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A New Model for Sustainable Changeability and Production Planning

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Abstract

Changeable Manufacturing Systems have the capability to adapt to varying production plans and different product designs by changing their configuration and layout. This paper presents a new linear mixed integer mathematical model to maximize sustainability of Changeable Manufacturing Systems based on the daily varying energy pricing. The daily production demand of several product variants has to be satisfied by corresponding configuration of the manufacturing system. System configuration planning consists of machine arrangement and job sequencing for each planning day. The proposed linear mixed integer mathematical model is solved by CPLEX solver in GAMS software for nine different problem sizes. The new LMI model finds the optimum configuration plan and job sequence in a reasonable time, which illustrates the efficiency and practicality of the proposed model.

Keywords: Changeable Manufacturing System; Sustainability; Linear Mathematical Model; Gams;

1. Introduction

Changing the configuration and layout enable manufacturing systems to adapt to different product design and production plans. However, the cost of reconfiguring the Changeable Manufacturing Systems is not only dependent on the difficulty of the transition from a configuration to the next, but also on the time of the day through which it is performed, since energy pricing changes throughout the day.

The consumption of energy in industrial sector has been intensively increased over last decades. 50% of the total global energy consumption belongs to industrial sector which is the most important energy consumer in the world [1]. There is an increasing pressure on manufacturers to decrease their carbon footprint level due to cost of energy and climate change [1]. Improving the energy efficiency of manufacturing process and management tactics help reduce energy consumptions [2].

The literature on energy efficient manufacturing processes and machinery is rich [3]. However, in a mass production environment, the majority of the energy is consumed by indirect production operations [4]. The focus of energy saving is to improve machines or processes consumption separately, which results in missing the opportunity of energy saving by a system-level approach [1].

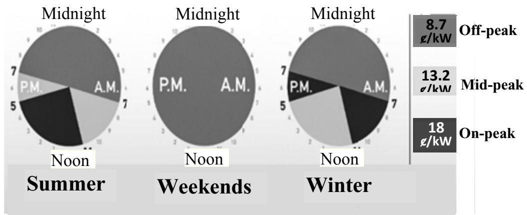

Figure 1. A sample of TOU electricity price(Ontario energy Board) [13]

There are several studies through the last decade which show the barriers and the policies of energy efficiency program implementation [5,6]. Demand-Side Management (DSM) considers peak decreasing and load shifting to off-peak from on-peak energy tariff rates in order to reduce energy cost [7]. Great endeavor in DSM have resulted in many benefits in economic and environmental points of view. A variety of strategies has been implemented in some countries to decrease energy consumption cost such as adopting time-of-use (TOU) pricing with great differences between on-peak and off-peak tariff rate [8]. The changes in energy prices play a crucial role in energy consumption costs.

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In this paper, TOU pattern of energy pricing is considered (figure 1). TOU is identified as a successful pricing pattern to find electricity demand response [8]. TOU structure divides the full day into the on-peak and off-peak periods in most cases. Sometimes a mid-peak period is also considered as a time period [8]. The on- and mid-peak periods are defined as daylight hours while the off-peak period is defined as night time hours. All these period times are the Local Standard Time [8]. For instance, each state of U.S.A has unique on-, mid-, off- peak periods with different rates of energy price. In the United States, industrial sector accounts for approximately 34% of the country' total energy consumption [1].

This paper introduces a novel linear mixed integer mathematical model to maximize sustainability of the Changeable Manufacturing Systems. The daily production demand of several product variants has to be satisfied by corresponding configurations of the manufacturing system according to unstable energy price. System configuration planning consists of machine arrangement and job sequencing. The proposed model considers three main factors that affect system sustainability in the environmental and economic domains, which are, 1) the change pattern in energy prices throughout the day, 2) the transportation cost of jobs between machines, which depends on machines locations in the system, 3) the setup cost of each machine, which is dependent on the job sequence. The model output is a system configuration plan, indicating arrangement of machines in the system, and the sequence of jobs, which need to be produced on that day.

In the following section, a brief literature review is provided, and the mathematical model is described in detail in section 3. Section 4 presents numerical experiments. Finally, the study's conclusion and future research are presented in section 5.

2. Literature review

Flexible and changeable manufacturing systems have played an effective role in energy saving. Many studies about the energy and resources efficiency of manufacturing systems has been conducted based on increasing attention to global environmental and energy saving concerns in manufacturing.

Choi and Xirouchakis proposed a linear holistic production planning model to minimize energy consumption and maximize the output in a changeable manufacturing system. The proposed model considers numerous part handling systems in detail to find an optimum energy consumption model [9]. Rajabinasab and Mansour consider different set-up planning and pallet arrangements as alternative process plans in the dynamic flexible job shop scheduling problem to minimize the energy consumption [10]. Fang et al. presented a new multi-objective mixed integer mathematical model to optimize energy consumption and peak power load of shop scheduling problem [1].

Kuster et al. proposed a new approach of changeable manufacturing system utilizing evolutionary algorithm to rearrange and optimize the production schedule with the aim of energy consumption reduction. Shifting energy consuming processes and their interconnected sub-process required reconfiguring of the individual processes to minimize the energy cost [11]. Yusta et al. presented a mathematical model to optimize production schedule and maximize the system throughput by simulating hourly electricity price differences and demand of a machining process [12].

Luo et al. proposed a multi-objective model for hybrid flow shop scheduling problem based on ant colony optimization which aims to increase the efficiency of electricity consumption based on time of use prices (TOU) and minimize the makespan [13]. Tan et al. considered the scheduling problem in the steel manufacturing process in two phases based on the variable electricity price [14].

Moon et al. proposed a hybrid genetic algorithm to maximize the energy and production efficacy of the dissimilar parallel machine scheduling problem. Decision maker can use this approach to find a solution by the use of weighted sum objective to minimize the makespan of production and time-dependent electricity costs [15].

Wang et al. developed a systematic optimization approach for scheduling and process planning of shop floor problem in order to optimize multi objectives including enhancement of adaptability, productivity and energy efficiency of system. The proposed approach includes a process stage and a system stage. In this problem, milling a part in the process stage and scheduling of whole shop floor in the system stage are optimized in order to increase energy efficiency and productivity [8].

Shrouf et al. provided a mathematical model for single machine scheduling problem to optimize the energy consumption costs. In this model, job processing time on the machine, idle time, "turning off" and "turning on" of machine are determined by applying genetic algorithm to implement the sustainable production scheduling and minimize energy consumption throughout peak periods [16].

Several optimization-based approaches have been studied for production planning in changeable manufacturing systems, including heuristics, metaheuristics, systematic approaches, and mathematical programming. None of these studies, considered energy related objective in linear mathematical modeling of the system configuration plan, including arrangement of machine, and the sequence of jobs in changeable manufacturing system.

3. Problem description

3.1. Assumptions

The system consists of a number of machines which have to be arranged in a closed loop layout. A number of different jobs are required to satisfy the daily production demand. Each job should be processed by a unique set of machines in a specified order. The sequence of required machines for processing each job is given. A job represents the demand of a specific product or product variant. A job requires at least one machine and at most all machines in the line in order to be finished. There is a unidirectional material handling system to transport work-in-process from one machine to another. A job may need the same machine more than one time to be done. Each job starts processing immediately when the last preceding job processes are completely finished. A maximum