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Investigation of RFID investment in a single retailer two-supplier supply chain with random demand to decrease inventory inaccuracy

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ABSTRACT

Inventory information inaccuracy is one of the main causes to the inventory waste in supply chain operations, which motivates many companies to adopt modern tracing technologies, e.g. radio frequency identification (RFID), to decrease inventory errors and strengthen the cooperation between the supply chain stakeholders. Considering different types of RFID possess unequal technique features in tracing items in more practical environment, for the first time this paper explores the *different effectiveness* of RFID in decreasing the inventory inaccuracies in a supply chain containing one retailer and two suppliers. Firstly, a novel scale factor function is introduced to illustrate the relationships between the variable cost of RFID and the *non-full* abilities of RFID in decreasing inventory inaccuracies. Then, under the stochastic demand and inaccurate inventory, analytical models are formulated to investigate the cost-effectiveness of different RFIDs to the optimal order quantities and the expected profits in different scenarios (uncoordinated and coordinated supply chains), hereby the best coordination strategies are addressed. At last, numerical results obtained from different scenarios on adopting RFID and a practical case-level RFID system for recycling packaging cases indicate that RFID can not only decrease inventory inaccuracies, but also strengthen the supply chain coordination.

1. Introduction

Current supply chain management gradually walks toward to the direction with environment-friendly, operation efficient and cost controllable features, which can be considered as the most typical essentials for the *sustainable supply chain* and the basic requirements to realize supply chain coordination (Hoof and Thiell, 2014; Fahimnia et al., 2015). Inventory inaccuracies, or more specifically, inventory errors are the prime culprits that are caused by undetected item losses, shrinkages, misplacements, out of date storages and inconsistencies between the physical storage and the records in the information system, these phenomenons are even worse in the fast moving product transactions (Bottani and Rizzi, 2008; Xu et al., 2012), which are the main obstacles for the realization of the *sustainable supply chain*. Hence, in 2004, Wal-Mart invited its eight main suppliers, namely, Gillette, Hewlett-Packard, Johnson & Johnson, Kimberly-Clark, Kraft Foods, Nestlé Purina PetCare Co., Procter & Gamble and Unilever, to pilot case and pallet-level RFID during their procurement processions to increase transaction accuracies and decrease inventory errors. Since then, the public has gradually observed the large-scale commercial applications of RFID. The applications and actual effectiveness of such a technology in supply chains have drawn both the researchers' and the practitioners' attention (Gaukler et al., 2007; Cui et al., 2014). Currently, different RFIDs are widely employed in the distribution centers (receiving, picking and sorting), the retail stores (receiving, backroom management and expositive area management), and even the product returns or recycles (Bottani and Rizzi, 2008; Shaharudin et al., 2015), all of which constitute the most basic elements for performing *sustainable supply chain* (Zhu and Sarkis, 2004).

What specific features of RFID can contribute to the *sustainable supply chain*? RFID is a system that consists of tags and readers, application software, computing hardware and midware (Ngai

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et al., 2008). The superior feature of RFID lies in its unique tracing ability. For example, the contactless and anti-interference abilities of RFID make it extremely helpful in monitoring and tracing tagged objects, thereby contributing to profitable labor savings. Lee and Özer (2007) once cited a quotation stating that, in 2004, Metro Group saw a 17% of labor reduction. These researchers also reported two estimations from Accenture (2002) and SAP (2003), in which 100% of labor in physical inventory count was eliminated, whereas 20–30% and 40–50% receiving and picking costs in the retail warehouse were reduced, respectively. Another appealing feature of RFID is that it can realize unique identification, providing the supply chain with less shrinkages and higher visibility. IBM estimated that, after RFID was introduced, inventory shrinkages reduced to 2/3 at manufacturers, and 47% in sales in 2002 (Lee and Özer, 2007). With automatic sensing RFID, information at different organizational levels in can be distributed in real-time (Delen et al., 2007). Due to the contribution of RFID to item level information visibility, Zhou (2009) simulated about 6.7% (1.24/18.76) more units were sold per day. The above-mentioned figures in practical operations are only the partial profiles of RFID's contributions in building the *sustainable supply chain* (by cost decreasing and efficiency increasing) (Diabat and Govindan, 2011; Fahimnia et al., 2015; Govindan et al., 2015a), further benefits for performing RFID are still need us to investigate.

