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Manufacturing with item-level RFID information: From macro to micro quality control

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ABSTRACT

Radio Frequency IDentification (RFID) tags have gained wide-spread popularity in a wide variety of application domains. However, their use in the manufacturing environment still remains at a low level. Despite maturity of related technologies, the lack of managerial understanding of potential benefits has been a major impediment to RFID tag's inroad in the manufacturing domain. In addition to their item-level identification capability, RFID tags enable local storage and retrieval of relevant features associated with each item. We consider the dynamic associated with the availability of item-level information in a mass manufacturing context, propose and develop a knowledge-based adaptive learning system for this scenario, and present related managerial insights. We use modeling as well as manufacturing process simulation to illustrate the proposed framework. Results from this study indicate that the benefits for manufacturing with item-level information increases, although bounded, with increasing variance present in the manufacturing process.

1. Introduction

RFID (Radio Frequency IDentification) tags have been successfully used for identifying and tracking objects of interest. A majority of extant literature on RFID applications are in supply chain management and health care. A large number of these are case studies or simulations of domain-specific RFID implementations in inventory management and replenishment, supply chain operations, and retailing. For example, Atali et al. (2004) investigate the value of RFID under imperfect inventory information. Doer et al. (2006) present an analysis of the costs and benefits of RFID technology for the management of ordnance inventory using both qualitative and quantitative methods. Gaukler et al. (2007) study item-Level RFID in the retail supply chain. Lee and Ozer (2007) investigate the value of RFID in a supply chain. Dutta et al. (2007) examine three dimensions of the value proposition of RFID: generic architecture of RFID implementations and the drivers of value; measurement issues associated with quantification of value; incentives for achieving diffusion when multiple independent organizations deploy the technology and coordinate the resulting information flows. Whang (2010) considers a supply chain where the incorporation of RFID tags on products by firms upstream could possibly lead to the free-rider problem by firms downstream. He finds that technology coordination and cost-splitting contribute to the mitigation of this problem in RFID adoption decisions. Gaukler (2011) considers RFID cost sharing between nodes upstream and nodes downstream in a supply chain. Sarac et al. (2010) provide an excellent overview of RFID applications in supply chain management.

RFID tags have also been used in other application domains. Some examples include means to deal with the issue of inventory inaccuracies in supply chains (e.g., Rekik et al., 2009; Rekik, 2011), material handling systems (e.g., Dai and Lee, 2011), retailing (e.g., Marco et al., 2011; Wong et al., 2011), cruise service operations (Veronneau and Roy, 2009), service operations (e.g., Lee et al., 2008), B2B mobile commerce (e.g., Stender and Ritz, 2006), logistics (e.g., Klein and Thomas, 2009; McKelvey et al., 2009; Mondragon et al., 2009), among others.

From an automated identification perspective, RFID tags have numerous advantages over competing technologies (Zhou, 2009). However, RFID tag applications in the manufacturing shop floor setting still remain rather limited and unexplored. Nevertheless, it is critical for manufacturers to know an item's instantaneous status, the processes it has gone through, and its trajectory through the manufacturing system. An item's instantaneous status includes its unique identity, precise physical location, physical status, and special key features. Sahin et al. (2002) provide a list of potential benefits of RFID technology on supply chain processes including

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(1) reduction in labor costs, (2) increase in store selling area, (3) acceleration of physical flows, (4) reduction in profit losses, (5) efficient control of the supply chain due to increased information accuracy, (6) better knowledge of customer behavior, (7) better knowledge of out-of-stock situations, (8) reduction in delivery disputes, (9) better management of perishable items, (10) better management of returns, (11) better tracking of quality problems, (12) better management of product recalls and customer safety, and (13) improved total quality control.

Ferrer et al. (2011) consider the use of RFID in a remanufacturing context. They use simulation and case study to consider scenarios where RFID tags are used and not used where few vs. several parts are considered in a army depot scenario. They specifically consider remanufacturing operations that have the most potential and observe that RFID implementations are beneficial in combination with a set of related process improvements. Using principles from Bayesian reasoning and decision theory, Kelepouris and McFarlane (2010) compare the effects of RFID systems and real-time location systems (RTLS) for asset location in a manufacturing context. Thiesse and Fleisch (2008) consider the use of RFID for real-time location of entities in a semiconductor fab. for dispatching and scheduling purposes.

