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Abstract

Purpose – The purpose of this paper is to present a new outsourcing model for materials management related to the operating theatre of hospitals. Two distinguishing features characterize the model: the long-term collaborative network established among the supplying companies (the "Network factor"), and the implementation of the RFID technology along the supply chain (the "RFID factor"). The network factor allows sharing transportation costs, while the RFID factor allows implementing a continuous review policy, instead of the periodic review policy normally utilized in hospitals. In the paper the effect of these two factors on the minimization of total materials management costs is investigated.

Design/methodology/approach – An analytical model, validated through a simulation study, is proposed to calculate total management costs of materials, depending on the presence of the network and the RFID factors. Throughout the model it is possible to perform a scenario analysis and individuate the inventory management policy that allows minimizing total costs. The procedure has been applied to a real case study of a long-term collaborative network of supplying companies in the healthcare sector that operates in Central Italy.

Findings – The optimal inventory management policy strongly depends on the mutual distances of supplying companies and the hospital. Both of the two factors have an impact on the reduction of total annual costs. The analysis of the scenario shows that a positive interaction effect exists between the two factors, so that higher savings are obtained when both factors are present.

Originality/value – The outsourcing model presented in the paper is new, and the managerial insights that can be drawn from the application of the model to the healthcare sector can be extended to many other industries.

Keywords Inventory management, Healthcare operations, Decision-support tool, Inventory control, RFID technology

Paper type Research paper

Nomenclature

i	different products line	A	cost per shipment for Company 2 without the network factor (€/roundtrip)
R	review period (year)	A'	cost per shipment for Company 2 with the network factor (€/roundtrip)
L	lead time (year)	r	inventory carrying charge (€/€/year)
S_i	order-up to level for item i (units)	v_i	unit variable cost of item i (€/unit)
s_i	reorder point of item i (units)	α	incorrect positioning coefficient
Q_i	order quantity of item i (units)	β	damage coefficient
D_i	mean annual demand of item i (units/year)	γ	theft coefficient
TRC	total relevant cost (€/year)	δ	incomplete delivery coefficient
HC	total holding costs (€/year)	k_i	safety factor for item i
SC	total transportation costs (€/year)		

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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 trends in the public healthcare sector is to entrust some outsourced services, optimizing performance through a contract. In this way, healthcare managers try to reduce spending without affecting the quality of service offered (Roberts, 2001). The spread of non-core processes outsourcing in healthcare has become very fast because, the hospital being a set of many departments handling large number of activities, there is the need to entrust outside the non-core services (Baffo *et al.*, 2009). The past few decades have witnessed the boom of outsourcing in which firms transfer their non-core business activities to third-party suppliers (Zhao *et al.*, 2014). Outsourcing is increasingly viewed as a policy tool with the potential to increase the access, equity, quality and efficiency of healthcare (Laamanen *et al.*, 2008) because to achieve cost-effectiveness in secondary activities allows hospitals to use more resources on patient care (van de Klundert *et al.*, 2008).

Cost-effectiveness is important even for activities that have a great impact on the hospital core business such as those related to the operating theatre (OT). Indeed, even if the actual expenditures for OTs are not known with certainty, some estimates suggest that OTs account for 10-30 per cent of total hospital expenditures. These data indicate that surgical facilities within hospitals are one of the most costly functional areas in the hospital (May *et al.*, 2011). Among the most expensive and sensitive core activities performed inside the OT there is the surgical instruments reprocessing process. This is a very expensive process and a potential area for cost savings (Reymondon *et al.*, 2008). However, the outsourcing of this kind of process is not yet deeply studied.

Outsourcing of the reprocessing service gives the possibility to achieve further savings related to material management, due to specific characteristics of the supplying process (daily shipments of surgical instruments kits). These extra-savings are achievable through a supplying network, formed by the external company that reprocess surgical instruments and by other suppliers of materials utilized in the OT (such as non-woven items or surgical devices).

The paper presents this innovative business model, inspired by a real case, which is characterized by two main features: the implementation of the RFID technology along the supply chain; and the collaborative nature of the supplying network. The first feature (RFID implementation) allows cost reduction because it enables the implementation of a continuous review (CR) replenishment policy, instead of the periodic review (PR) policy usually adopted by healthcare structures. The second feature (collaborative network) allows cost reduction because it makes it possible to share transportation costs among suppliers.

In the paper an analytical model is presented, through which it is possible to:

- calculate the expected savings achievable by the adoption of the new business model; and
- evaluate the contribution on the expected savings of each one of the two characteristic features of the business model.

The analytical model is approximated due to the stochastic nature of the processes involved in the problem. For this reason, the analytical model is validated via simulation.

The paper is organized as follows. The literary review is presented in Section 2. In Section 3 the new outsourcing business model is described and the corresponding analytical model is presented. In this section, four different scenarios are formalized, corresponding to four different possible ways to implement the business model. In Section 4 the design of experiment is described. The experiment will be conducted both through the analytical model and through a simulation model, for validating purposes. The data utilized are taken from a real case. Results are discussed in Section 5. In Section 6 a sensibility analysis on one of the factor that has the main influence on expected savings is performed. In Section 7 conclusions are drawn.

2. Literary review

The underlying research question of this work is:

RQ1. Which benefits can be achieved through the adoption of an innovative business model for materials management in healthcare, characterized by the implementation of the RFID technology along the supply chain and by the collaborative nature of the supplying network?

In order to outline the relevance of this topic and the contribution of the work with respect to the "state of the art", the literary review is divided in three sections, each one concerning the main topics involved in the study: materials management in healthcare, outsourcing in healthcare and application of RFID technology in healthcare.

