Profit Analysis Model of Smart Item Implementation in Integrated Supply Chain Process

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Abstract. Nowadays all links of the entire supply chain need to integrate their different infrastructures and they have better control of them to drive better profits. This integration should offer the ability for companies in order to have an overall and transparent insight to its supply chain activities. An intelligent supply chain which is mainly supported by Smart Items technology can satisfy the need of those integration. By means of Smart Items, a company can benefit some advantages. Those are cost reduction and value creation. However, currently there is no comprehensive Smart Item infrastructure exists yet so it is difficult to calculate the true benefit information. This paper attempts to recommend a model for estimating the benefits of implementing Smart Items in a company which has an integrated supply chain process. The integrated supply chain means that three echelons (supplier, shipper and retailer) of supply chain are belonged to a company. The proposed model was used to determine the shrinkage value and RFID tag price which can give the maximum benefit of Smart Items implementation. A numerical example is also provided to give a better comprehension on model calculation.

1. Introduction

Technology advances quite rapidly at this time in which industry needs to adapt with this condition in order to stay competitive. Smart Item technology also grows with a high capability to track goods in more detail and easier to be integrated into the whole business process. Through automatic real-time data acquisition, this technology can improve business operations efficiently. A Smart Item is a device capable of independently collecting information from its environment, processing, and communicating data. Barcode is the first and still largely used technology to recognize items electronically. The barcode label is attached to an item and then optically the item can be detected by the barcode reader. The reader is a printed identification and sends the data to the information system, which updates the data received. Since barcodes can only support tracking, consequently, they can only be used in loading and unloading processes on roads with very rough scales [3]. Radio Frequency Identification (RFID) has a higher level of technology than barcode. It is a method of remotely storing and retrieving data using devices called RFID tags equipped with small antennas. Basically, an RFID infrastructure comprises of RFID tags, readers either fixed or mobile, and device controllers. The information stored includes object location, aggregate information, and information about the environment of a tagged object [5]. Nowadays, sensor nodes are the latest state-of-the-art technology of Smart Item which can detect phenomena at different
locations, such as temperature changes, vibration, pressure, movement, pollutant levels, etc. The technology doesn’t need human beings to serve as intermediaries between the real and virtual worlds. An example of a simple smart item is a temperature sensor that can capture the current temperature, compare it to a certain threshold and decide to send an alert message to an enterprise system if the value of the measurement exceeds the threshold [2]. Smart Item has been integrated to certain supply chain system. Some applications of the smart item in supply chain involved almost all the processes from manufacturing, warehousing, and distributing from the distributor, retailer and transportation agent [6]. The purpose of this paper is to propose a model which can used to analyze the optimum benefits of implementing smart items in an integrated supply chain process consisting of suppliers, shippers and retailers.

2. Notations and Proposed Model

2.1 Notations

The notations used in this research are shown in Table 1.

| Symbol       | Parameter                                                                 |
|--------------|---------------------------------------------------------------------------|
| $\rho_{good}$| Price charged for good                                                   |
| $C_{production}$| Variable costs of production per good                                      |
| $q_{sales}$| Amount of sold/distributed good                                           |
| $C_{return}$| Cost of manual processing of returned goods (defective or perished)       |
| $C_{fix}$| Fixed costs                                                              |
| $C_{fix, SI}$| Additional fixed costs using Smart Items (infrastructure)                |
| $C_{operation}$| Variable operational costs per Smart Item and shipment (e.g. recharge battery, programming) |
| $C_{SI}$| Acquisition costs of Smart Item                                           |
| $s$| Penalty depending on cost of goods (shipper $\rightarrow$ supplier)    |
| $P_{transport}$| Price of shipping per good (to be paid by the customer)                 |
| $C_{transport}$| Variable transportation costs per good (for shipper)                    |
| $P_{special}$| Additional shipping charge for usage of Smart Item per good              |
| $C_{capacity}$| Costs of capacity loss for reshipping                                    |
| $C_{GSM}$| Costs of message sent over GSM to ERP-System                             |
| $F$| Fleet size of shipper                                                     |
| $W$| Non quantifiable advantage through usage of Smart Items (consumer satisfaction, etc.) |
| $\rho \in (0,1)$| Factor of density, ratio of Smart Item quantity to quantity of goods   |
| $\nu \in (0,1)$| Factor of maintenance: $\nu = 0$ all Smart Items get shipped back (reusable); $\nu = 1$ no Smart Item is returned |
| $\omega \in (0,1)$| Ratio of defective goods delivered to customer                           |
| $\phi \in (0,1)$| Ratio of triggered Smart Items, $0 \leq \phi \leq \omega \leq 1$        |
| $\psi \in (0,1)$| Ratio of searched (potentially lost) goods during shipping              |
| $K \in (0,1)$| Ratio of recovered goods (previously lost)                               |
| $\Pi(Qo)$| The expected profit of the news vendor problem                           |
| $\Pi(Qi)$| The expected profit of scenario $i(i=1,2)$                             |
| $F(x)$| The cumulative distribution function of $x$                            |
| $Qo$| The ordering quantity of the newsvendor problem                        |
| $Qi$| The ordering quantity of scenario $i(i=1,2)$                           |
| $x$| The random variable representing demand                                |
| $\alpha$| The available rate of ordering quantity                               |
| $b$| The improvement rate of RFID                                           |
| $c$| The unit product purchase cost                                         |
The unit product selling price
The shortage cost
The unit product salvage price
The unit RFID tag price

