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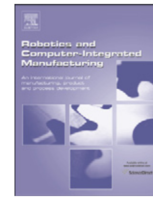

RFID-enabled real-time manufacturing execution system for mass-customization production

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ABSTRACT

Mass-customization production (MCP) companies must fight with shop-floor uncertainty and complexity caused by wide variety of product components. The research is motivated by a typical MCP company that has experienced inefficient scheduling due to paper-based identification and manual data collection. This paper presents an RFID-enabled real-time manufacturing execution system (RT-MES). RFID devices are deployed systematically on the shop-floor to track and trace manufacturing objects and collect real-time production data. Disturbances are identified and controlled within RT-MES. Planning and scheduling decisions are more practically and precisely made and executed. Online facilities are provided to visualize and manage real-time dynamics of shop-floor WIP (work-in-progress) items. A case study is reported in a collaborating company which manufactures large-scale and heavy-duty machineries. The efficiency and effectiveness of the proposed RT-MES are evaluated with real-life industrial data for shop-floor production management in terms of workers, machines and materials.

1. Introduction

Mass-customization production (MCP) is a competitive mode of producing a wide variety of customized products using a large-scale mass production strategy to satisfy diverse customer requirements and to reap benefits both from mass and craft production [32,40]. In typical MCP companies, the arrival of customer orders and operation times are highly stochastic, resulting in a variety of disturbances such as emergency orders and frequent engineering changes. Because a considerable amount of parts and components used in mass-customized products are one of a kind, the involved setup times and processing times are difficult to estimate. Such uncertain disturbances will affect normal production plans and schedules [9]. Furthermore, these disturbances cause snow-ball effects such as delays on customer orders, logistics errors and high level of work-in-progress (WIP) inventories. Fire-fighting becomes common between the production department planner whose primary aim is to deliver the products on time, and shop-floor supervisor whose major objective is to maximize machine utilization and productivity [16].

In order to address the above challenges, MCP companies have been introducing ERP (Enterprise Resource Planning) systems. The use of ERP systems achieves a better integration and flow of information between business functions inside and outside an organization [10]. However, this ERP approach alone is not adequate. First, ERP concentrates on the managerial level of decision-making and its shop-floor supervision is relatively weak to support frontline workers and supervisors. Second, ERP usually needs real-time and accurate shop-floor data to generate perfect decisions. Unfortunately, MCP companies do not have such real-time data collection mechanisms in place. That causes a serious gap between the flow of shop-floor physical materials and the flow of information or decisions.

The recent movement has advocated the approach of complementing the ERP system with MES (manufacturing execution system). ERP and MES form a bi-level twinned systems overcoming each other's shortcomings [28,38]. MES mainly concentrates on managing shop-floor operations such as scheduling as well as its execution and control, timely informing shop-floor supervisors in terms of equipment status, material delivery and consumption as well as manufacturing progress [2]. Due to its tangible and intangible benefits, MES has been adapted and adopted in great many of manufacturing fields [12,8].

Since most MCP items are one of a kind and their statuses must be uniquely tracked on manufacturing shop floors, data

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collection is significant when such companies contemplate to implement MES. Unfortunately, the paper-based data collection system dominates in their manufacturing sites such as shop floors and warehouses. As a result, field data are often incomplete, inaccurate and untimely [34]. The paper-based system forces them to make plans and schedules manually and cannot address the disturbances efficiently and effectively. Furthermore, the visibility and traceability of manufacturing items such as WIP are so weak that high inventory level of WIP is common in MCP companies.

In order to facilitate the real-time data collection, RFID (radio frequency identification) has been proposed to capture manufacturing data, aiming at real-time synchronization of physical flow of materials and associated information flow [33,31,29]. Based on the synchronization, Kohn firstly used real-time RFID data for supporting the repair work control [20]. Since then, RFID-enabled real-time applications have been widely expected, reported and recognized [22,44,19,23].

This paper presents an RFID-enabled real-time manufacturing execution system (RT-MES) for MCP shop-floor management including real-time data collection, real-time scheduling as well as real-time WIP tracing and tracking. The paper addresses three research questions: (1) How does RT-MES systematically deploy RFID devices on MCP shop-floors to capture real-time manufacturing data? (2) How does RT-MES adopt the real-time data to support MCP shop-floor scheduling? And (3) How does RT-MES enable real-time traceability and visibility of materials (e.g. WIP items) to reduce WIP inventory?