2.1 Materials management in the healthcare sector

Studies performed in the past, as well as more recent researches, suggest that inventory costs in the healthcare sector are substantial and are estimated to be between 10 and 18 per cent of net revenues (e.g. Jarrett, 1998). Indeed hospitals deal with a large amount of materials serving their numerous departments that must be stored inside the structure. Among those materials, some are defined critical; they should be present in sufficient numbers to meet emergencies. Inventory management has therefore 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 (de Vries, 2011).

One of the distinctive features of material management in a hospital is the use of the PR (or order-up-to level) replenishment policy (Nicholson *et al.*, 2004). Medical and nursing staff check each stock at regular intervals and examine each product inventory level and then they replenish stocks up to order-up-to levels. The staff determines the policy of inventory management for the different departments' warehouses and the optimum amount of product, the delivery frequency and the level of service desired for each typology (Little and Coughlan, 2008). To define the parameters of the PR policy it is essential to establish the service level the hospital intends to provide.

On the issue of tasks not related to nurses' competencies, Bendavid *et al.* (2012) conducted a study within a North America clinic. They noted that the stocks replenishment process was done manually and it is very widespread because it involves a large amount of subjects and departments. This process is time consuming, due to the entirely paper-based inventory management. Another study on this issue was conducted by Tucker and Spear (2006). Their research confirms how this manual process generates a series of time wastages and oversights from clinical tasks, especially for nurses.

The innovative business model presented in the paper, as it will be described in Section 3, gives an answer to these issues, providing the complete outsourcing of the materials management process related to the OT, and the adoption of a more efficient CR policy instead of the traditional PR policy.

2.2 Outsourcing in the healthcare system

The past few decades have witnessed the boom of outsourcing in which firms transfer their non-core business activities to third-party suppliers. Typical outsourcing areas include information technology management, services, manufacturing, logistics and customer support (Goles *et al.*, 2008; Kakabadse and Kakabadse, 2005). The primary motivation for outsourcing is to maintain a competitive edge by reducing costs and focusing on core-competencies.

There is increasing interest in contracting out in the healthcare sector even if there is no consensus about the optimal mix of in-house and outsourced functions or services in healthcare (Vining and Globerman, 1999). From the literature, the most pointed drivers to outsource in healthcare units are: cost reduction, risk mitigation, adapting to quick changes without jeopardizing internal resources and value stream redefining (Guimarâes and De Carvalho, 2011). For these reasons, outsourcing is increasingly viewed as a policy tool with the potential to increase the access, equity, quality and efficiency of healthcare (Laamanen *et al.*, 2008). Generally, in the healthcare sector there is a trend to outsource non-core functions in order to focus resources on core business and create a network of external competence for non-core services (Roberts, 2001). By contracting out some of the non-core services, a healthcare facility can contain its expenditures taking advantage of the vendor's expertise and economies of scale that result from the pooling of demand. Macinati (2008) also highlighted that there is still considerable contracting out of only non-medical services currently in the healthcare sector. Outsourcing of activities is viewed with more scepticism for processes closely linked to the core business.

The outsourcing of these kinds of services, such as the sterilization of surgical instruments, has not yet been treated in a systematic manner. Van de Klundert *et al.* (2008) approached the issue of the optimization of the flow of sterile instruments in hospitals, but considering that surgical instrument are reprocessed in the sterilization department of the hospital. Paltriccia *et al.* (2014) proposed a decision-support tool for outsourcing the reprocessing service of surgical instruments on the basis of expected annual costs.

In the paper we propose an innovative outsourcing model actually not present in the healthcare sector. Indeed, with respect to the literature, our model considers the outsourcing of a core-linked process, like the rental and the reprocessing service of surgical instruments, combined with the formation of a network of enterprises among the reprocessing outsourcer and other suppliers.

2.3 RFID technology in the supply chain

RFID is a technology that allows the identification of objects provided with tags. Through reading tags it is possible to have remote tracking. Inventory tracking becomes easier and many other probable applications of RFID technologies have been proposed (Choi, 2007). As evidenced by Sarac *et al.* (2010) this technology may improve the potential benefits along the supply chain reducing inventory losses, increasing efficiency and the speed of the processes involved and improving information accuracy and also improving total traceability of each item in order to ensure quality (Azuara *et al.*, 2012; Wu *et al.*, 2011).

Lee and Lee (2010) conducted a cost-benefit analysis through an investment evaluation on the RFID technology adoption in order to enhance the understanding on RFID value creation along the supply chain. Ustundag and Tanyas (2009) studied the impact of the RFID technology applied to inventory management as an instrument that allows improvements related to error reduction and theft elimination. These can be summarized in the elimination of item losses caused by theft; incorrect positioning and incomplete shipments; the possibility of implementing a CR policy and reduce stock-out risks; the possibility of achieving complete product traceability. Ustundag and Tanyas (2009) contribute to the literature on RFID by investigating how the factors of product value, lead time and demand uncertainty affect the performance of an integrated RFID supply chain in terms of cost factors at the echelon level. Using a simulation model, the expected benefits obtained from a RFID integrated supply chain were calculated considering the factors of lost sales, theft, inventory, order and labour costs.

Recent advances in RFID technology have allowed for its use in many commercial sectors such as transportation, logistics and supply chain management in the food industry as studied by Kelepouris *et al.* (2007). Even the fashion industry is among those that have recognized the importance of the information exchange along the supply chain (Lee and Ozer, 2007). RFID technology is also useful in enterprise collaboration as explained by Lekakos (2007).

