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Perception data-driven optimization of manufacturing equipment service scheduling in sustainable manufacturing

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ABSTRACT

Both sustainable manufacturing and manufacturing service are the trends in industry because they are regarded as ways to reduce the resource cost and energy consumption in manufacturing process, to improve the flexibility and responding speed to customers' demand, and to improve the production efficiency. In order to improve the sustainability of manufacturing equipment services in job shop, this paper presents a multi-objective joint model of energy consumption and production efficiency. The model is related to multi-conditions of manufacturing equipment services. The conditions are monitored in real-time to drive a multi-objective dynamic optimized scheduling of manufacturing services. In order to solve the multi-objective problem, an enhanced Pareto-based bees algorithm (EPBA) is proposed. In order to ensure the variety of population, to prevent the premature convergence, and to improve the searching speed, several key technologies are utilized such as variable neighborhood searching, mutation and crossover operation, fast non-dominated ranking, critical path local search, archive Pareto set, critical path taboo set, etc. Finally, the proposed method is evaluated and shows better performance in static and dynamic scenarios compared with the existing optimization algorithms.

1. Introduction

Sustainable development has been put forward since 1987 by the United Nations [1]. It is regarded as a way to achieve the balance of society, environment, and economy. According to statistics, the manufacturing sector consumes 90% of the total energy consumption of industry [2]. As the resources and energy in the earth are limited and getting fewer and fewer, sustainable manufacturing is gaining more and more attention. Energy efficient manufacturing is an important part of sustainable manufacturing. It aims to produce the same product with less energy consumption. For manufacturing enterprises, they should struggle with the increasing resource and energy prices to produce competing products with less resource and energy consumption. Moreover, manufacturing enterprises should take the responsibility of saving energy and reducing the carbon emission. Therefore, it is important for them to produce products in a sustainable way.

In the present world, the products are always completed by many participants. They need to collaborate with each other in the manufacturing process. Therefore, a manufacturing model which facilitates the collaboration of participants in manufacturing is very important. Cloud manufacturing [3–7] adopts a service-oriented manufacturing model and has been widely recognized as a novel business model to support the operation of future factories. In cloud manufacturing, all the manufacturing resources and capabilities are encapsulated into services and can be traded via Internet. Enterprises can buy and use services that they need. In such a way, enterprises can collaborate with each other conveniently. Xu et al. proposed the framework and methodologies of a service-oriented sustainable manufacturing [8]. The service-oriented manufacturing model is used to improve the efficiency of production and reduce the cost. By using this model, the optimized production processes and highly efficient utilization of different types of resources can effectively contribute to sustainable manufacturing such as reduction and recycling of raw material, reduction of energy conservation, waste, pollution, etc. Consequently, integrating service-oriented manufacturing with sustainable manufacturing will bring about a promising future.

Manufacturing equipments refer to physical devices in manufacturing, such as CNC machines, sensors, etc. They are the

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foundation of manufacturing. The scheduling of manufacturing equipments has a great influence on the energy consumption, time consumption, and cost of production. Due to the heterogeneous nature and diversity of manufacturing equipments, the long production cycle, the various production processes, and the vulnerability of manufacturing to uncertain factors such as equipment faults and task changes, traditional manual scheduling of manufacturing process cannot cope with them. The aforementioned service-oriented manufacturing model can be used to the schedule manufacturing equipments effectively. In this model, manufacturing equipments are encapsulated into services. Manufacturing equipment service is the logical entity of manufacturing cell and it can be consisted of a number of functions of the manufacturing equipment, a group of machining units or an assembly line, etc. The combination of services can adapt to dynamic production environment and provide flexibility and efficiency of the production. The way of applying manufacturing equipment services is that they can be matched to specific manufacturing task of the business layer through modeling and description of manufacturing equipment services. The scheduling of manufacturing equipments is then realized by service scheduling. Considering that the manufacturing equipment plays an important role in manufacturing, this paper focuses on the management of manufacturing equipment services to improve the sustainability of manufacturing, especially the energy-efficiency of manufacturing.

