Computers & Industrial Engineering 84 (2015) 12–23

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Real-time scheduling for hybrid flowshop in ubiquitous manufacturing environment

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ARTICLE INFO

Article history:
Available online 12 October 2014

Keywords:
Real-time scheduling
Hybrid flowshop
Ubiquitous manufacturing

ABSTRACT

This paper discusses the implementation of RFID technologies, which enable the shop floor visibility and reduce uncertainties in the real-time scheduling for hybrid flowshop (HFS) production. In the real-time HFS environment, the arriving of new jobs is dynamic, while the processes in work stages are not continuous. The decision makers in shop floor level and stage level have different objectives. Therefore, classical off-line HFS scheduling approaches cannot be used under these situations. In this research, two major measures are taken to deal with these specific real-time features. Firstly, a ubiquitous manufacturing (UM) environment is created by deploying advanced wireless devices into value-adding points for the collection and synchronization of real-time shop floor data. Secondly, a multi-period hierarchical scheduling (MPHS) mechanism is developed to divide the planning time horizon into multiple shorter periods. The shop floor manager and stage managers can hierarchically make decisions for their own objectives. Finally, the proposed MPHS mechanism is illustrated by a numerical case study.

1. Introduction

The need for real-time data in production shop floors has been long recognized in industry. Recent developments in wireless technologies and ubiquitous computing technologies have nurtured the emergence of ubiquitous manufacturing (UM) system (Zhang, Huang, Qu, Ho, & Sun, 2011; Zhang, Qu, Ho, & Huang, 2011). A UM system is based on wireless sensor network that facilitates the automatic collection and real-time processing of field data in manufacturing processes. In this way, the error-prone, tedious manual data collection activities are reduced or even eliminated (Jun, Shin, Kim, Kiritsis, & Xirouchakis, 2009).

The dropping cost of RFID technology motivated sporadic UM piloting efforts in material track and trace ranging from machine tools management, raw material management, WIP management and warehouse management (Chen & Tu, 2009; Huang, Zhang, Chen, & Newman, 2008a; Zhang, Jiang, & Huang, 2008; Zhang, Huang et al., 2011; Zhang, Qu et al., 2011). However, the significant role of UM system in production planning and control is still overlooked by both academia and industry. The real-time visibility and interoperability, which are core characteristics of UM, created opportunity to minimize the uncertainty and disturbance during the production process and close the loop of production planning scheduling and execution (Huang, Zhang, & Jiang, 2008).

Applying RFID technology in the production planning and control has significant advantages. In terms of data collection, RFID technology provides a most rapid and accurate way to capture real time data from shop floor. A seamless dual-way connection can be achieved between decision-making level and execution level. In terms of information transmission, RFID tag is a flexible data carrier, which can easily attach on production resources, such as product component, pallets, machines even operators. The production data in RFID tag can be written and rewritten without any manual intervention. The production resources can carry their own status information and interact with each other. This feature is extremely important in the dynamic production environment.

This research attempts to capitalize the benefits of RFID-enabled ubiquitous manufacturing technology for real-time planning and scheduling in a practical production environment.

The work has been motivated by several industrial collaborators involved in discrete manufacturing of a large variety of component module options and product variants of small or one-of-a-kind (OKP) quantities. Products include moulds and dies, lifts and industrial equipment.

For convenience of reference, this paper will take mould and die (MD) manufacturing as an example to discuss the real time scheduling problem. MD products are one-of-a-kind production and

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http://dx.doi.org/10.1016/j.cie.2014.09.019
0360-8352/

engineered-to-order (ETO) products. Only one or several products are typically ordered and manufacturing is non-repetitive. Normally, the process of MD production consists of a set of jobs which are to be processed in a series of stages. Each stage has a set of parallel machines. All jobs are processed following the same production flow from the first stage to the last. Each job must be processed by at most one machine in each stage. This type of manufacturing environment is defined as hybrid flowshop (HFS).

The HFS problem is, in most cases, NP-hard (Linn & Zhang, 1999).The standard HFS has attracted a lot of research attention given its complexity. Many solution approaches, which include exact methods, heuristics, and meta-heuristics have been investigated in previous researches (Kumar, Tiwari, & Shankar, 2003; Marimuthu, Ponnambalam, & Jawahar, 2007; Pan, Wang, & Qian, 2008). However, these standard HFS approaches are difficult to be applied in real life MD scheduling, since most of them are off-line scheduling. The off-line scheduling assumes that all jobs are available before the starting time. The information about all stage and machines is completely known in advance. Once a schedule is generated, all jobs can be continuously processed without any interruptions.