2.3.1 RFID in the healthcare sector. The provision of adequate medical care involves decision making in terms of planning and management of healthcare (Harper, 2002). E-pedigree requirements and state and federal laws and regulations require that information about the manufacturer, lot numbers, complete shipping information, dosage, etc. be registered on a drug's tag (Cakici *et al.*, 2011). Use of the RFID technology in this field has much potential (Chong and Chan, 2012). It is reasonable to assume that the healthcare sector can reap the same benefit reached by the fashion industry across the supply chain. In order to comply with regulatory requirements, enforce business partner-specific supply chain, increase efficiency logistics and quality management, supporting patient safety and ensure product authentication, the healthcare sector has to face a critical issue (Bendavid *et al.*, 2012).

Many existing studies suggest that RFID technology implementation can enhance many aspects of healthcare such as the service level of patients, lowering costs, making management more reliable and coherent and monitoring information and material flows (Kumar *et al.*, 2008). The real life practices of RFID implementation in the healthcare industry shows that most appreciate only automatic counting and hence lose the potential for larger savings (Cakici *et al.*, 2011). Tzeng *et al.* (2008) conducted a study in Taiwan, proposing a framework to evaluate possible RFID benefits for the healthcare sector. Their study shows how RFID has a great deal of potential in business automation and how useful it can be for rectifying inefficiencies in workflow. The novelty of RFID tagged products lies in the fact that this technology provides a service on two different fronts: the automated inventory management and monitoring. For example, it is not uncommon for pharmacists to manually record the expiration date of drug items, monitor their restocking requirements, track the number of items used in a ward and so forth (Ngai *et al.*, 2009) because RFID system enables operators to retrieve the information on inventory at once regardless of its quantity (Kim *et al.*, 2008). Chan *et al.* (2012) studied how the estimated real value obtainable from the introduction of RFID technology is not well defined. Some industrial relations, such as the AMR report, estimated that use of RFID systems could reduce the cost of the supply chain from 3 to 5 per cent and increase revenue from 2 to 7 per cent. Chong and Chan (2012) recently studied how RFID technology can help to improve the current stock management systems in hospitals and clinics. It is very difficult to administrate all the equipment involved in the management of hospital inventories, as they are very numerous. They studied how the presence of RFID technology allows implementation of a CR policy avoiding additional personnel costs while in the absence of such technology, stocks are handled in PR. Zhou and Piramuthu (2010) find that while RFID enabled real-time medical process and labour management provides marginal improvement for premium medical service providers, it generates appreciable improvement both in terms of efficiency and service quality for public healthcare institutions where availability of necessary resources such as medical staff and equipment are highly constrained. Ustundag and Tanyas (2009) contribute to the literature on RFID by investigating how the factors of product value, lead time and demand uncertainty affect the performance of an integrated RFID supply chain in terms of cost factors at the echelon level. Using a simulation model, the expected benefits obtained from an RFID integrated supply chain were calculated considering the factors of lost sales, theft, inventory, order and labour costs. It is shown that the factors of product value and demand uncertainty have a considerable influence on the expected benefits of RFID integrated systems. Reyes *et al.* (2012) contribute to the literature conducting a study in which the importance of RFID implementation in the healthcare sector emerges, in particular from a management point of view.

From a higher quality perspective, RFID technology enables traceability. Indeed, as studied by Fisher and Monahan (2008), RFID allows patient identification and tracking, and tracing improves healthcare value chain. Adopting this technology permits error reduction within patient care, including adverse drug effects, allergies, patient-medication mismatches and medication dosage errors (Thuemmler *et al.*, 2007; Tu *et al.*, 2009). All these new capabilities enabled by RFID technology have the potential to facilitate new value creation in healthcare service innovation (Dominguez-Péry *et al.*, 2013).

The positive impact of RFID on the healthcare sector emerges from the literature review. For this reason we propose an implementation of this technology combined with a network alliance among suppliers of different materials. We want to prove how the simultaneous implementation of these two features (RFID technology and collaborative supply network) allow to increase benefits with respect to traditional supplying models.

3. Conceptual model

In the conceptual model, a network of enterprises that supplies materials for the OT is considered. The model is built to study if cost reduction is possible by adopting innovative management solutions. This model considers a network of enterprises among which one of the companies (Company 1) daily supplies surgical instruments. The daily supply makes Company 1 a critical enterprise and allows the existence of a specific feature of the model, the "network factor" (see Section 3.1.1.1). On the contrary, the other companies monthly supply materials that shall be traced adopting the RFID technology; this characteristic allows the existence of the "RFID factor" (Section 3.2). These two factors determine the possibility of cost reduction by implementing a CR inventory management policy (RFID factor) and the possibility of transportation cost sharing thanks to the presence among the network enterprises (network factor).

The impact of these two factors on total relevant costs (*TRC*s) will be evaluated through an analysis of scenarios. We consider *TRC* as the sum of holding costs related to materials in the hospital's warehouse and the shipment costs incurred by the companies; among those costs, RFID technology implementation and cost related to theft and misplaced items are considered.

In order to evaluate the effect of the two factors, in the conceptual model two companies are considered: Companies 1 and 2.

3.1 Daily supplying and the "network factor"

Company 1 manages surgical instrument supply and the reprocessing services and ships every day sterile kits to the hospital, and collects the used ones. Transportation is carried out through a fleet of vehicles owned by the company.

Thanks to the cooperation as a network, the other companies can take advantage of the daily frequency of the shipments of Company 1 by sharing part of the route to the hospital. If the mutual geographical position of the companies and the hospital is favourable, transportation cost savings can be achieved.

This potential advantage is particularly important if the RFID technology is simultaneously implemented. As described in the previous section, RFID technology allows implementing a CR policy, which is particularly convenient when cost per shipment is low. Indeed, the number of shipments under continuous reviewing are expected to be higher than under periodic reviewing, because each item could reach the reorder level at a different time.

