Profit optimization using RFID under an Unreliable SCM

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Competition in business is higher in the electronics sector compared to other sectors. In such a situation, the role of a manufacturer is to manage the inventory properly with optimized profit. However, the problem of unreliability within buyers still exists in real world scenarios. The manufacturer adopts the radio frequency identification (RFID) technology to manage the inventory, which can control the unreliability, the inventory pooling effect, and the investment on human labor. For detecting RFID tags, a reasonable number of readers are needed. This study investigates the optimum distance between any two readers when using the optimum number of readers. As a vendor managed inventory (VMI) policy is utilized by the manufacturer, a revenue sharing contract is adopted to prevent the loss of buyers. The aim of this study is to maximize the profits of a two-echelon supply chain management under an advanced technology system. As the life of electronic gadgets is random, it may not follow any specific type of distribution function. The distribution-free approach helps to solve this issue when the mean and the standard deviation are known. The Kuhn-Tucker methodology and classical optimization are used to find the global optimum solution. The numerical analysis demonstrates that the manufacturer can earn more profit in coordination case after utilizing revenue sharing and the optimum distance between readers optimizing cost related to the RFID system. Sensitivity analysis is performed to check the sensibility of the parameters.

Keywords:supply chain management | inventory control | distribution-free approach | revenue sharing | radio frequency identification | information asymmetry

1. Introduction

Instead of a traditional business system, supply chain management (SCM) provides different kinds of business policies in terms of inventory management. The vendor managed inventory (VMI) is one of these in which the manufacturer takes full responsibility of the existing inventory at the buyer's position. Dong and Xu [1] found opportunities where buyers received more profit than the manufacturer. The manufacturer's profit may vary according to the business policy, where the short-term and long-term VMI affects the SCM, which were decided by them. They concluded that the short-term VMI can be a competitor for coordination business policy. In any business, the forecasting uncertainty is a major issue and Guo et al. [2] developed a method to reduce the supply chain forecasting uncertainty through information sharing via macro prediction which can reduce the system robustness. However, it is possible that not all information is shared by both parties. Then, unreliability occurs in the business system due to information asymmetry (Mukhopadhyay et al. [3]; Yan and Pei [4]; Xiao and Xu [5]). An information basically flows in the upward direction of SCM. The lack of information of the manufacturer may cause insufficient supply of products which can affect the inventory and production process. The situation is even more complicated when an imperfect production process takes place (Sarkar [6]). The rework of defective products was considered by Cárdenas-Barrón et al. [7] for an imperfect production process. They developed an improved algorithm to find the optimum lot size and replenish the defective production system. Cleaner production can be formed by discarding defective products, which was established by Tayyab and Sarkar [8]. Those defective products were reworked up to good quality through additional investment. This work was extended by multi-stage cleaner production by Kim and Sarkar [9] using budget constraints. There are several researchers who worked on imperfect products, reworking, and deterioration (Guchhait et al. [10], Majumder et al. [11], Tiwari et al. [12]). Finally, Sarkar [13] introduced an exact duration for reworking within a multi-stage multi-cycle production system. However, there is a lack of literature regarding RFID, i.e., RFID was not used to maintain the inventory pooling effect. Reworking was considered by Sarkar et al. [14] in a material requirement planning (MRP) system.

Production quantity mainly depends upon the market demand. In reality, it cannot always be the case that data related with demand are available. If no known distribution function is followed by the demand or no data are available, then instead of taking any arbitrary probability distribution, the distribution-free (DF) approach is used (Gallego and Moon [15], Sarkar et al. [16], Guchhait et al. [17]). This method was invented by Scarf [18]. Due to the complex calculations, it was not understandable to people in the industry at that time. Later, this approach was simplified by Gallego and Moon [15]. This method is used by Sarkar et al. [19] for a consignment stock-based newsvendor model. They allowed a fixed-fee payment technique to prevent loss from any participant. There are multiple manufacturers and retailers available for a single-type of products. Based on advertisements given by the manufacturer, retailers opted to choose their manufacturers. For the random demand, the variable production rate is useful (Sarkar et al. [20]) for modeling uncertain demand. A service level can help avoid shortages (Moon et al. [21]) and backorder (Sarkar [22]) due to the uncertain random demand. Partial trade credit for deteriorating items in the inventory model was discussed by Tiwari et al. [23]. For any industry, it may be that they need to analyze their previous data. Tiwari et al. [24] provided a big data analysis of SCM from 2010 to 2016.