Apart from the direct and superficial benefits of RFID in labor saving, shrinkage error diminishing, and visibility improving, also RFID assists in reducing out-of-stock (Szmerekovsky and Zhang, 2008), compressing lead time (Rekik, 2011), and improving transportation efficiency (Lee et al., 2011), which help firms achieve a *smooth supply chain*. However, one of the remarkable challenges in supply chain management is the *inventory inaccuracies*, which involve imperfect quality products (Sana, 2011a), mismatches between the physical flow and the information flow (Rekik, 2011), and invisibility of inventory storage (Lee and Özer, 2007). Among those researches, the contribution of RFID on the order lead-time and safety inventory level has already been addressed, but it leaves spaces to investigate the role of RFID in dealing the inventory inaccuracies. Generally, there usually have difficulties in calibrating the effectiveness of a new technology to an old supply chain system (Ribeiro et al., 2015), even numerous researchers have developed diverse strategies for modeling the improvement abilities or effects of new technologies like RFID in the supply system and their investment scales. Thus, Xu et al. (2012) believed that before investigating RFID investment effectiveness, the causes and types of inventory inaccuracies should be identified. They, correspondingly, differentiated inventory errors as temporary errors (e.g., the misplacement), and permanent shrinkages (e.g., theft). Meanwhile, Rekik (2011) noted four kinds of errors (i.e., transaction errors, misplacement, shrinkage, and product quality) in the yield and supply process. From the perspective of the inventory holding levels, inventory errors exhibit positive and negative features (Heese, 2007). This viewpoint, however, has not been taken into account in constructing research models.

Constructing the *analytical model* is a feasible and practical means for investigating the effectiveness of new technologies on the supply chain system. However, Dubey et al. (2016) admitted that the dynamic nature of the *sustainable supply chain* system makes it difficult in connecting practical qualitative observations with quantitative analysis. Hence, it is meaningful to see Lee et al. (2011) summarized three means for assessing a novel technology: (1) obtaining empirical estimation from experts or practitioners, (2) conducting in-depth case studies and (3) employing analytical models. At present, inventory record inaccuracies in the supply chain are normally modeled on the premise that either the inventory is independent of the customer demand or not. Uçkun et al. (2008) adopted a normally distributed, demand independent random variable to represent the errors of the inventory record. Xu et al. (2012) once specified that parameterized RFID investment should be assumed to introduce 0%, 50% and 100% effects on modeling errors, but in current models, RFID is all assumed to have 100% ability to eliminate inventory errors. Furthermore, inventory errors were simplified as two fixed ratios and are proportional to demand, which could be easily in processing the errors, but some randomness in the practical application might be lost.

The game model has been testified as a convenient and reasonable model in modeling the complex relationships of different stakeholders in cleaning production and *sustainable supply chain* system (Huang et al., 2016; Liang et al., 2016; Ouyang and Shen, 2017). If taking a look at the supply chain coordination models, we can easily draw that the two-level supply chain with a supplier/manufacturer and a buyer/retailer is the most prevailing modeling structure (Aljazzar et al., 2016; Sana, 2013; Li et al., 2015), while the purpose of formulating the two-level supply chain with a supplier and two buyers (Roy et al., 2015) or two suppliers and one buyer (Hu et al., 2013) is to set the extra supplying member as the comparison counterpart. Of all constructed models, customers' demand is usually assumed as stochastic (Sana, 2011b; Roy et al., 2016). Besides, the other most commonly mentioned uncertainty factors, such as stochastic lead-time (Hayya et al., 2009) or stochastic selling price (Sana, 2011b) are usually discreetly assumed in different models, it would be very intractable when considering two random variables simultaneously Hayya et al. (2009). Moreover, related researches on the uncertainty factor like inventory inconsistencies in operations, are rare, our research would provide supplements to the literature of this realm.

When considering implement new technologies, different stakeholders in supply chain usually harbor different stands. Thus, such an undertaking induces numerous risks, such as security (Lee et al., 2011), investment scale (Uçkun et al., 2008) and credibility of information technology (Dutta et al., 2007). However, there have no clear discussions on the role of RFID in smoothing the supply chains. The coordination of stakeholders for collaborative investment in new technology is a proper means of achieving more benefits and decreasing risks (Lee et al., 2011). Hence, the implementation of RFID is largely affected by the actual attitude of the other stakeholder, hence, the considerable coordination work is evidently required, e.g. the buy-back price strategy, to deal with uncertainties in transactions (Dutta et al., 2016; Hou et al., 2010; Hu et al., 2013). Moreover, in the two-echelon supply chain established by Xu et al. (2012), four cases (i.e. shrinkage ignorance, error elimination, information sharing and RFID adoption) are compared to depict the different efforts that supply chain partners spend in reality to improve the supply chain cooperation level. Our research would provide a supplement research based on above outcomes.

Accordingly, by drawing the predecessors' implications on investigating inventory inaccuracy and new technologies adoptions, this research would contribute related literature in below aspects:

(1) Considering the inventory error plays a significant role in causing inventory waste, this research constructs analytical models to uncover the secrets of different scale RFID investment endeavors in decreasing the stochastic inventory errors under different supply chain coordination scenarios assuming the stochastic customer demand.