3.1.1 The network governance. Usually, integrated outsourcing non-core services is provided by temporary joint ventures. However, this kind of alliance is not suitable for providing integrated services when these are very close to the core business. Indeed, when outsourced services can have a great impact on the core business, the temporary nature of the alliance may not guarantee the necessary requirements in terms of trust, reliability and coordination capabilities; a long-term strategic network of enterprises is a much more suitable form of collaboration. Among those, the Virtual Development Office (VDO), proposed by Saetta *et al.* (2013) permits a long-term cooperation. The VDO combines two characteristics that are usually in contrast to traditional form of alliances: the goal-oriented nature and the long-term strategic alliance.

In this case, the VDO establishes business relations with the hospital and coordinates companies' logistics by organizing replenishments using a single shipment instead of a shipment per enterprise.

3.1.1.1 Network factor. The network factor allows companies to share setup costs, which correspond to shipment costs. We assume that the cost per shipment is proportional to the distance covered for the shipment. Companies 1 and 2 may share some part of the way to the hospital. In particular, Company 2 can take advantage of the daily shipment of Company 1.

In this case, the lower distance that can be covered in a roundtrip is equal to the perimeter of the triangle (see Figure 1) formed by the hospital (point H), Company 1 (point F), and Company 2 (point G).

Thus, when the two companies cooperate as a network, the shipment trip will always start from, and finish at, Company 1 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 1 plants;
- trip from Company 1 to 2;

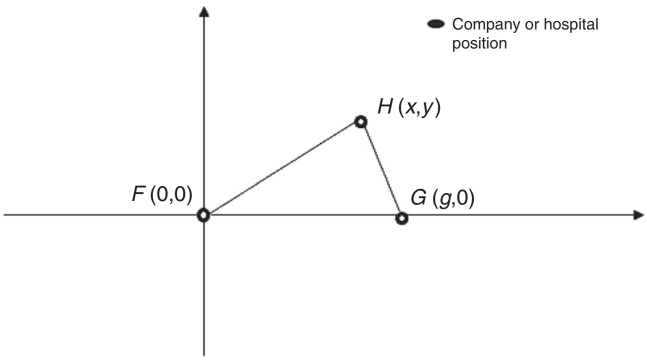

Figure 1.
Schematic position of companies and hospital

- load of packs from Company 2;
- trip from Company 2 to the hospital for the delivery of kits and packs; and
- trip from the hospital to Company 1 to bring back utilized kits.

To evaluate the savings achievable through the network factor, 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 the following:

$$FG+FH+GH < 2GH+2FH \quad (1)$$

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.

Relation (1) can be simplified in the following way:

$$FG < GH+FH \quad (2)$$

As the sum of two sides of a triangle is always greater than only one side, relation (2) is always verified. This implies that working as a network always allows reducing cost per shipment.

From (1), the total savings SV achievable under the "network factor" will be proportional to:

$$SV = 2GH+2FH-[FG+FH+GH] \quad (3)$$

From a network perspective, this reduction of shipment cost can be entirely assigned to Company 2. Indeed, it is noteworthy that shipment cost does not affect the replenishment policy of Company 1, 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 2. In fact, in this conceptual model it is assumed that the optimal reorder quantity for each item i is equal to the economic order quantity (EOQ):

$$EOQ = \sqrt{\frac{2A\cdot D}{v\cdot r}} \quad (4)$$

So if the shipment cost A drops to A' when the network factor is present, the optimal order quantities of each item also decrease. In this view, considering a cost per unit length equal to 1, as the Company 2 shipment without the network is equal to $A = 2GH$, A' can be estimated as:

$$A' = A - SV = 2GH - [2GH + 2FH - (FG + FH + GH)] = GH + FG - FH \quad (5)$$

We can now define the "Network coefficient" λ as the ratio between A' and A, with $0 \leqslant \lambda \leqslant 1$. From (5):

$$\lambda = \frac{A'}{A} = \frac{GH + FG - FH}{2GH} = \frac{1}{2} + \frac{FG - FH}{2GH} \quad (6)$$

λ depends from the mutual positions of Companies 1, 2 and the hospital.

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

$$Q_i = \sqrt{\frac{2\lambda A \cdot D_i}{v_i \cdot r}} \quad (7)$$

We will show in Section 5 how the optimal replenishment policy of the network depends on λ.

3.2 RFID factor

Among the advantages related to the implementation of RFID technology, we consider only the ones related to the supplier (see Section 3):

(1) to avoid incomplete shipments, misplacements and theft; and

(2) to possibly implement a CR policy.

The first benefit has been modelled using the study by Ustundag and Tanyas (2009). 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). The error rates from the experimental study of Ustundag and Tanyas (2009) related to the corresponding causes are reported in Table I.

As far as the second benefit is concerned, the conceptual model assumes that without the implementation of the RFID technology a PR policy is adopted, while the RFID factor allows implementing a CR policy. In the following subsections, the description of both policies is carried out.

Table I. Error rates of non-RFID and RFID integrated systems

Technology	α (misplacement, %)	B (damaged, %)	γ (theft, %)	δ (incomplete shipment, %)
non-RFID	2	0.2	0.5	0.3
RFID	0	0.2	0	0

3.2.1 PR – no RFID factor. Without the RFID factor, Company 2 actually adopts a PR policy (R, S), with a review period R equal to 1 month, which is common for all the four items. This type of policy is often adopted when it is not possible to have an automatic monitoring of the warehouse, and when the same company supplies different items. 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 as follows:

$$S_i = SS_i + D_i(R+L) \tag{8}$$

$$SS_i = k_i \sigma_{(R+L)i} \tag{9}$$

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 $P = 99.9$ per cent of demand satisfied immediately from the shelf ("fill rate"). From this condition, the value of k_i can be calculated in the following way (Silver *et al.*, 1998):

$$G_u(k_i) = \frac{(1-P)D_i R_i}{\sigma_{(R+L)i}} \tag{10}$$

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

$$G_u(k) = \int_k^{\infty} (u-k)\phi(u)\,\mathrm{d}u = \phi(k) - k(1-\Phi(k)) \tag{11}$$

$\phi(k)$ being the unit normal density function, and $\Phi(k)$ the corresponding distribution function. From the value of $G_u(k_i)$, calculated from (10), it is possible to determine the value of k_i using the tabular form of Equation (11).