2.2 Proposed Model
Decker (2008) has developed a model to perform cost benefit analysis to the application of smart item in supply chain involving suppliers, shipper, and retailers. Equation (1) shows the model to determine the profit of a supplier per shipment in Decker (2008).

\[
\Pi_1 = \left( (1 - \omega) P_{good} - C_{production} - \rho \cdot \left( C_{SI} \cdot v + C_{operation} \right) \right) \cdot -\left( \omega - \varphi \right) \cdot Q_{sales} \cdot C_{retour} \\
+ \varphi \cdot Q_{sales} \cdot s + (1 - k) \cdot \Psi \cdot s \cdot Q_{sales} + W - (C_{fix} + C_{fix,SI})
\]

From the equation we can see that the model considered several costs including processing cost, which consists of \( C_{production} \), \( C_{operation} \), \( C_{retour} \), \( C_{SI} \), \( C_{fix} \) and \( C_{fix,SI} \), one of important parameter in equation (1) is the density factor (\( \rho \)) which measure the matter of smart item needed in one pallet. For example in a pallet consisting of 20 boxes and in 1 box consisting of 16 pcs of goods, then \( \rho = 1/320 \) if only 1 smart item on the pallet. If 1 smart item per box, then \( \rho = 1/16 \). If the smart item is not used anymore, then the maintenance factor (\( v \)) = 1. In the ideal case, smart item is reused as long as it is not damaged or lost. Ratio of damaged products in shipment process is denoted by \( \varphi \), supplier will get penalty payment (\( s \)) from shipper if any goods are damaged during shipment and no need to pay back cost (\( C_{retour} \)). With smart items, the location of the goods can be known and the risk of loss of goods can be reduced by the parameter \( K \). Variable \( W \) shows the advantages of Smart Item usage such as customer satisfaction, good reputation due to fast delivery, delivery optimization, and so forth. Equation (2) calculation the profit of the shipper per Shipment [3].

\[
\Pi_2 = \left( (1 - \phi) (P_{special} + P_{transport}) - C_{transport} \right) \cdot Q_{sales} - C_{GSM} \cdot (\phi + \psi \cdot 2 \cdot F) \cdot Q_{sales} \\
- \phi \cdot Q_{sales} \cdot s - (1 - k) \cdot \Psi \cdot (s + C_{capacity}) \cdot Q_{sales} + W - (C_{fix} + C_{fix,SI})
\]

With the use of Smart Item on the shipper side, the shipper service will better and in the same time requires a harder effort. So the price will be more expensive (\( P_{transport} + P_{special} \)), but the risk of losing the product becomes smaller and the cost of the shipper will also decrease.

[4] explained the effect of shrinkage on inventory control inaccuracies. The application of RFID technology is considered as a promising solution to solve such problem. The paper proposed a mathematical model that can be used to analyze the effect of RFID application in reducing shrinkage problem on retailer inventory. The relation between availability rate, RFID tag price and other parameters can be described as follows [4] :

\[
s \left( a^* + b \left(1 - a^* \right) \right) + \frac{1}{a} \left( c - a^* s \right) \left( a^* + b \left(1 - a^* \right) \right) = c + 1
\]

The determination of optimal order quantity with RFID implementation has been developed as follows [4] :

\[
Q^*_2 = \frac{\beta}{a+b(1-a)} \left[ 1 - \frac{c+t-(a+b \left(1 - a \right)) s}{(p+g-s)(a+b \left(1 - a \right))} \right]
\]

