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Collaborative supplying networks: reducing materials management costs in healthcare

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Abstract. Materials and inventories management is becoming a more and more important subject in the health care sector, because of its impact on efficiency, and quality of services provided. This study is focused on the inventory management and the service of surgical instruments reprocessing related to the operating room. The aim is to analyse which benefits may produce the combination of two different factors: the implementation of the RFID technology along the supply chain and the cooperation thorough a long-term collaborative-networked organization of the supplying companies. The first factor, named ‘RFID effect’, allows implementing a Continuous Review policy, instead of the Periodic Review policy normally utilized. The second factor, named ‘Network effect’, gives to supplying companies the possibility to share transportation costs. The model is inspired by a real case study of a long-term collaborative network of supplying companies in the health care sector that operates in central Italy. A numerical experiment shows that combining the RFID and Network effects may bring to a relevant reduction of expected costs.

1 Introduction

Providing health services with high quality standards and containing public expenditure are increasingly important objectives to be achieved in the context of public healthcare. Among the solutions adopted to contain healthcare spending, one of the most important trend in the public healthcare sector is to entrust some outsourced services, optimizing performance through a contract. In this way, healthcare managers tried to reduce spending without affecting the quality of service offered [1]. The spread of non-core processes outsourcing in healthcare has become very fast because, being the hospital a set of many departments handling a large number of activities, there is the need to entrust outside the no core ones [2]. Cost effectiveness is important even for activities that have greater impact on the hospital core business; among those, there is the surgical instruments reprocessing process, which is considered to be a potential area for important cost savings [3]. van de Klundert, Muls and Schadd [4] studied the logistic activities between the central sterilization service department and the operating theater. These activities affect total costs faced by the operating block. Hospitals that outsource these types of activities are still very few.

Inventory management of drugs and medical devices is also become a very important argument for hospital management. Many medical organizations reorganized their logistics in order to contain costs and ensure quality in services provided [5].

This paper investigates a new outsourcing model for the management of the operating room materials, inspired by a real case study of a network of enterprises born in Central Italy, in the Umbria Region. The network is based on the VDO network model [6] and provides the supplying of all the consumables for the operating room and the reprocessing service of surgical instruments. The network business model provides the implementation of the RFID technology for the automatic and continuous monitoring of hospital's inventories, and for the total traceability of all the materials utilized during surgeries. Through reading tags, stickers on which one can transcribe information on circuits, it is possible to have remote tracking. Inventory tracking becomes easier than ever and many other probable applications of RFID technologies have been proposed [7]. As evidenced by Sarac, Absi and Dauzere-Peres [8] this technology may improve the potential benefits along the supply chain reducing inventory losses, increasing efficiency and speed of the processes involved and improving information accuracy.

The integrated service, provided by the network as a single entity, includes: 1) surgical instruments sterilization service; 2) provision of sets of surgical instruments for surgical procedures; 3) provision of disposable non-woven materials, such as surgical drapes, masks, gloves, caps, gowns; 4) provision of disposable surgical devices, such as suture threads, syringes, video-laparoscopic devices; 5) provision, control and maintenance of medical equipment.

The specific characteristic of the case study, with respect to traditional models of materials management, consists in the implementation of the RFID technology, and in the long-term strategic cooperation between the supplying companies. Aim of the work is to provide a model to evaluate the effect of these two key factors on total operational costs.

2 The model

This case study refers to a stable network of companies located in central Italy, in the region of Umbria. The network provides an integrated set of services for the operating room. The network, named Sanitanet, is composed of five companies: four of them are companies already operating as single suppliers in the healthcare sector, while the fifth one is a University Spinoff in the field of collaborative networks management. For the purpose of the present work, we consider in the model just two of the five companies (Company A and Company B).

Company A provides a 'pay per use' service of sterile surgical instruments kits. These single-use kits are specifically designed for each surgery. This company owns all the surgical instruments composing the kits and reprocesses them in its own plant outside the hospital. At the beginning of each day, the company brings all the surgical kits needed for the daily planned surgery to the hospital. At that time, it withdraws the kits utilized the day before to reprocess them at its plant.