3.2.2 CR – RFID factor. When RFID technology is implemented, Company 2 can apply a CR policy (s, Q). In this case the optimal order quantity Q_i, for each item i, is calculated through the (EOQ):

$$Q_i = EOQ_i = \sqrt{\frac{2AD_i}{v_i r}} \tag{12}$$

Note that, if the network factor is simultaneously present, the network coefficient λ has to be considered to calculate order quantities, using Equation (7).

The reorder point s_i is calculated for each item through:

$$s_i = SS_i + D_i L \tag{13}$$

$$SS_i = k_i \sigma_{(L)i} \tag{14}$$

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 $P = 99.9$ per cent, it is necessary to calculate the loss function as:

$$G_u(k_i) = \frac{(1-P)Q_i}{\sigma_{(L)_i}} \tag{15}$$

Then the value of k_i can be determined using the tabular form of Equation (11).

3.3 Scenarios

3.3.1 Scenario "AS IS". In the "AS IS" scenario (Figure 2(a)) neither the "Network factor" nor the "RFID factor" are present. Thus, companies operate individually; Company 2 utilizes the PR policy described in Section 3.2.1. in which A is the cost per shipment per roundtrip between Company 2 and the hospital. Note that the entire products line share the same shipment, as provided by the PR policy and for each one of them it is necessary to consider also costs related to theft and misplacement. Note that incomplete shipments and damages are not considered in the cost function:

$$ETRC = \frac{A}{R} + \sum_i \left(\frac{D_i}{2}R + k_i\sigma_{i,R+L}\right)v_i r_i + \sum_i \left(\frac{\alpha}{2} + \gamma\right)D_i v_i \tag{16}$$

3.3.2 Scenario 1 (Network factor). Scenario 1 (Figure 2(b)) concerns the presence of the network factor previously described. Company 2 adopts a PR policy, but since the two companies belong to the same network, VDO, which represent the network governance, can coordinate companies so that it is possible to share cost per shipment every R days. The roundtrip shipment cost for Company 2 decrease from A to A':

$$ETRC = \frac{\lambda A}{R} + \sum_i \left(\frac{D_i}{2}R + k_i\sigma_{i,R+L}\right)v_i r_i + \sum_i \left(\frac{\alpha}{2} + \gamma\right)D_i v_i \tag{17}$$

3.3.3 Scenario 2 (RFID factor). Scenario 2 (Figure 2(c)) provides the implementation of the RFID technology. In this scenario, the companies still operates individually, but Company 2 implements the CR policy described in Section 3.2.2. The cost per shipment between Company 2 and the hospital are still equal to A, because they cannot be shared between the two companies. Furthermore, each shipment contains only one product line, due to the different times each product line reaches the respective reorder point. In this scenario among the costs the annual payment related to RFID implementation has to be considered:

$$ETRC = A\sum_i \frac{D_i}{EOQ_i} + \sum_i \left(\frac{EOQ_i}{2} + k_i\sigma_{i,L}\right)v_i r_i + C_{RFID} \tag{18}$$

3.3.4 Scenario 3 (Network+RFID factors). In Scenario 3 (Figure 2(d)) the network factor and the RFID factor are simultaneously present. Thanks to RFID technology Company 2 can implement a CR policy. At the same time, each time a product line reach the reorder point, the corresponding shipment can be shared with Company 1, thanks to the network factor. The cost per shipment will be equal to A':

$$ETRC = \lambda A\sum_i \frac{D_i}{EOQ_i} + \sum_i \left(\frac{EOQ_i}{2} + k_i\sigma_{i,L}\right)v_i r_i + C_{RFID} \tag{19}$$

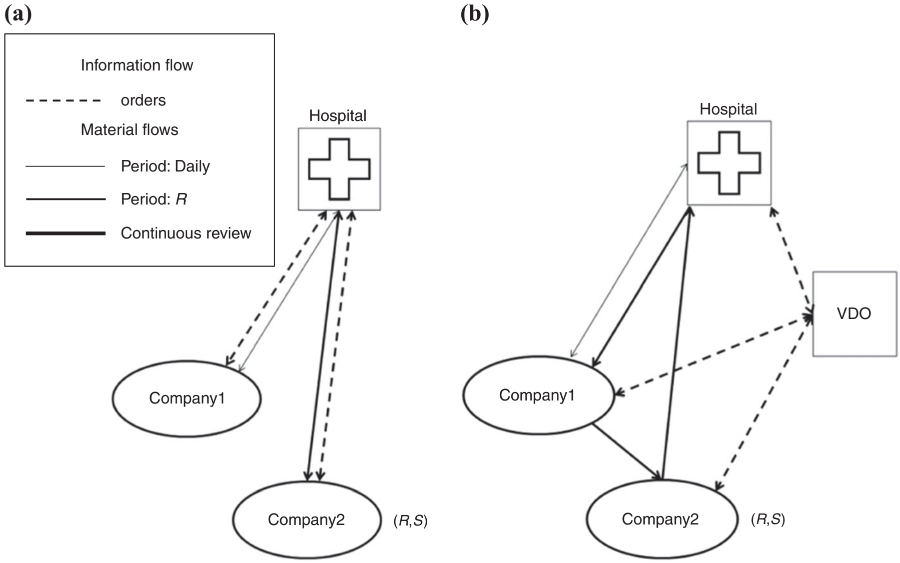

Figure 2.
Scenarios analysis

Notes: (a) Scenario "AS IS"; (b) scenario 1 (Network factor); (c) scenario 2 (RFID factor); (d) scenario 3 (Network+RFID factors)

3.4 Automated inventory management and traceability

Traceability refers to the capability of an application to track the state (e.g. location, temperature) of goods, discover information regarding its past state and potentially estimate its future state. Traceability is vital for efficient business operations and for making effective decisions, which is fundamental to a wide range of business applications such as inventory control, distribution planning, manufacturing control, product recalls, counterfeit detection and re-usable asset management (Wu *et al.*, 2011).