The expression for maximum profit with the implementation of RFID is shown as follows [5] :

\[
\Pi(Q^*_2) = \frac{\beta}{2} \left( p + g - s \right) \left[ 1 - \frac{c+t-(a+b \left(1 - a \right)) s}{(p+g-s)(a+b \left(1 - a \right))} \frac{\beta}{2} g \right]^2
\]
3. Results and Discussions

Based on [3], the proposed model in equation (1) shows that variable W indicates the profits. There are fixed costs ($C_{fix}$ and $C_{fix1}$) incurred by the company which previously mentioned the profit of supplier per shipment were eliminated because this paper aims to calculate the optimum profit of Smart Item implementation. So the intangible profit and fixed cost are not considered. Profits are generally came from revenue less the cost of production. In this paper, suppliers and shipper are considered to have their own profit even though they are still the part of supply chain system. Supplier’s profit is determined as follows [3]:

\[
Revenue_{supplier} = (1 - \omega). P_s + \phi.C_d + (1 - k). \psi.C_d). Q_{sales} \tag{6}
\]

\[
Cost_{supplier} = \left(\omega. c_{retour} + c_s + \rho(c_{SI}. v + c_{operation})\right). Q_{sales} \tag{7}
\]

\[
Profit_{supplier} = \left(\left(1 - \omega). P_s + \phi. C_d + (1 - k). \psi. C_d\right) - \left(\omega. c_{retour} + c_s + \rho(c_{SI}. v + c_{operation})\right)\right) \tag{8}
\]

Shipper’s profit is modeled as follows [3]:

\[
Revenue_{shipper} = (1 - \omega). P_r. Q_{sales} \tag{9}
\]

\[
Cost_{shipper} = \left(C_t + c_{GSM}. \left(\omega + 2. \frac{Q_{sales}}{T_e}. \psi\right) + \phi. C_d + (1 - k). \psi. (C_{capacity} + C_d)\right). Q_{sales} \tag{10}
\]

\[
Profit_{shipper} = \left(\left(1 - \omega). P_t - \left(C_t + c_{GSM}. \left(\omega + 2. \frac{Q_{sales}}{T_e}. \psi\right) + \phi. C_d + (1 - k). \psi. (C_{capacity} + C_d)\right)\right) \tag{11}
\]

The determination of the optimum value of order quantity by implementing RFID ($Q_{sales}^*$)is based on [4], which referred to as $Q_{sales}$:

\[
Q_{sales} = \frac{\beta}{r} \left(1 - \frac{c + t - (\alpha + b. h). s}{(p + g - s) (\alpha + b. h)}\right) \tag{12}
\]

The change of $\alpha$ affects the value of $t$ (price tag RFID) so greater shrinkage ($1-\alpha$) or $h$ requires higher RFID tag price. The same condition also applies to improvement rate ($b$) component. The value of $t$ that is affected by the change of $\alpha$ is calculated as follows:

\[
t = \left(s(\alpha + b. h) + \frac{1}{\alpha}(c - \alpha. s)(\alpha + b. h)\right) - c \tag{13}
\]

The profit model on the retailer side at in equation (6) will be affected by $t$. A retailer profit model (15) with respect to changes of $\alpha$ can be compiled by substituting $t$ element with equation (14) to get equation (15):

\[
Profit_{retailer} = \frac{\beta}{2} (p + g - s). \left(1 - \frac{1}{r} \frac{(c - \alpha. s)}{p + g - s}\right)^2 = \frac{\beta}{2} g \tag{14}
\]

The total benefits in the supply chain consist of suppliers, shipper, and retailers are obtained by summing up the profits of each level. Any changes of $\alpha$ is followed by RFID tag price ($t$), and consequently changes of $t$ resulted in changes of the optimum order quantity. Equation (16) expresses the total profit of the entire part in supply chain.

\[
Total \ profit = \frac{\beta}{r}\left[\frac{1}{r}\frac{(c - \alpha. s)}{(p + g - s)}\right]. \left[\left((1 - \omega). P_s + \phi. C_d + (1 - k). \psi. C_d\right) - \left(\omega. c_{retour} + c_s + \rho(c_{SI}. v + c_{operation})\right)\right] + \left(1 - \omega). P_t - \left[\left(C_t + c_{GSM}. \left(\omega + 2. \frac{Q_{sales}}{T_e}. \psi\right) + \phi. C_d + (1 - k). \psi. (C_{capacity} + C_d)\right)\right]\right] + \left[\frac{\beta}{2} (p + g - s). \left(1 - \frac{1}{r} \frac{(c - \alpha. s)}{p + g - s}\right)^2 - \frac{\beta}{2} g\right] \tag{15}
\]
4. Numerical Example