Such assumptions are not true in real-time MD manufacturing. Firstly, not all jobs are known at the beginning. New jobs may dynamically arrive during the schedule horizon and current schedule should be updated immediately. Secondly, the production of each stage is not continuous. A typical product needs 2–3 days to cross all stages in the shop floor. The standard working shift is 8 h but the actual working hour of each stage may different. Thirdly, there are two types of decision maker with different objectives. The order progress is charged by shop floor manager, who is responsible for delivering the products on time. The stage operations are chaired by stage managers, whose primary objective is to maximize machine utilization and finish the job as soon as possible.

Therefore, the standard off-line HFS approaches are not suitable for the real-time production. The truth is that most companies use the simplest dispatching rule to make the daily scheduling (Mittler & Schoemig, 1999): the shop floor manager releases the new orders to shop floor every day and checks the order status on the due date. The stage managers try to process the jobs as many as possible in each working shift. Such dispatching rule is simple to apply but it always encounters significant challenges:

(1) Since there is no real-time data feedback channel, the operation in shop floor will become a black box, after the shop floor manager dispatches the orders. The manager does not know what happens in the shop floor until the product goes to the last stage. Once the product cannot finish on the due date, "fire-fighting" in the shop floor is very common. Three shifts of workers and managers worked together around the clock to meet the deadline
(2) Since there is no information-sharing channel among stages, the workloads of each stage cannot be balanced. It is very common that one stage may process jobs much faster and it does not control the throughput. Then, those jobs may be accumulated sharply in its downstream stage.
(3) Since there is no coordination mechanism from the upper level to control the order progress during the whole time horizon, the operation in each stage is always busy. The order tardiness in peak-season and order earliness in off-season is very common.

The aim of this research is to develop a solution to overcome the production scheduling difficulties in the real-time HFS environment discussed above. Two major measures are taken to deal with the information barrier and uncoordinated decision between the shop floor level and stage level. Firstly, a ubiquitous manufacturing (UM) environment is created by deploying advanced wireless devices such as RFID reader into value-adding points for the collection and synchronization of real-time shop floor data. The disturbances and changes are tracked and traced by RFID-enabled real-time events. Secondly, based on the real-time data, a multi-period hierarchical scheduling (MPHS) mechanism is developed. The shop floor manager divides the scheduling time horizon into multiple shorter periods and makes shop floor scheduling on each period to control the production progress of all orders and balance the workload for all stages. Each stage manager works out the local stage schedule within the periods to coordinate with its neighbour stages and try to satisfy the requirement from upper level scheduling.

This paper is structured as follows. Section 2 reviews the related literatures on real-time manufacturing. Section 3 gives a description of the real-time HFS problem. Section 4 presents how RFID technologies are deployed in a typical real-time HFS to create the UM environment. Section 5 discusses a multi-period hierarchical scheduling (MPHS) mechanism. Section 6 gives a case study to illustrate the proposed MPHS. The paper is concluded in Section 7.

2. Literature review

Related work is categorized according to the following six aspects:

Project and production scheduling under uncertainties. The literature on project scheduling under uncertainty is scarce. A typical treatment is to consider the project network as deterministic while some of activity parameters as stochastic (Neumann, 1999). A more general consideration is to treat project networks as stochastic. Most references on scheduling problems under uncertainty are for production scheduling. Aytug, Lawley, McKay, Mohan, and Uzsoy (2005) provide a comprehensive review of the literature, covering reactive, predictive, stochastic and fuzzy scheduling. Sabuncuoglu and Bayiz (2000) and Vieira, Herrmann, and Lin (2003) discuss reactive scheduling.

JIT and Kanban-based production planning & scheduling. Benton and Shin (1998) compare and contrast MRP (Material Requirement Planning) and JIT (Just In Time) as "Push" and "Pull" representatives. Their integration is discussed to use their strengths while avoid their limitations. A typical integration is to use JIT Kanbans together with MRP system. Deleersnyder, Hodgson, King, O'Grady, and Sawwa (1992) conduct comparative analysis of push, pull and push–pull production control with a conclusion that the push–pull mixture system is more responsive to changes but simpler to use. Hirakawa, Hoshino, and Katayama (1992) examine the capability of the push–pull system in dealing with changes in production and inventories. Khalouli, Ghedjati, and Hamzaoui (2010) study a JIT HFS problem. The JIT requirement is reflected by the optimization objective with minimization of total earliness and tardiness. Ant colony optimization method is proposed to deal with the problem. Similar study is conducted by Hazır and Kedad-Sidhoum (2014). They address the optimal batch sizing and JIT scheduling problem where upper and lower bounds on the size of the batches are imposed. Qing, Xue-tao, and Zhong (2011) propose a new technology called visualization Kanban to handle the varieties of small batch production. Turner, Madachy, Ingold, and Lane (2012) integrate systems and software engineering at the enterprise level, where rapid response software development projects incrementally evolve capabilities of existing systems and/or systems of systems. A Kanban-based scheduling system is defined and implemented with connected discrete, continuous and agent-based models. However, Kanbans mechanism is more suitable for repetitive manufacturing. Its use for OKP is rare in the literature.