World Academy of Science, Engineering and Technology
International Journal of Medical and Health Sciences
Vol:7, No:3, 2013

# The Use of Information for Inventory Decision in the Healthcare Industry

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***Abstract*—**In this study, we explore the use of information for inventory decision in the healthcare organization (HO). We consider the scenario when the HO can make use of the information collected from some correlated products to enhance its inventory planning. Motivated by our real world observations that HOs adopt RFID and bar-coding system for information collection purpose, we examine the effectiveness of these systems for inventory planning with Bayesian information updating. We derive the optimal ordering decision and study the issue of Pareto improvement in the supply chain. Our analysis demonstrates that RFID system will outperform the bar-coding system when the RFID system installation cost and the tag cost reduce to a level that is comparable with that of the bar-coding system. We also show how an appropriately set wholesale pricing contract can achieve Pareto improvement in the HO supply chain.

***Keywords*—**Efficient consumer response program, healthcare, inventory management, RFID system, bar-coding system.



## I. Introduction

IN healthcare industry, we observe that demands of some healthcare products, such as vaccinations, medicines, and masks (disposable apparel products), are highly volatile along with short shelf lives. In addition, industrial practice shows that these healthcare products will be disposed if their expiry dates have passed due to the health and hygiene issues. Even though the hospitals have to provide a high service level to the patients, they are facing a challenge on the ordering decision because both shortage and leftover inventories will incur significant costs and lower their operations flexibility. In the retailing industry, efficient consumer response program (ECRP), also called quick response, is one of the measures which can reduce the ordering lead time and react responsively to the consumer market changes [1], and companies such as Benetton and Sport Obermeyer are examples of companies employing ECRP [2]. Undoubtedly, by shortening lead time, retailing companies can improve their demand forecasting by collecting information from the market [3]. Similarly, HO, as a healthcare "retail" service provider, can also reduce the demand uncertainty level of its healthcare product through observing the demand of correlated products to adjust their initial demand forecast for the forthcoming consumption period.

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Nowadays, bar-coding and RFID are two well established systems used for collecting transactions data related information. However, they do exhibit different features and are associated with different costs. Obviously, employing different information systems (i.e., either bar-coding or RFID) will affect the performance of the ECRP in the HO [4]. In this paper, motivated by real world industrial practice, we consider the scenario in which the HO can make use of the information collected from some correlated products to enhance its inventory planning. We derive the optimal ordering decision, examine the effectiveness of the bar-coding and RFID systems for information updating, and study the issue of Pareto improvement in the HO supply chain. Important findings are derived.

## II. Literature Review

In the literature on inventory decision with information revisions, Bayesian approach has been widely adopted. For example, in [3], Iyer and Bergen consider a simple supply chain with single-supplier and single-retailer that the retailer can update the demand distribution parameters for determining the optimal order quantity before the selling season. As the analytical expression demonstrates that the supplier always suffers a loss from the ECRP when the retailer maintains a reasonably high inventory service level, they propose three important policies which can achieve Pareto improvement. Later on, numerous studies also explore a supply chain in a two-stage single-ordering setting. For example, Choi et al. [5] discuss two Bayesian information updating models with the normal observation processes. The first model considers that both prior unknown demand mean and variance can be revised by the observed information while the second model revises only the unknown demand mean given the constant demand variance. They find that the information updating always beneficial to the retailer and entire supply chain in the second model (when the service level is larger than 0.5) but not necessarily the case under the first model. Consequently, in [6], Choi and Chow quantify the payoff and risk associated with the ECRP of each channel member by the mean-variance approach. They also propose three specific measures and develop the analytical conditions to achieve a mean-variance win-win situation.

Apart from having one order opportunity before the selling season, some recent studies extend to dual ordering flexibility with demand information updating. For example, in [7], Gurnani and Tang explore the two-stage dual ordering decisions with unknown future wholesale price under the bivariate normal distribution. They compare the scenarios with two cases, worthless and perfect information. See [8-15] for more studies related to dual ordering with Bayesian information updating.