Company B provides non-woven surgical protective drapes for patients, operators and furniture (beds, trolleys, etc.). The supplied materials include masks, gloves, caps, gowns and drapes. All these items are packaged as single-use ‘custom pack’, specifically designed for each surgery type. Thus, each custom pack provides all the necessary materials for a single surgery. The company periodically delivers its supplies, based on orders placed by the hospital staff every month.

As already mentioned, the specific characteristic of the case study consists in: 1) the implementation of the RFID technology; 2) the long-term strategic cooperation between the supplying companies. We will refer to these two key factors with the terms ‘RFID effect’ and ‘Network effect’ respectively. The impact of these two factors on the Expected Total Relevant Costs (ETRC) will be evaluated through an analysis of scenarios. In the next sections we will formalize the ‘Network effect’ and the ‘RFID effect’.

Notation

- i : different products line
- Q_i : order quantity of item i [units]
- D_i : mean annual demand of item i [units/year]
- A : cost per shipment for Company B without the network effect [€/roundtrip]
- A' : cost per shipment for Company B with the network effect [€/roundtrip]
- r : inventory carrying charge [€/€/year]
- v_i : unit variable cost of item i [€/unit]
- k_i : safety factor for item i

2.1 Network effect

The Network effect allows companies to share setup costs, which substantially correspond to transportation costs. We assume that cost per shipment is proportional to the Euclidean distance covered for the shipment. Companies A and B may share some part of the way to the hospital. In particular, Company B can take advantage of the daily frequency of the shipment of Company A.

In this case, the lower distance that can be covered in a roundtrip is equal to the perimeter of the triangle (see **Fig. 1**) formed by the Hospital (point H), Company A (point A), and Company B (point B). Thus, when the two companies cooperate as a network, the shipment trip will always start from, and finish at, Company A plant, due to the necessity to bring back the utilized kits from the hospital. The round trip will consist of:

- load of sterile kits at Company A plants
- trip from Company A to Company B
- load of packs from company B
- trip from Company B to the Hospital for the delivery of kits and packs
- trip from the Hospital to Company A to bring back utilized kits

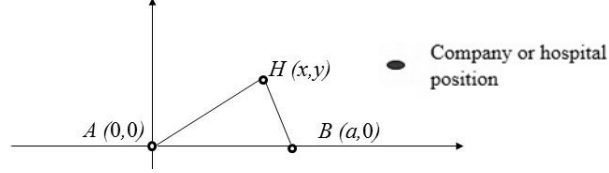


Fig. 1. Schematic position of companies and hospital

To estimate the savings achievable through the network effect, the cost per shipment related to the network configuration have to be compared with cost per shipment when companies act individually. The condition for evaluating the convenience of the network collaboration is that $(AB + AH + BH < 2BH + 2AH)$. In this relation, the first term represents the total length of the round trip in a network collaboration. The second term describes the total distance travelled by the two companies, if they work individually. The relation can be simplified in the following way: $AB < BH + AH$. As the sum of two sides of a triangle is always greater than only one side, the last relation is always verified. This implies that working as a network always allows reducing cost per shipment.

The total savings SV achievable under the ‘network effect’ will be proportional to $SV = 2BH + 2AH - (AB + AH + BH)$. From a Network perspective, this reduction of shipment cost can be entirely assigned to Company B. Indeed, it is noteworthy that shipment cost does not affect the replenishment policy of Company A, which is obliged to ship the required quantities on a daily basis. On the contrary, a reduction of shipment cost could determine a variation of the optimal quantity shipped by Company B. In fact, the optimal reorder quantity for each item i is equal to the Economic Order Quantity $EOQ = \sqrt{2A \cdot D / v \cdot r}$. So if the shipment cost A drops to A' when the network effect is present, the optimal order quantities of each item also decrease. In this view, as the Company B shipment cost without the network is equal to $A = 2BH$, A' can be estimated as: $A' = A - SV = 2BH - [2BH + 2AH - (AB + AH + BH)] = BH + AB - AH$. Thus, it is possible to define the ‘Network coefficient’ λ as the ratio between A' and A , with $0 \leq \lambda \leq 1$:

$$\lambda = \frac{A'}{A} = \frac{1}{2} + \frac{AB - AH}{2BH} \quad (1)$$

λ depends from the mutual positions of Company A, Company B and the Hospital.