Competitive markets in the business industry becoming more intense everyday. To handle this situation, companies prefer to adopt smart technologies within the SCM. The fast movement of products for the electronic industry is a key feature since competition is very high in the electronics sector. The implementation of technology instead of labor-based production is helpful not only for fast production, but also to profit gain. The use of RFID technology in SCM for managing inventory has been studied by several researchers. A wireless sensing problem for coverage was first studied by Meguerdichian et al. [25]. Zhang and Hou [26] investigated how many readers need to be implemented to provide a complete coverage of a search area. The coverage area sensing radius and transmitting radius were discussed by Hefeeda and Ahmadi [27]. They established that probabilistic sensing coverage can function as deterministic coverage. Dias [28] implemented RFID for a multi-agent system. Sarac et al. [29] surveyed the literature and found several implementation and usages of RFID in different sectors of SCM. They found that inventory loss can be reduced with increased efficiency of the system and real-time information of the inventory. Kim and Glock [30] investigated the effectiveness of an RFID tracking system for container management and found that the return rate of container was increased after using RFID. A four-echelon SCM was studied by Sari [31] to examine the effects of collaboration. They found through simulation that the integrated RFID technology is more beneficial for good collaboration between participants. Besides SCM, warehouse efficiency can be improved using RFID technology (Biswal et al. [32]). In the production sector, RFID improves the efficiency and maintenance, as investigated by Chen et al. [33]. They established that operation time can be increased by up to 89% and that the labor cost is reduced significantly by using RFID. Even, remanufacturing companies can get benefit from RFID via just-in-time (JIT) features or transiting towards a closed-loop SCM (Tsao et al. [34]).

From literature, it is found in most of the studies that RFID is used in SCM to prevent inventory shrinkage as well as minimize the operation time of the system, reduction of lead time, and labor consumption (Ustundag and Tanyas [35]; Jaggi et al. [36]) and improve the efficiency. However, the reason behind this efficiency improvement by RFID is not discussed in the literature. This study introduces for the first time the RFID distance function $f(d)$ based on the sensing and transmitting radii. The distance between two readers can be optimized and thus, the number of RFID readers can be found to increase the efficiency. Based on the transmitting and sensing radii, two types of readers are used by the manufacturer, namely Type 1 and Type 2. To understand the complete search capacity of a Type 1 reader, the area is divided into sub-areas that are under the coverage of Type 2 readers. This combined system may enhances the system accuracy and provides strong coverage of the sensing and transmitting areas. **Table 1** gives the contribution of different authors in the literature. This study shows benefits for the buyer in the optimum order quantity, optimizes distance the between two readers, and optimizes the service given by the buyers.

Table 1. Comparison of author's contribution.

Author(s)	Model Type	Business Policy	Unreliability	RFID
Dong and Xu [1]	stochastic	VMI	NA	NA
Guo et al. [2]	stochastic	macro prediction market	NA	NA
Mukhopadhyay et al. [3]	deterministic	mixed channel	information	NA
Yan and Pei [4]	deterministic	mixed channel	information	NA
Xiao and Xu [5]	deterministic	VMI	NA	NA
Sarkar [6]	stochastic	production model	reliable	NA
Guchhait et al. [10]	deterministic	traditional	NA	NA
Majumder et al. [11]	deterministic	traditional	NA	NA
Gallego and Moon [15]	stochastic (DF)	inventory model	NA	NA
Scarf [18]	stochastic (DF)	inventory model	NA	NA
Sarkar et al. [19]	stochastic (DF)	CP	NA	NA
Moon et al. [21]	stochastic (DF)	inventory model	NA	NA