In this section we briefly describe how in our model automated inventory management and treatability are enabled by RFID technology.

The kits and packs are equipped with RFID tags on which data for univocal item identification is recorded.

Each surgical instrument is provided with a re-usable tag. In this way it is possible to record data related to the reprocessing process (temperature, time, number of machine cycle, etc.) for each single device. If patients are also provided with a tag it is possible to associate patient's data and material data to each surgery.

All the other consumable items, such as non-woven drapes and sutures, are equipped with a single use tag on their external envelope. On each tag data related to production lot and the expiration date, are recorded.

Data related to surgical instruments kits and non-woven drapes are recorded at their respective production plant, while data related to consumable items are recorded at the hospital. Tag application on kits occurs in company plants during the packaging process before the sterilization process. The data logging gates are positioned in key points along the processes in companies' plants and inside the hospital as shown in Figure 3. In the hospital, tag reading gates are installed at the entrance and at the exit of the warehouse and the operating room. Data related to item movements are recorded on a dedicated server, which is accessible from the company's remote control.

This RFID-based configuration provide the following advantages:

(1) For the hospital:
- To achieve complete and automatic traceability of every single item along the supply chain.
- To improve cost allocation: by associating all the items to each single surgery that have been used, it is possible to precisely calculate the total expenditures related to each surgery department.

(2) For the company:
- To avoid incomplete shipments, misplacement and theft.
- To implement a CR policy, which can potentially achieve the same service level with lower holding costs than PR policies. Thanks to the remote control, the company can always read updated stock levels. By setting inventory level alerts, it is also possible to automatically generate orders.

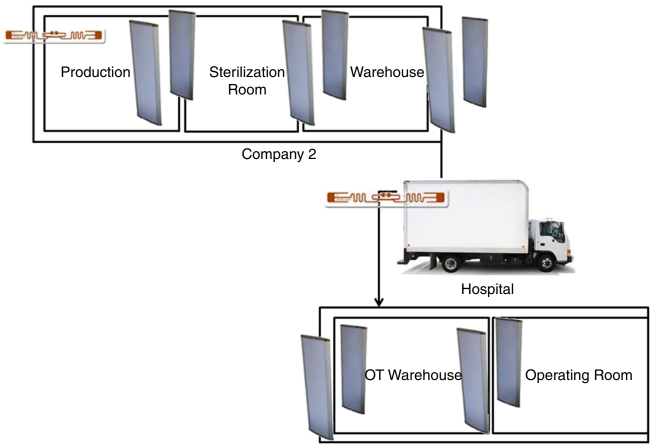

Figure 3. Traceability process

4. Design of experiment

The aim of this work is to investigate how *TRC* varies by changing the previously described scenarios. 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 round trip between Company 2 and the Hospital $A=50$ (€), network coefficient $\lambda=0.1158$, inventory carrying charge $r=25$ per cent, lead time $L=2$ days, required service level (demand satisfied directly from the shelf, i.e. fill rate) $P=99.9$ per cent.

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 II.

Due to the exponential distribution, the coefficient of variation *cv*, defined as the ratio between the average demand and its standard deviation, is equal for all the items. This implies that the daily demand standard deviation is equal to the daily demand average value. The value of k_i for both the PR and the CR policies have been derived using the procedures described in Sections 3.2.1 and 3.2.2, respectively. The reorder points s_i and the order-up-to levels S_i, calculated, respectively, though Equations (13) and (8), have been rounded up to the next integer. The order quantities Q_i, calculated through Equation (7), have been rounded to the nearest integer. All these values are reported in Table III.

The hardware and software investments related to the RFID implementation are listed in Table IV.

Considering an interest rate equal to 10 per cent and an amortization period of 15 years, it is possible to evaluate the annual cost related to scenarios in which a CR policy is implemented. The periodic amortization payment is calculated as follows:

$$C_{RFID} = C_I \cdot (A/P, i, n) + C_E \tag{20}$$

Table II. Value calculation variables for the four product line

Product line	Description	Average demand (units/year)	Item value (€/unit)
1	Surgery	560	208
2	Otorhinolaryngologist	20	198
3	Orthopaedics	673	220
4	Obstetrician e genecology	454	247

Table III. Parameters values for periodic and continuous review policies

	Product line 1	2	3	4
Periodic review				
k	2.1	2.66	2.07	2.14
S	64	2	77	50
Continuous review				
k	2.19	2.19	2.18	2.21
s	10	2	11	8
Q	11	2	12	9

where C_{RFID} is the equivalent annual cost (€/year); C_I is the total investment for RFID implementation; C_E is the annual RFID management cost; i is the periodic interest rate; and n is the number of payments.

The total annual costs related to RFID implementation has been calculated by summing the periodic amortization payment and the annual costs of the "one use" UHF tags, and it is equal to 4,434 (€/year).

The impact of thefts on the *TRC* 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 items are expired and cannot be used if they are found. In the model it is assumed that the 50 per cent of misplaced items expire before being found, and a cost equal to the value of the item is considered; the other 50 per cent is considered utilizable and for this reason it does not represent a cost.