2. State of the art

In the area of sustainability-oriented shop scheduling, He et al. studied task-oriented flexible job-shop scheduling problem in order to reduce the energy consumption of manufacturing system [9]. Fang et al. considered peak power load and energy consumption in addition to cycle time in shop scheduling and enhanced the sustainability of manufacturing in the shop [10]. Bruzzone et al. established an energy-aware model of the flexible flow shop and proposed a scheduling algorithm based on mixed integer programming [11]. Although their studies aimed to reduce energy consumption of the shop under certain conditions, more complex multi-objective problems were not studied. Dai et al. proposed an improved genetic-simulated annealing algorithm to make a trade-off between the make-span and the total energy consumption of the flow shop [12]. Other factors such as resource consumption were not considered. Du et al. considered make-span and energy consumption as well and developed a Preference Vector Ant Colony System to search for a set of Pareto-optimal solutions using meta-heuristics [13]. The algorithm showed better performance than some well known genetic algorithms. Wang et al. considered manufacturing systems with multiple machines and buffers and integrated electricity consumption into system modeling [14,15]. Solution of joint production and energy scheduling problem was discussed. Energy consumption is a very important issue that should be considered in the manufacturing service and resource selection and scheduling, and it has attracted the attention from many researchers. For example, in order to realize the energy-efficient manufacturing service selection and scheduling, an Internet of Thing (IoT) and cloud computing based energy consumption data collection method was designed by Tao et al. [16], and a device for collecting energy consumption data was designed and developed by Tao et al. [17]. The above method and device proposed by Tao et al. [16,17] can be used to effective collect energy consumption data in a real time and dynamical way, which is widely referenced by the researchers in related fields, and has been widely used by practitioner in industry both in China and Europe. These studies focus on the energy consumption issue of manufacturing. However, to increase the sustainability of manufacturing, more factors should be considered.

There are some studies which consider the disturbance in manufacturing and focus on dynamic scheduling of manufacturing. Zhang et al. considered the energy consumption and the unexpected events occurring in flexible manufacturing system and used the genetic algorithm with elite strategy to optimize the energy consumption and scheduling efficiency simultaneously [18]. Gholami et al. considered dynamic events in real-world environments and the unavailability of machines such as unanticipated breakdowns or preventive maintenance, and used genetic algorithm to minimize the expected makespan and mean tardiness [19]. Nguyen et al. developed four multi-objective genetic programming-based hyper-heuristic methods for automatic design of job shop scheduling policies [20]. The proposed methods could be employed in stochastic and dynamic job shops.

On manufacturing services, Xu et al. proposed a service oriented sustainable manufacturing framework which was consisted of perception layer, data layer, service layer and application layer [8]. Wang et al. proposed a new adaptive process planning method. Function Blocks were introduced to the monitoring of job shop and the control of manufacturing equipment [21,22]. The Function Blocks were data and event driven. Scheduling algorithms were encapsulated in Function Blocks. Tao et al. firstly investigated the relation of cloud computing, Internet of Things, and cloud manufacturing, and proposed a cloud computing and Internet of Things based Cloud Manufacturing Service System [23], and then Tao et al. [24] proposed a parallel method for service composition optimal-selection in cloud manufacturing system, and a new method or dynamic migration of virtual machines in cloud computing [25]. Tao et al. also studied the key issues on manufacturing service and established QoS based model for optimization of manufacturing services [26]. Xia et al. developed an improved ant colony algorithm to realize dynamic combination of optimization services [27]. Xiang et al. considered the importance of energy consumption in cloud manufacturing services and proposed a framework for energy consumption evaluation of cloud manufacturing service [28]. Tao et al. [7] studied the intelligent management of manufacturing service from a lifecycle perspective, and first proposed the concept of manufacturing service network [29] and its scale-free characteristics [30], which developed a new research field both in the field of manufacturing and service computing. It can be concluded that sustainable manufacturing has not been adopted widely in manufacturing services and this should be studied future to improve the sustainability of manufacturing.

Besides the above studies on energy-efficient manufacturing mostly in an operational research view, there are many studies on engineering driven approaches. Many software packages such as Simu8, 3DCreate, Arena, Automod, Plant Simulation, Witness, ProModel, ExtendSIM, Simio, Flexsim, Anylogic, Enterprise Dynamics, and Gold-Sim, and ongoing research have been developed or studied to model and simulate energy and environmentally related aspects in manufacturing system [31]. Salonitis et al. summarized the engineering methods to make manufacturing system more energy efficient, such as switching off equipment at end of shift or powering down clean room air handling when not in use at night, and harvesting energy, etc. [32].

The use of sensors in sustainable manufacturing is also a hot topic. Vijayaraghavan and Dornfeld correlated energy data from process equipment, ancillary equipment, and embedded sensors with the operations being performed in the manufacturing system, in order to reduce the energy consumption of machine tools and improve the environmental performance of manufacturing system [33]. O'Driscoll and O'Donnell provide a review on industrial power and energy metering to enable a sustainable energy future of manufacturing [34]. Duque Ciceri et al. regarded RFID as a powerful