In the healthcare industry, we observe that many hospitals are using the bar-coding system for managing different kinds of healthcare products. On the other hand, some pilot studies, such as [16-18], show that the RFID system can also be used to manage inventories so as to improve the operations efficiency and achieve significant cost saving. However, limited existing literature compares the quantitative performance of the RFID system and bar-coding system for managing the healthcare products. In [19], Cakici et al. study the pharmaceutical products and provide analytical comparisons between the periodic and continuous review policy. In [20], Chan et al. model the optimal cost for deploying a scanning system when there is a transaction error associated with the RFID and the bar-coding systems. Besides, they also evaluate the condition that the HO should switch the scanning and propose a revenue-sharing policy to achieve a win-win situation. Most recently, in [21], Chan et al. address a healthcare apparel supply chain with forecast updating. They first determine the optimal number of market observations to be taken for the information updating process and then examine the expected value of information. They conclude that the adoption of a scanning system depends on the ratio of number of market observations to the corresponding information acquisition cost. However, the major limitation of [21] is that they consider the case when the information acquisition cost is the only cost component of a scanning system. In order to have a better evaluation on the performance of each scanning system and the ordering decision with information updating, in this study, we consider the scenario that a scanning system consists of three cost components and there are some other extra costs incurred in the model to facilitate the ECRP. We aim at determining the optimal order quantity of the HO and study the performance of the commonly adopted wholesale pricing contract in the HO supply chain with information updating. In addition, we consider the presence of a stochastic transportation cost at the future time point which also differentiates this paper substantially from the other related studies such as [20,21].

This paper is organized as follows. We present the basic model in Section III and then conduct a numerical analysis to illustrate a situation for achieving Pareto improvement and generate insights on the scanning system selection in Section IV. We conclude our study in Section V.

## III. Model Development

In this model, there is one supplier and one (private) hospital in a supply chain system. We consider a situation that the hospital orders a healthcare perishable product (such as the vaccination or the surgical mask) from the supplier for the forthcoming season at a unit wholesale price $c_0$ (we define this time point as Stage 0 which means that it is far away from the consumption period begins) and each unit of product will generate a revenue $r$ when it is consumed by a patient. On the other hand, the supplier adopts the make-to-order policy and produces this product at a unit cost $m$. At the end of the consumption period, the hospital will dispose all the leftover products due to the health and hygiene issue and this practice can reassure the patients about the quality of products. Thus, there is no salvage value on the leftover products. Notice that, in practice, we can observe similar disposal scheme in the local private hospitals in Hong Kong. Under the ECRP, the hospital postpones the ordering decision at Stage 1 (i.e., the time point which is closer to the consumption period begins), but has to bear a higher unit wholesale price $w$ (i.e., $w > c_0$). The order quantity at Stage 1 is determined based on the observed demand information of the correlated products between Stage 0 and Stage 1. Motivated by the observations in the local hospital in Hong Kong, in this study, we assume that the hospital collects demand information of two correlated products for updating the demand prediction. For example, demand of the new vaccination for the forthcoming seasonal influenza disease can be predicted based on the medicine consumptions for curing (i) cold and (ii) flu.

The objective of the private hospital is to determine the order quantity of a perishable product which maximizes its expected profit for the upcoming consumption period of that product.

Following the basic demand uncertainty structure as in [1] and many others (see [22]), we denote the predicted demand of a healthcare product at Stage 0 as $x_0$ which is normally distributed with a mean $\theta_0$ and a variance $\delta$ as follows:

$$x_0 | \theta_0 \sim N(\theta_0, \delta), \tag{1}$$

where $\theta_0$ is a random variable and follows a normal distribution with a mean $\mu_0$ and a variance $d_0$,

$$\theta_0 \sim N(\mu_0, d_0). \tag{2}$$

With (1) and (2), the unconditional distribution of $x_0$ at Stage 0 is also normally distributed with a mean $\mu_0$ and a variance $\sigma_0^2$ (where $\sigma_0^2 = d_0 + \delta$):

$$x_0 \sim N(\mu_0, \sigma_0^2). \tag{3}$$

Between Stage 0 and Stage 1, we assume that the hospital collects two observations on the demand of two correlated products from a set $\Omega$ with a mean of $\tilde{m}$. According to [22], the distribution of $\theta_0$ is updated and becomes $\theta_0 | \Omega \sim N(\mu_1, d_1)$,

$$\text{where } \mu_1 = \left(\frac{\delta}{\delta + 2\sigma_0^2}\right)\mu_0 + \left(\frac{2\sigma_0^2}{\delta + 2\sigma_0^2}\right)\tilde{m}, \tag{4}$$

and $$d_1 = \frac{\delta\sigma_0^2}{\delta + 2\sigma_0^2}. \quad (5)$$

At Stage 1, the distribution of the predicted demand $x_1$ and the mean demand $\mu_1$ under the ECRP are shown respectively as below:

$$x_1 \sim N(\mu_1, \sigma_1^2), \quad (6)$$

and $$\mu_1 \sim N(\mu_0, \sigma_\mu^2), \quad (7)$$

where $\sigma_1^2 = d_1 + \delta$ and $\sigma_\mu^2 = \left(\frac{d_0}{\sigma_0}\right)^2$.

