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Material supply scheduling in a ubiquitous manufacturing system

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ABSTRACT

Recently, ubiquitous manufacturing has attracted wide attention in both academia and industry. To create a successful ubiquitous manufacturing system, an efficient material handling system is essential. In accordance with this reason, mobile robots have been used for transporting materials. This paper aims at developing a methodology for scheduling the material supply for a single mobile robot in a ubiquitous manufacturing environment. In this type of environment, the processing rate of the materials along with supply quantity corresponds to the cycle of material supply. The carrying capacity of the robots are limited and thus the problem of determining the material supply quantity and material supply schedule without lack of materials for production or service processes becomes complicated. In this work, a nonlinear program is formulated to schedule the supply of material and determine the required material quantity. A heuristic algorithm based on genetic algorithm is developed to solve the problem. From the numerical experiments conducted in this study, it is observed that the proposed algorithm shows good performance and can also be implemented to solve large scale problems.

1. Introduction

In modern manufacturing systems, especially flexible manufacturing system, many new technologies such as RFID, wireless network and intelligence devices are used to reduce the operation times. Customers prefer highly customized products, which leads to a need of change: from traditional production paradigm, where highly customized products are associated with high production cost, to mass customization, where production cost can be reduced while maintaining product quality and on-time delivery to satisfy diversified demands [1,2]. This requires the manufacturers to produce products with short life-cycles with mass production scale. Moreover, outsourcing is gaining popularity among industries, where it presents an alternative of a reduced production cost to the costlier in-house production. These challenges have given birth to the concept of ubiquitous manufacturing. Dubey et al. [3] defined ubiquitous manufacturing as activities which are both market oriented and have a frequency of occurrence greater than a specified limit. In ubiquitous manufacturing, many kinds of pervasive and intelligent networked computers embedded in objects and environments will make human life easier and more comfortable [4].

Yoon et al. [4] mentioned that the material handling system is the most widely applied area of ubiquitous technology. Material handling system has to ensure that the materials are supplied on time without machine idling and the system must quickly update its material supply schedule. Therefore, ubiquitous technology is well adapted to satisfy these requirements. The material handling system uses flexible vehicles to transport materials. These vehicles are programmed to automatically supply materials to machines and continuously communicate with the ubiquitous system via a wireless network. Mobile robots (i.e., unmanned ground vehicles) have recently played an important role in handling materials including raw materials, work-in-process parts, unfinished assembly parts and traveling around machines to ensure the smooth flow of materials, and hence, improve the productivity [1]. Moreover, automatic vehicles can be operated in dangerous and hazardous environment. A major issue encountered while using automatic vehicle in ubiquitous system is that the material supply schedule must be quickly updated (often in an online mode) due to the frequent changes in the demands from the customers. To solve this, there is a requirement of developing a methodology for the problem of material supply scheduling where feasible schedules should be found quickly. The main role of automatic vehicle is to deliver unfinished parts from warehouses and/or machines to

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other machines following the production process. In addition, more functions are designed on an automatic vehicle to assist the production process and this further increases the complexity of the scheduling problem. Thus, considering the problem of scheduling material supply for an automatic vehicle in a ubiquitous system is very essential and necessary.

This paper focuses on the material supply scheduling problem for a mobile robot, an automatic vehicle, in a ubiquitous system. These types of robots are capable of loading materials automatically from warehouses and deliver materials to the buffers of machines. Mobile robots are operated based on a programmed procedure which is downloaded from a control server to the robot memory via wireless network. Moreover, robots are designed to move flexibly on pre-defined routes in the manufacturing layout. Aforementioned advantages of mobile robot are well-suited in overcoming the challenges for material supply scheduling problem in ubiquitous system.

In a supply schedule, one must ensure that there are no material shortages at any of the machines. However, there is a limitation on the energy consumption of mobile robots for performing the activities. Due to this limitation, saving energy consumption is one of the criteria to indicate how well a supply schedule is. To reduce energy consumption, which mainly occurs due to robot travels, the supply schedule should minimize the travel distance of the robot. If there is only a single machine in the system, a large amount of supply quantity can reduce the number of visits, and hence, reduce the travel distance of the robot. However, this cannot be implemented for an environment with multiple machines, where the carrying capacity of the robot is limited. If the mobile robot transports too many materials to be supplied to a machine, it has no capacity to transport materials for other machines. This results in the robot traveling longer distance because it has to travel back to the warehouse more frequently. Moreover, the length of the cycle to supply a machine is proportional to the supply quantity and different cycle length leads to different supply schedules of the robot. Hence, the problem to find the optimal supply quantity in each visit at each machine and the supply schedule for the mobile robot is necessary. This paper aims at developing a heuristic based on genetic algorithm to solve this problem.