In summary, when the scenario provides the network effect, the cost per shipment will be equal to λA , and consequently, if a continuous review policy is adopted, reorder quantity Q_i will be calculated as:

$$Q_i = \sqrt{2\lambda A \cdot D_i / v_i \cdot r} \quad (2)$$

2.2 RFId effect

Among the advantages related to the implementation of RFID technology, we consider: 1) to avoid incomplete shipments, misplacements and theft; 2) to possibly implement a continuous review policy. The first benefit has been modelled using the study by Ustundag and Tanyas [9]. They considered that RFID technology implementation eliminates item losses caused by theft, incorrect positioning and incomplete shipments. Only damages that can occur during transportation cannot be avoided. This effect can be considered using the following four coefficients: α (incorrect positioning), β (damage), γ (theft) and δ (incomplete shipment). They represent the error rates related to the corresponding causes. Table 1 shows the values, derived from the experimental study of Ustundag and Tanyas [9], that has been assumed in our study.

As far as the second benefit is concerned, the conceptual model assumes that without the implementation of the RFID technology a periodic review policy is adopted, while the RFID effect allow implementing a continuous review policy. In the following subsections, the description of both policies is carried out.

| Technology | α (%) | β (%) | γ (%) | δ (%) |
|------------|--------------|-------------|--------------|--------------|
| non RFID | 2 | 0.2 | 0.5 | 0.3 |
| RFID | 0 | 0.2 | 0 | 0 |

Table 1. Error rates of non-RFid and RFid integrated systems

Periodic review – no RFId effect.

Without the RFID effect, Company B actually adopts a periodic review policy (R, S) , with a review period R equal to 2 weeks, which is common for all the four items. This type of policy is very common in healthcare [10], and it is often adopted when it is not possible to have an automatic monitoring of the warehouse. Indeed, if the inventory has to be checked manually, it is usually preferred to limit the number of times the checking activities have to be performed. Furthermore, if the orders are placed on a periodic basis, different items can be incorporated in the same shipment in order to save on transportation costs. For each item i , the order-up to level S_i and the safety stocks SS_i are calculated respectively as: $S_i = SS_i + D_i(R+L)$; $SS_i = k_i \sigma_{(R+L)i}$, where $\sigma_{(R+L)i}$ is the standard deviation of demand during $R+L$, and k_i is the safety factor. The safety factor k_i is determined by imposing a specified service level required by the customer. Given the critical function of the supplied items, the required service level is high. We assumed a value of $P = 99.9\%$ of demand satisfied immediately from the shelf ('fill rate'). From this condition, the value of k_i can be calculated in the considering the following function [11]:

$$G_u(k_i) = \frac{(1-P) D_i R_i}{\sigma_{(R+L)i}} \quad (3)$$

where $G_u(\cdot)$ is the loss probability function, equal to:

$$G_u(k) = \int_k^{\infty} (u - k)\phi(u) du = \phi(k) - k(1 - \Phi(k)) \quad (4)$$

$\phi(k)$ being the unit normal density function, and $\Phi(k)$ the corresponding distribution function. From the value of $G_u(k_i)$, calculated from (3), it is possible to determine the value of k_i using the tabular form of eq. (4).

Continuous review – RFID effect.

When RFID technology is implemented, Company B can apply a continuous review policy (s, Q). In this case the optimal order quantity Q_i , for each item i , is calculated through the Economic Order Quantity (EOQ):

$$Q_i = EOQ_i = \sqrt{2AD_i / v_i r} \quad (5)$$

Note that, if the network effect is simultaneously present, the network coefficient λ has to be considered to calculate order quantities using eq. (2), because A decrease to $A' = \lambda A$. The reorder-point s_i and safety stocks SS_i are calculated in this case through: $s_i = SS_i + D_i L$; $SS_i = k_i \sigma_{(L)_i}$, where $\sigma_{(L)_i}$ is the demand standard deviation during the lead time L . To find the values of the safety factors k_i that allows us to reach the fill rate $P = 99.9\%$, it is necessary to calculate the loss function as (see [11]):

$$G_u(k_i) = \frac{(1 - P)Q_i}{\sigma_{(L)_i}} \quad (6)$$

Then the value of k_i can be determined using the tabular form of eq(4).