We denote $\phi(\cdot)$ as the standard normal density function, $\Phi(\cdot)$ as the standard cumulative distribution function, and $\Phi^{-1}(\cdot)$ as the inverse function of $\Phi(\cdot)$. We also denote $\psi(x)$ as the standard normal linear loss function which is defined as $\psi(x) = \int_x^\infty (y-x)\phi(y)dy$. Notice that the above Bayesian information updating model is widely used in the literature and we just follow and employ it for our analysis.

At Stage 0, following the classical newsvendor model, the expected profit of the private hospital $(H)$ can be derived as follows:

$$EP_{0,H}(q_0) = r\mu_0 - c_0 q_0 - r\sigma_0\psi[\Phi^{-1}(s_0)], \quad (8)$$

where $s_0$ is the (inventory) service level at Stage 0 with an expression $s_0 = (r - c_0)/r$. From the second order condition, it is easy to find that $EP_{0,H}$ is a strictly concave function in $q_0$. The optimal order quantity can hence be found by solving the first order condition and it is shown below:

$$q_0^* = \mu_0 + \sigma_0\Phi^{-1}(s_0). \quad (9)$$

With (9), the corresponding expected profit of the supplier $(M)$ at Stage 0 is derived as:

$$EP_{0,M}(q_0^*) = (c_0 - m)[\mu_0 + \sigma_0\Phi^{-1}(s_0)]. \quad (10)$$

Between Stage 0 and Stage 1, the hospital captures the demand information by using either a RFID system $(R)$ or a bar-coding system $(B)$. We consider that adopting a scanning will incur three cost components: a tag/sticker cost $h_\ell$, an information acquisition cost $a^\ell(n_\ell)$ [21], and a system installation cost $\xi_\ell$; where $\ell$ represents which system is adopted, i.e., $\ell \in \{R, B\}$. Similar to [21], we define $a^\ell(n_\ell) = k_\ell n_\ell$, where $k_\ell$ is the cost for conducting one market observation and $n_\ell$ is the number of market observations with the use of a scanning system, in this study, $n_\ell = 2$. As the RFID system can automatically count the inventory level, therefore, the cost for collecting the demand information is less than that of the bar-coding system, we have: $k_R < k_B$. However, it is well agreed that the fixed installation cost of the RFID system is more expensive than that of the bar-coding system because of the sophisticated infrastructure of the RFID system. For a notational purpose, we define $Z_\ell = a^\ell(n_\ell) + \xi_\ell$. As observed in practice, $a^\ell(n_\ell)$ is much smaller than $\xi_\ell$, we hence also consider this situation (i.e., $a^\ell(n_\ell) < \xi_\ell$) in our analysis throughout this paper. As a remark, we assume that the scanning system can be used to manage inventory for two different kinds of healthcare items (i.e., the two observation targets) and $\xi_\ell$ is the total installation cost divided by the number of products adopting a particular scanning system (i.e., 2 in this paper).

At Stage 1, the supplier will charge the hospital a higher unit wholesale price $w$ (i.e., $w > c_0$) for a higher operations cost due to a shorter production and delivery time. Besides, the ordering lead time at Stage 1 is shorter than that at Stage 0 and hence, an extra cost is incurred to facilitate a faster delivery. We denote $\tilde{t}$ as the stochastic transportation cost incurred at Stage 1, and define the total wholesale price at Stage 1 as $c_1 = w + \tilde{t}$. Here, we consider the situation in which there are two kinds of transportation mode (one faster and more expensive; one slower and less expensive) for the delivery process. If the supplier has enough vacant capacity to produce the product for the order placed at Stage 1 quickly, the hospital can employ the slower and cheaper transportation mode (e.g., by ship). However, if the supplier has insufficient vacant production capacity, it will take a longer production time and hence the hospital has to employ a faster and more expensive transportation mode (e.g., by air). We assume that the hospital at Stage 0 has assessed the chance that the supplier has insufficient vacant capacity as $p$, and hence the chance that the supplier has enough vacant capacity is $(1 - p)$. Thus, there is a $p$ chance for the hospital using a relatively faster delivery mode with a cost $\bar{t}$ and a $(1-p)$ chance using a relatively slower delivery mode with a cost $\underline{t}$, where $\bar{t} > \underline{t}$.

