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Minimizing total tardiness and energy cost by considering layout and scheduling in a flexible job shop

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Abstract

Most sustainable manufacturing studies have discussed scheduling with energy consumption (EC), while the effect of layout on both scheduling and EC can be significant. This paper therefore investigates the interaction between layout and scheduling in a flexible job shop, and shows how considering them together affects EC (energy cost) and a conventional performance measure (tardiness cost). A mixed-integer nonlinear programming is proposed in this study to integrate layout with scheduling, and the objective function of the model is designed to minimize total tardiness and energy cost. The efficacy of the proposed model is evaluated by solving an illustrative case study. The results show that the objective function value can be in average improved by approximately 21% using the integrated model when compared to a non-integrated model.

Keywords

Layout, scheduling, energy consumption, mixed-integer nonlinear programming, tardiness cost

1. Introduction

Manufacturing is responsible for 31% of global energy consumption (EC), which is predicted to increase by approximately 28% from 2015 to 2040 [1]. This growth of EC increases monetary and non-monetary costs for manufacturing. From the monetary point of view, clients should invest money for production and distribution of energy. From the non-monetary point of view, manufacturing produces 36% of CO2 emissions in the atmosphere [2]. Therefore, manufacturing systems need to reach sustainability in all design factors in order to minimize the EC and the relevant costs.

Scheduling and layout are two important factors, which affect the EC in the manufacturing systems. Scheduling is to determine the processing sequence of job operations on each machine, and layout is defined as assigning the machines to the existing locations. A sustainable scheduling decreases the EC by optimizing the processing sequence of operations in order to minimize the processing/idle time of each machine [3]. A sustainable layout also reduces the EC by optimizing the distances between machines, which results in a decrease in transportation time of jobs between the machines. For example, the material heating consumes a lot of energy in the glass industry, where the distance between the glass furnace and lehr can cause the temperature reduction of incoming materials. Therefore, this distance needs to be minimized in order to avoid the reheating of materials [4]. As a consequence, both scheduling and layout can play a key role in the reduction of total EC without redesigning any machine or product, which needs enormous financial investments [5,6].

Layout and scheduling need to be investigated together since they are inter-related in a flexible job shop system. The interdependency between layout and scheduling can be shown with transportation time. Transportation time is the time needed to transport a job between two machines. This time depends on the distances between the machines, which is determined by the layout. Thus, layout affects the transportation time as a part of scheduling. In a flexible job shop system, each operation is allowed to be processed on different machines. Therefore, a job can be processed on different machines based on the machine type selected for each job in the scheduling stage. The machine selection affects the machine layout in such a way that the transportation time of jobs can be optimized. In other words, layout and scheduling are inter-related, and the transportation time of jobs connects them. Therefore, an integrated approach considering layout and scheduling simultaneously can help to provide a better solution for production systems [7,8].

While previous studies have considered the EC with either scheduling or layout, the two areas have not been studied together so far. On the one hand, a few studies have investigated the EC with layout problems. For instance, Gadaleta et al. [9] studied the layout of industrial robots in the work-cells in order to perform the defined tasks with minimum EC. Yang et al. [10] also considered energy and layout criteria together to find a solution for a layout design problem. On the other hand, most researchers have studied the EC with scheduling problems [11,12]. For example, Fang and Lin [13] studied an energy-efficient scheduling problem in order to minimize the total tardiness and energy cost in a flexible job shop system. Zhang and Chiong [14] proposed a mixed integer linear programming with multiple