. A multi-objective mixed-integer programming model for the flow-shop scheduling problem was proposed by Fang et al. (2011) whose objective is to find the schedule that minimizes the makespan, the peak power consumption and the carbon footprint. Xu et al. (2014) considered the reduction of the power demand for the scheduling problem in a hybrid flow-shop system.

As far as lot-sizing problems are concerned, Absi et al. (2013) suggested four alternatives to introduce carbon emission constraint in the single item lot-sizing problem; which are periodic carbon emission constraint, cumulative carbon emission constraint, global carbon emission constraint and rolling carbon emission constraint. Yu et al. (2013) presented a lot-sizing model with carbon emission constraint in each period. For Heck and Schmidt (2010), power usage, carbon dioxide emission and water consumption are considered in their lot-size study.

In this paper, lot-sizing problem in flow-shop is considered. Several research studies have dealt with this type of system. Babaei et al. (2011) and Babaei et al. (2014) presented a multi-level and multi-period capacitated lot-sizing and scheduling problem with sequence-dependent setups, backlogging and setup carry over in flow-shop system. Ramezanian et al. (2013) developed a mixed integer programming model for lot-sizing and scheduling problem with availability constraints that aims to minimize the production, holding and sequence-dependent setup costs. Mortezaei and Zulkifli (2013) developed a mixed-integer model for lot-sizing problem in flow-shop system. The objective is to minimize the production, storage and

⋆ The authors would like to thank the Champagne-Ardenne region.

10.1016/j.ifacol.2015.06.169

makespan costs. Sahling et al. (2009) presented a mixed-integer model for multi-level capacitated lot-sizing problem with objective to minimize setup, holding and overtime costs. Mohammadi et al. (2010) proposed a multi-product multi-capacitated lot-sizing and scheduling problem with sequence-dependent setups. The objective of this model is to minimize the sequence-dependent setup costs, holding and production costs. For this type of problem, neither energy consumption nor environmental impacts are taken into account.

Therefore, this paper proposes a Capacitated Single Item Lot-Sizing Problem in flow-shop with energy consideration. According to Goldman (2010), there exist two types of demand response programs: price driven and event driven. For the first category, the price of electricity varies over different time periods and thus leading to the existence of "off-peak" period and "on-peak" period. The price during the off-peak period is lower than the on-period's one. Consequently, the manufacturers planify and organize the activities in a way that minimizes the electricity costs. Time Of Use (TOU), Critical Peak Pricing (CPP) and Real-Time Pricing are some example of price driven programs. In the event-driven program, rewards will be allocated to customers who reduce their energy consumption in response to specific triggering events, depending on several factors like weather conditions and systems economics.

The outline of this paper is organized as follows. In section 2, a definition of the problem, assumptions and the models are presented. Section 3 reports the numerical examples obtained by exact methods of the proposed models. The last section presents concluding remarks and future studies.

2. PROBLEM DESCRIPTION

A typical manufacturing system with N reliable machines and N buffers with infinite capacity as illustrated in Fig. 1 is considered. Rectangles denote machines and circles denote buffers.

2.1 Assumptions

The model assumptions are as follows:

- The horizon is split into T periods where each one is characterized by its electricity price.
- The demand must always be satisfied at each period.
- For each period, the demand is known in advance.
- The first machine is never starved.
- The last machine is never blocked.
- Only one product type is to produce.
- Capacity of each machine is limited.
- A machine m cannot begin producing $x_{m,t}$ products in period t if this quantity is not available at the output of the previous machine $m-1$.

This last assumption, translating handling equipments constraints, results in production configuration in which overlaps may be encountered in a given period.

In the example illustrated in Fig. 2, all the production (covering demand for the two periods $t1$ and $t2$) is carried out on machine m_1 during t_1. The production of quantity $x_{2,1}$ on machine m_2 at period t_1 can only start once $x_{2,1}$

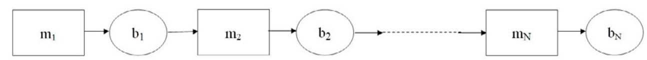

Fig. 1. A typical manufacturing system with N machines and N buffers

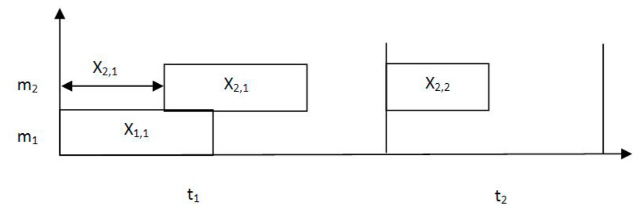

Fig. 2. A possible scenario

products start to be available at the output of machine m_1.

2.2 Mathematical formulation

The parameters used in the model are:

T : Number of periods.
ϕ_m : The power of the machine m.
Co_t : The price of electricity during period t.
p_m : Processing time for machine m.
h : Holding cost per unit.
$w_{m,t}$: Setup cost of machine m in period t.
d_t : External demand at period t.
L_t: Length of period t.
M : A large real number.
θ_t : Price of power in period t.
α_t : The allowed maximal power in period t.
$\psi_{m,t} = \phi_m \cdot p_m \cdot Co_t$: Electrical consumption cost of machine m at period t.

The decision variables used in the model are:

- Principal decision variables

$x_{m,t}$: Quantity produced on machine m in period t.
$I_{m,t}$: Inventory level downstream of machine m at the end of period t.
$C_{m,t}$: Completion time of machine m in period t.
$y_{m,t}$: A binary variable, equal to 1 if machine m is setup in period t, 0 otherwise.
P_t^{max}: The maximum power demand during period t.

- Complementary decision variables

$v_{m,t}$: A binary variable, equal to 1 if the quantity $x_{m,t}$ is available in buffer $m-1$ at the beginning of period t, 0 otherwise.
$f_{m,r,t}$: A binary variable, equal to 1 if $C_{r,t} \geq C_{m,t} - x_{m,t} \cdot p_m$, 0 otherwise.
$g_{m,r,t}$: A binary variable, equal to 1 if $C_{m,t} \geq C_{r,t}$, 0 otherwise.