The expected profit and the corresponding optimal order quantity of the private hospital under the ECRP at Stage 1 are shown as follows:

$$EP_{1,H}^\ell\Big|_{\mu_1,\tilde{t}} = r\mu_1 - (w + \tilde{t} + h_\ell)q_1 - r\sigma_1\psi\left(\frac{q_1 - \mu_1}{\sigma_1}\right) - Z_\ell. \quad (11)$$

Since $\mu_1$ and $\tilde{t}$ are random variables before Stage 1 (e.g., at Stage 0), to get the unconditional expected profit back to Stage 0, we first take the expectation of $EP_{1,H}^\ell\Big|_{\mu_1,\tilde{t}}$ with respect to $\mu_1$ with the following expression:

$$\underset{\mu_1}{E}\left[EP_{1,H}^{\ell}\Big|_{\mu_1,\tilde{t}}\right] = r\mu_0 - (w+\tilde{t}+h_\ell)q_1 - r\sigma_1\psi\left(\frac{q_1-\mu_0}{\sigma_1}\right) - Z_\ell\ .$$

Afterwards, we take another expectation with respect to $\tilde{t}$ to determine the unconditional expected profit as below:

$$EP_{1,H}^{\ell}(q_1) = r\mu_0 - [w + p\bar{t} + (1-p)\underline{t} + h_\ell]q_1 - r\sigma_1\psi\left(\frac{q_1-\mu_0}{\sigma_1}\right) - Z_\ell\ . \quad (12)$$

The expression of (12) brings us to have Proposition 3.1.

**Proposition 3.1.** *The unconditional expected profit at Stage 1, $EP_{1,H}^{\ell}(q_1)$, is a strictly concave function of $q_1$ and the optimal expected order quantity $q_1^*$ is $\mu_0 + \sigma_1\Phi^{-1}[ps_{1,\bar{t}} + (1-p)s_{1,\underline{t}}]$, where $s_{1,\bar{t}} = (r-w-\bar{t}-h_\ell)/r$ and $s_{1,\underline{t}} = (r-w-\underline{t}-h_\ell)/r$.*

**Proof of Proposition 3.1.** As $\frac{\partial EP_{1,H}^{\ell}(q_1)}{\partial q_1} = (r-w-p\bar{t}-(1-p)\underline{t}-h_\ell) - r\Phi\left(\frac{q_1-\mu_0}{\sigma_1}\right)$ and $\frac{\partial^2 EP_{1,H}^{\ell}(q_1)}{\partial q_1^2} = \frac{-r}{\sigma_1}\phi\left(\frac{q_1-\mu_0}{\sigma_1}\right)$, the expression of the second order condition shows that $EP_{1,H}^{\ell}(q_1)$ is a strictly concave function of $q_1$. Therefore, the optimal order quantity can be determined by setting $\frac{\partial EP_{1,H}^{\ell}(q_1)}{\partial q_1} = 0$. (Q.E.D.)

From the Proposition 3.1, we can derive the corresponding expected profit of the supplier $(M)$ at Stage 1 as the following:

$$EP_{1,M}(q_1^*) = [w + p\bar{t} + (1-p)\underline{t} - m]\{\mu_0 + \sigma_1\Phi^{-1}[ps_{1,\bar{t}} + (1-p)s_{1,\underline{t}}]\}. \quad (13)$$

Once the optimal order quantity is determined, the hospital has to decide which scanning system should be adopted to collect the demand information for facilitating the ECRP. We have Proposition 3.2.