The remainder of the paper is organized as follows. A detailed literature review on ubiquitous manufacturing and its application are presented in Section 2. Section 3 describes the problem in detail and the mathematical formulation of the proposed problem is presented. Section 4 explains the problem along with the solution method to determine the feeding quantity for each machine and the feeding schedule for the mobile robot. Section 5 presents the numerical experiments to illustrate the performance of the proposed algorithm. Finally, Section 6 concludes the finding of this research.

2. Literature review

Recently, many researchers have been focusing on developing the framework for ubiquitous system. Yoon et al. [4] applied ubiquitous computing technology to develop a conceptual framework for a ubiquitous factory (the u-factory). Three phases (information transparency, autonomous control and sustainable manufacturing) should be featured in the future factories [4]. Yoon et al. [4] analyzed the current manufacturing system using the framework of ubiquitous factory and proposed a new model for manufacturing resource management. A comparison between the current and the proposed model is conducted to understand the advantages of the proposed model in different aspects such as measurements, maintenance, safety, environment and energy. Another work on ubiquitous system for a shop floor environment is proposed by Suh et al. [5]. A technology roadmap for a u-factory is proposed where computer-aided ubiquitous system includes u-system optimization and the communication system which is mainly based on wireless technology. In the aforementioned papers, the authors mainly considered the strategic level of ubiquitous technology. This makes a good starting point for ubiquitous technology application. However, not many papers could be found which dealt with the tactic level which occurs during short-term operation (eg. daily, weekly, or monthly activities). Sallinen et al. [6] developed a system named "isle of automation" where ubiquitous robot cells are used for flexible manufacturing. The architecture of the production cell includes robot manipulator and controller, cell controller, and device controller are presented. In the proposed automation system, they considered different modules for programming, sensing, material handling and flow, and communication. However, there was no focus on scheduling material supply in the manufacturing process. Activities at the tactic level such as the list of materials to be supplied at each machine by a robot, the sequence of material supply, the time to supply at a machine has been discussed only in some of the literatures.

The problem to schedule the operations including material loading, movement between warehouse and machines, and material unloading for a mobile robot is similar to traveling salesman problem (TSP). However, in general, the travel time and distance can be distinguished into two directions of two locations. For example, the path for transporting material from warehouse to a machine can be different with the path from that machine back to the warehouse because of safety reason. Several approaches and models for exact or heuristic algorithms have been proposed to address these types of problems. There have been many studies on solving Asymmetric Traveling Salesman Problem (ATSP). Some researchers focused on implementing branch-and-bound algorithm [7]. However, in some studies it is reported that mobile robot (unmanned ground vehicles and unmanned aerial vehicles) scheduling problems cannot be treated as an ATSP due to some additional constraints such as the carrying capacity of the mobile robots and multiple visits.

Only few researchers have studied the robot task-sequencing problem, which is one of the major aspects of the addressed problem in this paper. Ascheuer et al. [8] considered the sequential ordering problem which is close to the robot task-sequencing problem. Dang et al. [9] proposed an MIP model to obtain the optimal feeding sequence of a mobile robot in a manufacturing cell. Some studies conducted by Relich and Muszyński [10] and Do et al. [11] focused on planning and scheduling in manufacturing and services. There have been few papers which focused on solving the robot task-scheduling problem using heuristic algorithm. Han et al. [12] developed the nearest neighbor rule in which robot travels to nearest pick up point from its current position. Askin and Standridge [13] proposed the closest insertion algorithm. Suárez and Rosell [14] used dispatching rules to determine the sequence of tasks. These algorithms showed good performance in short computation time. Researchers implemented metaheuristics to solve the combinatorial optimization problem, especially for robot task scheduling problem. A hybrid approach of constraint programming and integer programming is developed by Sitek and Wikarek [15,16] to solve a supply chain optimization problem. Tsai et al. [17] developed ant colony algorithm (ACO) to solve TSP problem, whereas López-Ibáñez and Blum [18] solved TSP problem with time windows (TSPTW) using Beam-ACO algorithm. Others approached TSPTW problem with simulated annealing in [19,20], while Carlton and Barnes [21] used tabu search algorithm. For a large scale TSP, Hasegawa et al. [22] developed an algorithm based on tabu search and neural network. A tabu search algorithm is also proposed by Hurink and Knust [23] to solve the scheduling

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