Damages and incomplete shipments could affect the realized service level, but does not generate an extra cost as theft and misplacements. In our model damaged items are replaced for free, and an incomplete shipment generates the backorder of the missing quantity which is supplied together with the succeeding replenishment.

In Section 5 the resulting *TRC* will be analysed for each scenario. In particular *SC*, *HC* and costs related to thefts and misplacements are calculated both with the analytical model and a simulation model, described in the next section.

4.1 Simulation model

Using the software Arena™, a discrete event simulation model has been developed in order to validate the analytical model presented in Section 3. Indeed, the presence of stochastic processes, such as demand, and stochastic events like misplacements, thefts and incomplete shipments, makes the equations used to calculate reorder points and to estimate *TRC* approximated.

For example, considering a CR (s, Q) replenishment policy, if a "theft" event happens before the inventory position reaches the reorder point s, the event will have an impact just on total costs, but not on the expected service level. On the contrary, if the "theft" event happens during the uncertainty period, i.e. after the replenishment order has been placed, it will have an effect even on the expected service level. The analytical model proposed herein does not catch these details.

Another example of the approximation of the analytical method is the fact that it considers that items managed through a CR (s, Q) policy does not reach the reorder point s on the same day. This implies that items are never grouped within the same order, and transportation sharing is never possible. In reality, the simultaneous

	Cost per item (€/unit)	Item requested Enterprise	Hospital	Total(€)
Installation costs				
UHF RFID gate	1,870	3	2	9,350
UHF RFID tag printer	2,500	1		2,500
Personal computer	1,300	1		1,300
Personnel training	6,000	1		6,000
Software	11,328	1		11,328
Annual costs				(€/y)
Only read UHF RFID tag	0.25	1,707		426.75

Table IV. Hardware and software investment for RFID technology implementation reaching of the reorder point by one or more items is possible. For this reason the analytical model is expected to overestimate transportation costs.

Through the simulation model it is possible to quantify if the analytical model provides a desirable degree of approximation. The settings related to the simulation experiment are:

(1) the demand value is assumed stochastic with an exponential distribution;

(2) the simulation length is equal to one year, with a warm-up period of one year; and

(3) each scenario has been replicated 100 times.

To simulate misplacements, theft and incomplete shipments, four different types of dummy entities have been created. Each of them simulates the happening of the corresponding event (theft, misplacement, incomplete shipments, damage). Theft events are generated considering a rate equal to $\alpha \cdot D_i$, and when it happens, the inventory level of the item is decreased by one item. Misplacements, damages and incomplete shipments events are randomly generated each time a replenishment takes places and decrease the number of items arrived, so that the average number of annual events corresponds, respectively to $\beta \cdot D_i$, $\gamma \cdot D_i$, $\delta \cdot D_i$. A supplementary dummy entity is also necessary to simulate the finding of the misplaced items before their expiration date; this event happens with a rate equal to:

$$\frac{\beta}{2D_i} \tag{21}$$

assuming, as already mentioned, that only the 50 per cent of misplaced items are found before the expiration date, while the other 50 per cent is lost.

5. Results

Results obtained through the simulation study and the analytical model are reported in Tables V and VI, respectively. *TRCs* calculated through the analytical model differ from those calculated through the simulation for less than 4 per cent in every scenario. Considering that the *TRC* ranking between the four scenario does not change between analytical and simulation model, this approximation can be considered acceptable.

It is evident that the more expensive configuration is the first one, the AS IS scenario. In this scenario, Company 2 incurs costs related not only to the inventory policy, but also to those related to misplacements and thefts. In scenario 1, by virtue of the option of cooperating as a network, there is the possibility for Company 2 to share shipment costs with Company 1, 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 factor, the implementation of the RFID technology makes adopting the CR policy more convenient. This is due to two reasons: first, the RFID annual investment is lower than the annual costs related to thefts and misplacements. Second, the parameters of the CR policy (reorder points s and order quantities Q) are optimized for each product line, while in the PR policy the review period R is the same for all product lines and it is imposed by the hospital organization ($R = 1$ month, i.e. 21 working days per month).

Table V. Results from the simulation model

Scenario	RFID factor	Network factor	Cost per shipment (€/roundtrip)	Replenishment policy	Calculation methodology	Transportation costs (€/year)	Holding costs (€/year)	RFID investment (€/year)	Thefts and misplacements (€/year)	*TRC* (€/year)	Annual saving (€/year) (%)
AS IS	No	No	A	(R, S)	Simulation	600	6,362	–	5,735	12,596	–
1	No	Yes	λA	(R, S)	Simulation	69	6,362	–	5,735	12,066	3.94
2	Yes	No	A	(s, Q)	Simulation	2,626	3,527	4,434	–	10,587	21.36
3	Yes	Yes	λA	(s, Q)	Simulation	764	1,810	4,434	–	7,008	47.95

In scenario 3, the results obtainable combining the RFID technology with networked cooperation are reported. We remind that in this scenario Company 2 has the possibility to adopt a CR policy due to the presence of the RFID technology and to share shipment costs with Company 1. The reduction achievable in terms of *TRC* is notable, reaching almost the 48 per cent with respect to the AS IS scenario. It is noteworthy that the interaction of the network and the RFID factors brings to a *TRC* reduction higher than the sum of the savings obtainable when the two factors are applied separately.

These results can be interpreted as follows. The network factor determines setup (i.e. transportation) cost reduction. Indeed, by virtue of the possibility of transportation costs sharing among the companies belonging to the network, it affects the materials management policy only in the cost per shipment (see section 3.1.1.1).