**Proposition 3.2.** *The RFID system outperforms the bar-coding system if and only if $q_1^* < \frac{2(k_B-k_R)-(\xi_R-\xi_B)}{h_R-h_B}$.*

**Proof of Proposition 3.2.** The RFID system outperforms the bar-coding system if its expected profit is higher than that of the bar-coding system, i.e.,

$EP_{1,H}^{R}(q_1^*) - EP_{1,H}^{B}(q_1^*) > 0 \Leftrightarrow$

$(h_R q_1^* + Z_R) - (h_B q_1^* + Z_B) < 0 \Leftrightarrow$

$(h_R - h_B)q_1^* + 2(k_R - k_B) + (\xi_R - \xi_B) < 0$. It is noted that the automation feature the RFID systems results in a lower cost for conducting one market observation, thus, we have $k_R - k_B < 0$. (Q.E.D.)

Proposition 3.2 reveals that the selection of a scanning system depends not only on the cost components of each system but also the optimal order quantity. Besides, it also illustrates that when the development of the RFID technology is mature, the difference between the systems' installation costs as well as between the RFID tag costs and bar-coding label costs will be smaller which will lead to a situation that the RFID system outperforms the bar-coding system.

With the ECRP, it is interesting to investigate its impact on each supply chain member in terms of the expected profit. With (8), (10), (12) and (13), we define the change of the optimal expected profit of each member as follows:

$$\Delta EP_H^{\ell} = EP_{1,H}^{\ell}(q_1^*) - EP_{0,H}(q_0^*)\ , \quad (14)$$

$$\Delta EP_M = EP_{1,M}(q_1^*) - EP_{0,M}(q_0^*)\ . \quad (15)$$

The analytical expressions of (14) and (15) allow both supply chain members to examine whether Pareto improvement can be achieved under the ECRP. We define Pareto improvement as a situation that both members will not be worse off and at least one member is strictly better off in term of the expected profit (i.e., (i) $\Delta EP_H^{\ell} \ge 0$ and $\Delta EP_M \ge 0$, and (ii) at least one condition in (i) is strict). Pareto improvement is important as it helps to ensure that the implementation of the ECRP is beneficial to at least one supply chain member and the other member is not worst off. Define:

$\tilde{\sigma}_1 = \underset{\sigma_1}{arg}\{\Delta EP_H^{\ell}(\sigma_1) = 0\}$,

$\hat{\sigma}_1 = \underset{\sigma_1}{arg}\{\Delta EP_M(\sigma_1) = 0\}$,

$\tilde{w} = \underset{w}{arg}\{\Delta EP_H^{\ell}(w) = 0\}$,

$\hat{w} = \underset{w}{arg}\{\Delta EP_M(w) = 0\}$,

$w' < 0.5r - p\bar{t} - (1-p)\underline{t} - h_\ell$,

$$\overline{w} = \begin{cases} \tilde{w}, & if \quad [r - \tilde{w} - p\bar{t} - (1-p)\underline{t} - h_\ell]/r > 0.5 \\ w', & otherwise \end{cases}.$$

We have Lemma 3.1.

**Lemma 3.1.** *Pareto improvement is achieved if $\hat{\sigma}_1 \le \sigma_1 \le \tilde{\sigma}_1$ for $\hat{\sigma}_1 < \tilde{\sigma}_1$ with at least one of the inequalities being strict.*

**Proof of Lemma 3.1.** Notice that $\Delta EP_H^{\ell}(\sigma_1+\Delta) - \Delta EP_H^{\ell}(\sigma_1) < 0$ and $\Delta EP_M(\sigma_1+\Delta) - \Delta EP_M(\sigma_1) > 0$ for the service level greater than 0.5. Therefore, it will result in $\Delta EP_H^{\ell} \ge 0$ for $\sigma_1 \le \tilde{\sigma}_1$ and $\Delta EP_M \ge 0$ for $\sigma_1 \ge \hat{\sigma}_1$. (Q.E.D.)

However, if $\sigma_1$ cannot satisfy the condition in Lemma 3.1, the proper setting of $w$ to achieve Pareto improvement is illustrated in Lemma 3.2.

**Lemma 3.2.** *Pareto improvement is achieved if the supplier sets the unit wholesale price at Stage 1 as (i)* $\hat{w} \le w \le \overline{w}$ *for* $\hat{w} < \overline{w}$ *with at least one of the inequalities being strict, or (ii)* $w = w'$ *for* $\hat{w} = w'$.