This paper is organized as follows. Section 2 gives a brief literature review related to the research under three categories: RFID-enabled data collection, RFID-enabled scheduling and RFID-enabled MES. Section 3 demonstrates the RT-MES for MCP in terms of framework and three innovative components. Section 4 reports on a case study on how RT-MES facilitates a real-life MCP company's shop-floor management in terms of workers, machines and materials. Section 5 concludes this paper by giving our findings and future research directions.

2. Literature review

Related research is reviewed under three categories: RFID-enabled data collection, RFID-enabled scheduling and RFID-enabled MES.

AUTO-ID enabled production data collection was emerging in the era of computer integrated manufacturing (CIM) [41,42]. In recent years, RFID has been emerging as an important Auto-ID technology which owns a lot of special advantages over others like barcode, including longer reading distance, larger data storage and so on. A preliminary approach was depicted to use RFID technology to capture repair-work data in a car production line [18]. Due to its powerful ability of real-time data collection, RFID technology has been widely utilized in supply chain management (SCM), warehouse management (WM) and production management [1,21,26,39,37].

RFID technology has been deployed to various manufacturing objects through different schemes such as individual items, tray-based or container-based approach [25,11]. Once the objects are tagged, they become smart objects (SOs) that can be traced and tracked. The data carried by them can be collected and are updated when their locations change from time to time [14]. Meanwhile, data are transferred to enterprise information systems (EISs) through communication networks such as Bluetooth, 433 MHz and TCP/IP [15]. In this way, manufacturing data such as machine statuses, workforce situations, material consumptions and order progresses are collected and managed at a level that is accurate, complete and real-time.

RFID-enabled scheduling has been discussed and reported in the literature by many researchers. Brewer et al. [3] used RFID real-time data to support dynamic scheduling in manufacturing and supply chain management so as to control production execution and logistics planning. Malhotra [24] reported on a real-time responsive system with the help of RFID tags to minimize the delay between a customer order, shipment and the restocking of inventory from Wal-Mart case. Chow et al. [6] proposed a RFID case-based resources scheduling system to help users to pick out the most suitable resource usage packages for handling warehouse operation environment. They integrated RFID and case-based reasoning (CBR) technologies so as to optimize forklift route in a multinational logistics company. Ngai et al. [30] presented an RFID prototype system that is integrated with mobile commerce to scheduling the containers. They also illustrated a case study to reflect the benefits and advantages of this system, aiming to improve the control processes through real-time scheduling. An RFID-based scheduling system was developed for walking-worker assembly islands with fixed-position layouts [17]. The paper integrated Just-In-Time (JIT) concept and RFID technology to reduce the WIP inventories as well as synchronize the real-time field data and physical material in manufacturing workshops. [13] utilized RFID technology to assist in lot splitting which was the practice of splitting production orders into smaller sub-lots. They quantitatively analyzed the trade-off between improved flow and tardiness metrics in material operations when splitting lot in the shop-floor, aiming at controlling the high levels of lot splitting and material tracking.

As early as 1990s, MESA (MES Association, US) has introduced a series of white papers to formalize and standardize MES [12]. Since the Auto-ID technology such as RFID had been used and recognized by many researchers and practitioners, MES integrated with RFID has been widely reported. Cheng et al. [5] presented a distributed object-oriented technique to develop a computer-integrated MES framework which was open, modularized, distributed, configurable, and interoperable. Monostori et al. [27] introduced a real-time MES approach to control MCP activities on the shop-floor, as well as gave the experiment results indicated that it was possible to implement real-time MES in real-life practice. Cândido et al. [4] integrated RFID and MES in the textile industry so as to achieve real-time decision transfer on shop-floors to realize an evolvable production system. Leading MES providers or research institutions such as Siemens' SIMATIC-IT, WONDERWARE's FactorySuite2000, CAMSTAR et al. unionized ISA, OPC and WBF to establish the RFID-enabled MES standards and specifications [36].

3. RFID-enabled real-time manufacturing execution system for MCP

Fig. 1 describes a typical information system framework widely used in industry field. There are three layers: manufacturing shop-floor layer, manufacturing execution system (MES) layer and enterprise information system (EIS) layer. EIS layer is consisted with ERP, PDM (product data management) and CAPP (computer-aided process planning), which are responsible for making enterprise-level decisions.

A typical MES, as middle of Fig. 1, usually contains 11 functionalities which are designed and developed as web services within several key services in this case. RFID middleware service is responsible for managing RFID devices and controlling data transfers between readers and tags as well as the hardware maintenance. Planning and scheduling service executes real-time production