To get an insight of the model, a numerical example is given, we assume that a company is engaged in the distribution and sale of high quality (premium) fruit products. The company has a delivery service facility and a number of retail stores owned by the company itself. The company’s supply chain product delivery line has been equipped with Smart Item’s advanced technology of sensor along with its IT system infrastructure. Table 2 shows the data parameters used in the model. The parameters (e.g. costs) from the model are derived from real world data.

| Symbol        | Parameter                | Value | Symbol        | Parameter                | Value  |
|---------------|--------------------------|-------|---------------|--------------------------|--------|
| v             | Maintenance factor       | 1     | p             | Retail price/unit        | $9.00  |
| c_{retour}    | Cost of retour           | $2.00 | g             | Shortage cost            | $0.50  |
| c_{operation} | Operation/unit           | $0.5  | s             | Salvage price            | $3.5   |
| c_{gsm}       | SI (smart item)/unit     | $50   | β             | Demand                   | 20,000 |
| c_{gsm}       | Loss/damage cost-shipment| $1.50 | k             | Improvement rate         | 0.3    |
| c_{gsm}       | GSM                      | $0.01 | Tc            | Truck capacity           | 10000  |
| c_{capacity}  | capacity                 | $0.25 | ρ             | Density factor           | 0.002  |
| c_{s}         | Production cost          | $1.00 | Ω             | Defect rate              | 5%     |
| c_{p}         | Supplier product price   | $2.00 | Ψ             | Lost product             | 5%     |
| c_{t}         | Transport cost/unit      | $0.05 | k             | Rate of return of lost product | 90% |
| c_{t}         | Transport price/unit     | $0.05 | φ             | Percentage of trigged items due to defective product | 1% |
| c_{r}         | Retail purchase/unit     | $2.50 |               |                           |        |

In every shipment, the company uses a truck with a maximum capacity of 20 pallets. Each pallet contains 10 boxes, and 1 box contains 50 goods. One smart item is installed on each pallet for easy monitoring of goods. The impact of mounting smart items on the pallet is assumed as shown in table 2. We propose an analytical critical tag cost which makes the deployment of RFID cost-effective, and we can derive a threshold value of the RFID tag cost. We illustrate the evolutions of the threshold value of RFID tag cost with available rate (α) of ordering quantity. If the RFID is subject to more shrinkage errors. The results show that the threshold value is decreasing with the available rate of ordering quantity and is increasing with the RFID read rate improvement. Such a result is intuitively expected, since shrinkage errors are not important, the RFID tag costs would be small to be adopted by the retail store. Therefore, for a retailer who suffers from serious inventory inaccuracies caused by shrinkage, it is still worthy to apply RFID technology even if the tag price is at a comparatively high level. Additionally, if RFID technology performs quite well (i.e, improvement rate t), the benefits from RFID technology will exceed the cost induced by the high tag price, which is definitely beneficial to the retailer. To determine the optimal total benefit, the range value of α is set between 0.1 to 0.975 by increasing the interval of 0.025. Based on parameter data in table 2, with α values less than or equal to 0.25, the company does not get a profit, yet get some losses. This is due to the high price of RFID tags at α = 0.25 which is $ 2.25. From figure 1 and 2, we can see that the optimum benefits of each level of supply chain are found at different points. Retailers have an optimum profit at α = 0.725 or at the RFID price tag (t) = $ 0.28. Unlike retailer, the supplier and shipper levels have the optimum profit at α = 0.7 or t = $ 0.32. The total profits of the company are at the same position as the supplier and shipper. The company's profit graph in figure 1 shows an almost stable value to the shrinkage value of 0.5 and begins to decline afterward the high shrinkage of 0.7, it is not profitable for the company. The use of RFID tags can not be a solution. From the RFID tag price point of view, the graph in figure 2 shows a sharp decline in profit when using RFID tags price more than $ 0.5. It also appears that RFID price tags above $ 2 are even detrimental to the company.
5. Conclusion

The proposed model in this paper showed the shrinkage value and RFID tag price that can give company an optimum profit if the company wants to implement Smart Item to its entire supply chain level. As the result of this research, it can be gained that optimum profit value for retailer at $\alpha = 0.725$ or $t = $ $0.28$ and for supplier and shipper the optimum profit value at $\alpha = 0.7$ or $t = $ $0.32$. Because supplier and shipper have same optimum profit value, it is considered that shrinkage factor is not influential for profit company. The company can be called lose out if the RFID tags price at $0.5$ until $2$. There should be other research data that has been empirically proven to be included in the model especially for parameter values.

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