**Proof of Lemma 3.2.** First, the first order condition of $\Delta EP_H^{\ell}(w)$ with respect to $w$ is $-\mu_0 - \sigma_1\left\{\Phi^{-1}[ps_{1,\bar{t}} + (1-p)s_{1,\underline{t}}] + \frac{p\bar{t} + (1-p)\underline{t} + + h_\ell}{r\phi\{\Phi^{-1}[ps_{1,\bar{t}} + (1-p)s_{1,\underline{t}}]\}}\right\}$. It shows that $\Delta EP_H^{\ell}(w)$ is a decreasing function of $w$. Second, the first order condition of $\Delta EP_M(w)$ with respect to $w$ is $\mu_0 + \sigma_1\left\{\Phi^{-1}[ps_{1,\bar{t}} + (1-p)s_{1,\underline{t}}] - \frac{w}{r\phi\{\Phi^{-1}[ps_{1,\bar{t}} + (1-p)s_{1,\underline{t}}]\}}\right\}$ which illustrates that $\Delta EP_M(w)$ is an increasing function of $w$ for $w$ is relatively small when compared with $r$ and this assumption is intuitive because a supplier will try to earn the profit margin as high as possible. Thus, $\Delta EP_H^{\ell} \ge 0$ for $w \le \overline{w}$ while $\Delta EP_M \ge 0$ for $w \ge \hat{w}$. Finally, as we assume the service level of the hospital is greater than 0.5 due to the fact that the HOs always concern about high service level achievement, therefore, we have $\overline{w} = w'$ if $[r - \tilde{w} - p\bar{t} - (1-p)\underline{t} - h_\ell]/r < 0.5$. Notice that $w' < \tilde{w}$ and hence we will achieve $\Delta EP_H^{\ell} > 0$. When $\hat{w} = w'$, the unit wholesale price at Stage 1 will be set as $w = w'$ and result in $\Delta EP_H^{\ell} > 0$ and $\Delta EP_M = 0$. (Q.E.D.)

## IV. Numerical Analysis

In Section III, we have: (i) developed the analytical conditions for the hospital to determine $q_1^*$ and to check when the RFID system should be implemented and (ii) illustrated the conditions for the appropriate setting of $w$ under the ECRP to achieve Pareto improvement. In this section, we conduct a numerical analysis to illustrate when the RFID system will outperform the bar-coding system in Section IV.I and demonstrate the proper setting of the unit wholesale price to achieve Pareto improvement under the ECRP in Section IV.II. We employ the initial parameters setting as below which follow all the model assumptions and close to reality:

$\mu_0 = 12$, $d_0 = 14$, $\delta = 2$, $r = 45$, $c_0 = 6.5$, $m = 6$, $p = 0.5$, $\bar{t} = 0.08$, $\underline{t} = 0.03$, $k_R = 0.7$, $k_B = 2$, $h_R = 0.15$, $h_B = 0.05$, $\xi_R = 13$, $\xi_B = 5$, $n_R = n_B = 2$.

### A. Performance of RFID System

In Table I, it shows the impact of the hospital's optimal expected profit with respect to different installation costs and different tag costs of the RFID system for $w = 6.75$ under the ECRP. Meanwhile, the optimal expected profit of the hospital if the bar-coding system is implemented with $w = 6.75$ is 430.56, which means that the RFID system outperforms the bar-coding system if $EP_{1,H}^{R}(q_1^*)$>430.56. From Table I, we can observe that the RFID system is superior to the bar-coding system if $\xi_R$ and/or $h_R$ are/is reduced. In other words, the hospital should carefully identify the cost components of each scanning system and adopts the RFID system when the installation cost and tag cost are reduced to a level that is comparable with that of the bar-coding system.

TABLE I
NUMERICAL RESULT OF THE IMPACT OF THE HOSPITAL'S EXPECTED PROFIT W.R.T. DIFFERENT INSTALLATION COSTS AND TAG COSTS

| $\xi_R$ | $EP_1^R(q_1^*)$ when $h_R =$ | | | | |
|---|---|---|---|---|---|
| | 0.150 | 0.100 | 0.075 | 0.060 | 0.052 |
| 13.00 | 423.79 | 424.47 | 424.82 | 425.02 | 425.13 |
| 11.50 | 425.29 | 425.97 | 426.32 | 426.52 | 426.63 |
| 9.50 | 427.29 | 427.97 | 428.32 | 428.52 | 428.63 |
| 8.00 | 428.79 | 429.47 | 429.82 | 430.02 | 430.13 |
| 7.00 | 429.29 | 429.97 | 430.32 | 430.52 | **430.63** |
| 6.50 | 429.79 | 430.47 | **430.82** | **431.02** | **431.13** |
| 6.00 | 430.29 | **430.97** | **431.32** | **431.52** | **431.63** |
| 5.75 | **430.79** | **431.47** | **431.82** | **432.02** | **432.13** |
| 5.50 | **431.04** | **431.72** | **432.07** | **432.27** | **432.38** |
| 5.30 | **431.29** | **431.97** | **432.32** | **432.52** | **432.63** |
| 5.20 | **431.49** | **432.17** | **432.52** | **432.72** | **432.83** |
| 5.10 | **431.59** | **432.27** | **432.62** | **432.82** | **432.93** |