2.3 Scenario Analysis

Four different scenarios will be compared on the basis of the annual Expected Total Relevant Costs (*ETRC*), which is considered composed by four components: replenishment costs, holding costs, RFID implementation costs, and costs related to thefts and misplacements. The total annual costs related to RFID implementation has been estimated by summing the periodic amortization payment, related to hardware and software investments, and the annual costs of the ‘one use’ UHF tags, and it is equal to 4434 [€/year] (the detailed costs are omitted due to space limitation). The impact of thefts on the *ETRC* is calculated considering a cost equal to the value of each item stolen. The cost of items misplaced is considered equal to item value only when item are expired and cannot be used if they are found. In the model it is assumed that the 50% of misplaced items expires before the finding, and a cost equal to the value of the item is considered; the other 50% is considered utilizable and for this reason it does not represent a cost.

The four scenarios considered are described in the following.

Scenario ‘AS IS’. In the ‘as is’ scenario neither the ‘Network effect’ nor the ‘RFID effect’ are present. Thus, the companies operate individually, Company B utilizes a

periodic review policy, with a cost per shipment equal to A , where the products line share the same shipment. $ETRC$ can be estimated through:

$$ETRC = \frac{A}{R} + \sum_i \left(\frac{D_i \cdot R}{2} + k_i \cdot \sigma_{(R+L)i} \right) \cdot v_i \cdot r + \sum_i \left(\frac{\alpha}{2} + \gamma \right) D_i \cdot v_i \quad (7)$$

In (7), the first term corresponds to replenishment costs, the second one to carrying costs, and the last one approximate costs associated to thefts and misplacements.

Scenario 1 - Network effect. Company A and B belong to the same network. Company B still adopts a Periodic Review policy, but it is possible to share the cost per shipment with Company A. Thus, $ETRC$ can be estimated through (7) by substituting the shipment cost A with $A' = \lambda A$.

Scenario 2 - RFID effect. In this scenario, the companies still operates individually, but Company B implements a continuous review policy, which is enabled by the RFID implementation. The cost per shipment between Company B and the Hospital is still equal to A , because it is not shared. Each shipment contains only one product line, due to the different times each product line reaches the respective reorder point. In this case, there are no costs related to thefts and misplacements, while the annual cost related to RFID implementation is considered:

$$ETRC = \sum_i A \frac{D_i}{EOQ_i} + \sum_i \left(\frac{EOQ_i}{2} + k_i \cdot \sigma_{(L)i} \right) \cdot v_i \cdot r + C_{RFID} \quad (8)$$

Scenario 3 - Network + RFID effects. The Network effect and the RFID effect are simultaneously present. Thanks to RFID technology Company B can implement a continuous review policy. At the same time, each time a product line reaches the reorder point, the corresponding shipment can be shared with Company A, thanks to the network effect. Thus, $ETRC$ can be estimated through eq.(8) by considering a shipment cost equal to $A' = \lambda A$, instead of A . Note that even the optimal quantities EOQ_i are affected by the decrease of the shipment cost (see eq. (5)).

3 Numerical experiment and discussion

The values utilized in the experiments are related to a hospital placed in a city in the south of the Umbria region, in Italy: cost per roundtrip between Company B and the Hospital $A = 50$ [€], network coefficient $\lambda = 0.1158$, inventory carrying charge $r = 0.25$ [€/€year], lead time $L = 2$ days, required service level (demand satisfied directly from the shelf) $P = 99.9\%$. The annual demand data of the four item lines considered are related to the surgeries done in the hospital during the year 2012. Each product line represents a specific surgical discipline custom pack of non-woven drapes. Demand is assumed to be exponentially distributed, and the annual average values D_i and the value v_i of each item are reported in Table 2.