There is a growing number of strategies for improving the general manufacturing process such as total quality management (Oakland, 1995), just-in-time production (John, 1989), design for manufacturability (Venkatachalam et al., 1993), lean manufacturing (Shah and Ward, 2003), reengineering, benchmarking and mass customization (Silveira et al., 2001). Traditional mass manufacturing operates based on standards that are established during pre-manufacturing design, planning, and testing that could possibly include trial runs. These standards are then consistently applied to all production activities until there is a need to update them due to changes in the work environment. It should be noted that in any manufacturing process, there is always a certain level of tolerance that is considered to be within an acceptable range. Clearly, variance is present even in a sample of objects that have passed the acceptable tolerance-level test. Acknowledging the presence of disparity in material quality and work environment over time, we argue that through utilization of item-level information during the manufacturing process, firms have the capability to produce higher quality products and thereby generate increased profit. We propose and study the innovative concept of item-level manufacturing facilitated by a knowledge-based learning support system.

We consider a scenario where a product is manufactured from several RFID-tagged component parts. Each of these tags contain information about the host part, including its unique identifier and other specifications of interest. Based on these specifications and some performance criterion, the most appropriate set of parts is selected to form the final product. The proposed knowledge-based framework aids this process by utilizing decision rules that select complementary parts based on their respective measured item-level specifications.

The benefits of the proposed framework is a direct result of increasing certainty (i.e., reducing uncertainty) that translates to improved manufacturing coordination (Zhou, 2009). We use the factor of certainty as a key element in modeling the value of item-level information visibility in a manufacturing environment. We then illustrate some potential benefits of incorporating item-level information in a manufacturing setting compared to a traditional mass manufacturing environment.

The remainder of this paper is organized as follows. We present the proposed item-level manufacturing framework and compare it to a traditional mass manufacturing setting in Section 2. We model the benefit of item-level manufacturing in Section 3. Section 3 also includes simulation analysis to illustrate and verify the developed model and to show its effectiveness in a manufacturing shop floor setting. Section 4 concludes the paper with a brief discussion on the insights garnered and their implications.

Table 1
Final product quality after the assembly process.

$Y=g(A_i,B_j)$	A_1	A_2	A_3
B_1	50	52	41
B_2	47	49	32
B_3	31	58	69

1.1. Motivating example

The concept of intelligent manufacturing has been widely studied in various engineering disciplines. An intelligent manufacturing control prototype utilizing automatic identification technology was first mentioned in McFarlane et al. (2003). Using an example, we illustrate how item-level visibility brings value to manufacturing by reducing uncertainty and by reducing waste. Consider a manufacturing scenario in which three machines need to be assembled, each with two component parts—A and B. Assume that we have all the necessary raw materials required as input $\{A_1,A_2,A_3\}$ and $\{B_1,B_2,B_3\}$—all of which have passed pre-determined tolerance levels, etc.

Without knowledge of item-level information on each component, the expected product quality can now be calculated with equal probability for each of the parts (Eq. (1)). The expected product quality using the example given in Table 1 is 47.67:

$$\Pi_1 = \frac{1}{ab}\sum_{i=1}^{a}\sum_{j=1}^{b} g(A_i,B_j) \tag{1}$$

When the exact specifications of all the components are known, the quality of the final product can be improved through appropriate combination of the component parts (Eq. (2)). The sum of the quality of the three final products is now 168, which corresponds to an average value of 56:

$$\Pi_2 = \max\left\{\sum_{i=1}^{a}\sum_{j=1}^{b} g(A_i,B_j)\right\} \tag{2}$$

Furthermore, assume that product with quality under 35 is considered 'inferior' and need to be recycled. With item-level information, such combinations (e.g., $\{(A_1,B_3),(A_3,B_2)\}$) that would result in unqualified set of products can be avoided. Without such information, there is a probability (of $\frac{2}{9}$) that one of the product will be recycled and a probability (of $\frac{1}{81}$) that two of the three final products will be recycled. As a result, assuming zero salvage value for unqualified product, the expected value of final products considered to be of 'inferior' quality is 40.67.

2. Manufacturing process

Traditional mass manufacturing, also known as repetitive flow production, series production or flow production, is the production of a large number of standardized products usually on automated production lines. The manufacturing procedure strictly follows a set of pre-defined standards that are generated from a test run of a small sample (Fig. 1). These standards include those related to parts, human labor, processes, machinery operations, and the general working environment. Once the standards are defined and generated, mass produced goods are oftentimes manufactured by strictly following these standards. The standards themselves are kept unchanged unless a large deviation in production occurs or a routinely scheduled test is arranged.