Author(s)	Model Type	Business Policy	Unreliability	RFID
Tiwari et al. [23]	deterministic	SCM	NA	NA
Meguerdicihian et al. [25]	networking	NA	NA	sensing
Zhang and Hou [26]	networking	NA	NA	sensing
Hefeeda and Ahmadi [27]	networking	NA	NA	coverage
Dias et al. [28]	survey	SCM	NA	survey
Sarac et al. [29]	value chain	survey	NA	survey
Kim and Glock [30]	stochastic	closed-loop	NA	tracking
Shin et al. [37]	stochastic (DF)	inventory	NA	NA
This model	stochastic (DF)	VMI	information	distance and readers

2. Problem Definition, Notation, and Assumptions

This section describes the problem definition for this study. Associated assumptions and notation are given here.

2.1. Problem Definition

A two-echelon supply chain model is considered under the newsvendor framework where participants are in a VMI contract. The inventory of the whole system is controlled by the manufacturer. Controlling the inventory manually by human labor is a time consuming task, as the manufacturer takes full responsibility of the full business of all buyers. To do this, the manufacturer installs smart RFID technology. The number of RFID readers is needed by the manufacturer such that the inventory can be controlled in a proper way within a minimum time duration. The number of readers depends on the sensing distance between two readers. Thus, the distance between readers is optimized for RFID investment. Buyers are not reliable with respect to the manufacturer's business. Buyers provide services to the customers, and therefore an unreliable SCM is formed as a single-manufacturer multi-buyer. The goal of the newsvendor model is to maximize profit for the buyer without incurring any storage or redundancy costs. However, the buyer is unable to decide on the optimum order quantity, where there should not be any understock or overstock costs. For that, the manufacturer takes the full responsibility of the buyers to for profits through the VMI strategy. Even though the manufacturer tries their best to help the buyer, the buyer is unreliable in nature and may provide wrong information regarding the demand to manufacturer. To mitigate this matter, the RFID technology is installed allowing the manufacturer to obtain more profit.

2.2. Notation

The following notation (**Table 1**) is used in the present study.

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2.3. Assumptions

The following assumptions are used for this model.

- A two-echelon SCM is considered for a single-type of electronic products, where the inventory is managed by a manufacturer through a VMI contract. To ensure the profit of the buyers, a revenue sharing policy for coordination case is used by the manufacturer. The finished products are sent to the n buyers.
- Buyers are not reliable enough and they are not sharing data to the manufacturer. It forms an information asymmetry in the business system. The manufacturer losses some information about market and installs the RFID system to solve the unreliability issue.
- As VMI recommends that the supreme controlling authority is the manufacturer and the manufacturer decides to use RFID technology for controlling the unreliability issues. Hence, the manufacturer decides the whole deployment for the design of installing RFID reader, which can be done by the third-party. As the manufacturer cannot reach to the retailer's place in each and every moment, the technology will support to solve the issue of the unreliability. Those support will be taken from the third-party by investing some fixed cost. That fixed cost is inserted within the cost of Type 1 and Type 2 reader. Therefore, the RFID reader deployment cannot be specified within the modelling part of the manufacturer. However, the design of RFID reader can be added for the entering gate or any other place, but it depends on the third-party who is dealing with the whole area for covering the RFID. Therefore, through VMI, it is not the responsibility for the manufacturer to check the design for the installed RFID readers as this is a paid service from the third-party. Two types of reader are used to give a complete coverage of the search area. The total search area is divided into subareas and each subarea is covered by Type 1 readers, based on a disk sensing model. Each subarea is again divided into small search areas that are covered by Type 2 readers, based on an exponential coverage protocol. The frequency range of the readers is measured for usual road transport.
- It may not be possible that the demand pattern always follows some distribution function. As data are random, it is assumed that the market demand is uncertain and does not follow any particular type of distribution. The known mean is μ_i and the standard deviation is σ_i (Shin et al. [37]).
- The planning horizon is [0,T] and the lead time is negligible.