The value of k_i for both the periodic and the continuous review policies have been derived using the procedures described in Section 5. Table 3 shows the results related

| Product line | Description | Average Demand [units/year] | Item value [€/unit] |
|--------------|---------------------------|--------------------------------|------------------------|
| 1 | Surgery | 560 | 208 |
| 2 | Otorhinolaringologist | 20 | 198 |
| 3 | Orthopaedics | 673 | 220 |
| 4 | Obstetrician e gynecology | 454 | 247 |

Table 2. Data related to the 4 product lines

| Scenarios data | | | | | Annual Costs | | | | | |
|----------------|-------------|----------------|--------------|-----------------------|------------------------|------------------------|-----------------------|------------------------|---------------|--------|
| Scen. | RFId effect | Network effect | Repl. Policy | Unitary shipment cost | Transp. Costs [€/y] | Holding Costs [€/y] | RFId Invest. [€/y] | Thefts mispl. [€/y] | ETRC [€/y] | Saving |
| AS IS | NO | NO | (R, S) | A | 595 | 6700 | - | 4568 | 11863 | / |
| 1 | NO | YES | (R, S) | λA | 69 | 6700 | - | 4568 | 11337 | 4.4% |
| 2 | YES | NO | (s, Q) | A | 2817 | 3466 | 4434 | - | 10717 | 9.7% |
| 3 | YES | YES | (s, Q) | λA | 969 | 1766 | 4434 | - | 7170 | 39.6% |

Table 3. Results of the numerical experiment

to the numerical experiment. In scenario 1, by virtue of the option of cooperating as a network, there is the possibility for Company B to share shipment costs with Company A, which supplies the hospital on a daily basis. This is of course preferable with respect to the AS IS scenario, because holding costs remain unchanged, and transportation costs are reduced by a factor equal to λ . Results related to scenario 2 show that, even in absence of the network effect, the implementation of the RFId technology makes the adoption of a continuous review policy more convenient. This is due to two reasons: firstly, the RFId annual investment is lower than the annual costs related to thefts and misplacements. Secondly, the parameters of the continuous review policy (s and Q) are optimized for each product line, while in the periodic review policy the review period R is the same for all product lines and it is imposed by the hospital organization ($R = 1$ month). In scenario 3, the effect obtainable combining the RFId technology with networked cooperation among enterprises is evaluated.

The reduction achievable in terms of *ETRC* is notable, reaching almost the 48% with respect to the AS IS scenario. It is noteworthy that the interaction of the two effects brings to a cost reduction higher than the sum of the savings obtainable when the two effects are applied separately. This is due to the fact that the Network Effect, by allowing decreasing the cost per shipment, has a much more great impact on policies with frequent of shipments (s, Q) then on policies with low number of shipments (R, S). Thus, only the simultaneous adoption of the RFId technology and the collaborative network model allows maximizing the expected savings.

Conclusions

In the paper a methodology to evaluate possible savings of a new business model of collaborative supply network in the healthcare sector is described. The case study show that an integrated supplying service for the operating room can be less expen-

sive than traditional models, while maintaining an adequate service level to the patient. In fact, the presence of RFID technology allows the implementation of a continuous review policy, which is known to reduce the uncertainty period with respect to periodic review policies. Consequently, relevant savings related to holding costs are achievable. At the same time, the collaborative network of suppliers allows sharing transportation costs. In this way, the costs connected to shipments, which are typically higher in continuous review policy, are limited.

It is reasonable to assume that the economic benefits achievable in reality may increase as the number of different products handled and the number of companies involved increase. In fact, when there are more than four products considered in this work, it is correct to assume that, even by adopting a continuous review policy, the replenishment instant may be the same for more products simultaneously. In the same way, shipment costs can be lowered even in the case where more than two companies are considered, by optimizing the routing from Company A to the Hospital.

In order to generalize the results obtainable by the proposed approach, future improvements consists in performing a sensitivity analysis on the parameters that can have a direct influence on total costs, starting from the network coefficient λ . Finally, a discrete event simulation model could be designed to accurately evaluate the impact of thefts and misplacement on real costs and service level, in order to better quantify the benefits connected to RFID implementation.

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