*The bolded number represents the situation that the RFID system outperforms the bar-coding system.

### B. Proper Setting of the Unit Wholesale Price

Table II shows the numerical result of the impact of the change of the supply chain members' optimal expected profit with respect to different unit wholesale prices when the RFID system is implemented. We can observe that (i) Pareto improvement can be achieved under the ECRP when $6.55 \le w \le 6.94$ with our numerical setting; (ii) the change of both hospital's and supplier's expected profit are in opposite direction and hence, the final decision on the value of $w$ depends critically on the bargaining power between the supply chain members.

TABLE II
NUMERICAL RESULT OF THE IMPACT OF THE SUPPLY CHAIN MEMBERS' OPTIMAL EXPECTED PROFIT W.R.T. DIFFERENT UNIT WHOLESALE PRICES

| $w$ | Hospital | | | Supplier | | | Pareto? |
|---|---|---|---|---|---|---|---|
| | $EP_1^R(q_1^*)$ | $EP_0(q_0^*)$ | $\Delta EP^R$ | $EP_1(q_1^*)$ | $EP_0(q_0^*)$ | $\Delta EP$ | |
| 6.55 | 426.54 | 421.08 | 5.46 | 14.38 | 8.12 | 6.26 | Yes |
| 6.60 | 425.85 | 421.08 | 4.77 | 14.42 | 8.12 | 6.30 | Yes |
| 6.65 | 425.16 | 421.08 | 4.08 | 14.47 | 8.12 | 6.34 | Yes |
| 6.72 | 424.20 | 421.08 | 3.12 | 14.52 | 8.12 | 6.40 | Yes |
| 6.75 | 423.79 | 421.08 | 2.71 | 14.55 | 8.12 | 6.43 | Yes |
| 6.80 | 423.10 | 421.08 | 2.02 | 14.59 | 8.12 | 6.47 | Yes |
| 6.85 | 422.41 | 421.08 | 1.33 | 14.63 | 8.12 | 6.51 | Yes |
| 6.94 | 421.18 | 421.08 | 0.10 | 14.71 | 8.12 | 6.59 | Yes |
| 7.00 | 420.35 | 421.08 | -0.73 | 14.76 | 8.12 | 6.64 | No |
| 7.50 | 413.52 | 421.08 | -7.56 | 15.18 | 8.12 | 7.06 | No |
| 8.00 | 406.73 | 421.08 | -14.35 | 15.61 | 8.12 | 7.49 | No |
| 8.50 | 399.97 | 421.08 | -21.11 | 16.04 | 8.12 | 7.92 | No |

## V. CONCLUSION

In this study, we consider a private hospital which adopts an efficient consumer response program (ECRP) to better predict the quantity requirement of a healthcare product through observing the demands of two correlated products using a RFID or a bar-coding system. However, when the ordering decision of the hospital is postponed to the time point that is closer to the consumption period, we consider an industrial practice that the hospital may need to bear a higher cost for a faster delivery which means a higher product cost. Under this setting with the ECRP, we first explore the optimal order quantity of the hospital and develop the conditions in which both the hospital and the supplier will not be worse off and at least one of them is better off with the information updating (which is called Pareto improvement). We then develop an analytical expression for the hospital to determine which scanning system should be adopted under relatively general cost structures. We conclude that the selection on the scanning system depends on all the three cost components of each scanning system as well as the optimal order quantity. We finally present a numerical analysis to (i) demonstrate the situation in which the RFID system will outperform the bar-coding system (i.e., when the RFID system installation cost and the tag cost reduce to a level that is comparable with that of the bar-coding system), and (ii) show how to set the unit wholesale price for achieving the Pareto improvement in the supply chain.

## ACKNOWLEDGMENT

This paper is supported partially by the project account of G-YK71.

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