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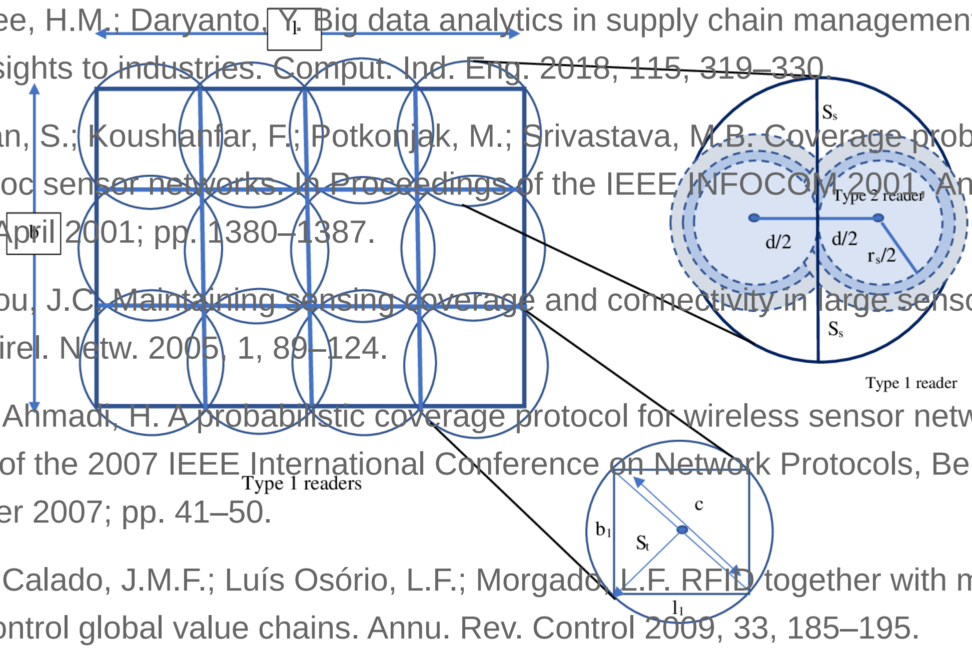

Figure 1. Execution of Type 1 and Type 2 readers for a search area.

3. Conclusions and Future Recommendations

The measurement of the distance between two RFID readers could lead an SCM towards sustainability, which not only helps to prevent inventory shrinkage, but also helps to collect used products via RFID tags and readers. The distance between two readers was optimized, and based on this an industry manager can decide how many readers are needed to cover the whole search area. Results confirmed that RFID could be profitable for a VMI contract. This business policy was shown to be beneficial for the entire supply chain for the coordinated case. Besides that, a non-coordinated business policy provided profit to both the manufacturer and the buyers. This study ensured that the manufacturer need not be worried about the installation of smart technology by themselves. The manufacturer was benefited from a third-party provider and can mitigate the problems of unreliability within the SCM. Implementation of an RFID system was beneficial for the electronics industry by reducing e-waste and reusing products and parts. However, this study did not consider the reuse of tags of used products, which can be an immediate extension for waste reduction. Within this study, it was assumed that the coverage area for Type 1 and Type 2 readers is perfectly circular. In general, it may not be circular always. Using any other geometrical shape or any non-geometrical shape, the number of the readers can be increased or decreased. Those will be further extensions of this model. This study did not consider any obstacles and interference sources within the range of the RFID readers. Therefore, using one or more obstacles or interference can change the number of Type 1 and Type 2 readers as Type 1 readers are more powerful than Type 2 readers. This study can be extended by optimizing the utilization of human labor and a comparative study can be made of human labor over autonomation. Another realistic scenario is imperfect production for which an autonomation policy can help reduce the unclear scarp faster than human labor.

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