The RFID factor on the contrary affects not only transportation costs but also holding costs. This factor determines the possibility related to the adoption of a CR policy by virtue of the continuous monitoring of inventories. In the healthcare sector, as in many other sectors in which items are expensive, this type of policy would be preferable with respect to the PR policy, because by reducing the uncertainty period it requires lower safety stocks to achieve a determined service level. It is usually not adopted because of the difficulties related to the implementation of continuous monitoring of inventory, and to the high-transportation costs that could occur. Indeed, in CR policy, items reach reorder points in different moments, so that different items can hardly be grouped in the same order. This makes it difficult to share transportations costs among different items.

Therefore, by simultaneously applying both the network factor and RFID factor, the minus of the CR policy (i.e. potential high-transportation costs) is balanced by the low cost per shipment allowed by the network factor, making it possible to maximize the potential savings (Figure 4).

6. Sensibility analysis – the network factor

The network factor is greatly influenced by the value of λ. This influence is analysed by performing a sensibility analysis on λ examining *TRC* for both the scenarios in which the network factor is present.

Table VII shows how the values of the parameters of the PR policy (k_i and S_i) and of the CR policy (k_i, s_i and Q_i) when λ ranges between 0 and 1. Note that the extreme values of the range correspond to two remarkable cases: when $\lambda = 0$ Companies 1 and 2 are in the same place, i.e. they can be viewed as a single company; when $\lambda = 1$ the network factor is not present, because $A = A'$, i.e. each company individually ships its own items. Moreover when $\lambda = 0$, following Equation (7), Q_i should be equal to 0. Of course, by

Table VI. Results from the analytical model and percentage variation compared to the simulation model

Scenario	Calculation methodology	Transportation costs (€/year)	Holding costs (€/year)	RFID investment (€/year)	Thefts and misplacements (€/year)	TRC (€/year)	Annual saving (€/year) (%)
AS IS	Analytical	595 (−0.8%)	6,700 (+5.04%)	–	5,709 (−0.5%)	13,004 (+3.1%)	–
1	Analytical	69 (–)	6,700 (+5.04%)	–	5,709 (−0.5%)	12,478 (+3.3%)	4.0
2	Analytical	2,817 (+6.7%)	3,466 (−1.7%)	4,434	–	10,717 (+1.3%)	17.6
3	Analytical	969 (+21.1%)	1,766 (−2.5%)	4,434	–	7,170 (+2.2%)	44.9

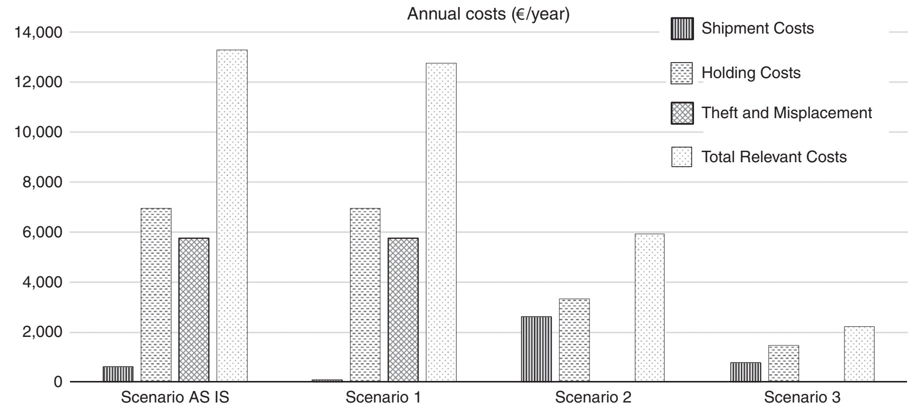

Figure 4. Annual costs in the simulation model

Table VII. Parameters values for each product for the sensibility analysis

	λ										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Scenario 1											
k_1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1	2.1
k_2	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66	2.66
k_3	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07	2.07
k_4	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14	2.14
S_1	64	64	64	64	64	64	64	64	64	64	64
S_2	2	2	2	2	2	2	2	2	2	2	2
S_3	77	77	77	77	77	77	77	77	77	77	77
S_4	50	50	50	50	50	50	50	50	50	50	50
Scenario 3											
k_1	2.94	2.21	2.07	2	1.94	1.91	1.857	1.84	1.82	1.79	1.72
k_2	2.43	2.2	2.04	2.04	1.93	1.93	1.85	1.85	1.78	1.78	1.78
k_3	2.97	2.21	2.09	2.02	1.96	1.91	1.87	1.84	1.81	1.8	1.78
k_4	2.91	2.21	2.11	2.03	1.98	1.94	1.9	1.86	1.85	1.82	1.8
Q_1	1	10	15	18	21	23	25	27	29	31	33
Q_2	1	2	3	3	4	4	5	5	6	6	6
Q_3	1	11	16	19	22	25	27	29	31	33	35
Q_4	1	9	12	15	17	19	21	23	24	26	27
s_1	11	10	9	9	9	9	9	9	9	9	9
s_2	2	2	1	1	1	1	1	1	1	1	1
s_3	13	11	11	11	10	10	10	10	10	10	10
s_4	10	8	8	8	8	8	8	8	8	8	8

applying this value of Q_i the required service level cannot be reached in a real case. For this reason when $\lambda = 0$, Q_i is set equal to 1, the minimum quantity that can be shipped.

From Table VII it is evident how λ does not affect any parameters of scenario 1, because the review period R does not depend on λ but, as previously described, it is fixed. On the contrary, scenario 3 parameters vary with λ: the order quantities Q_i increase as λ increases (Equation (7)); as a consequence, the safety factors k_i, and consequently the reorder points s_i, increase as λ decreases, being $G_u(k_i)$ a monotonically decreasing function (see Equation (15)).

Tables VIII and IX shows results obtained through the simulation and analytical model, respectively. Even in this case, the approximation introduced by the analytical

Table VIII. Simulation output of the sensibility analysis

	λ										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Scenario 1											
No. of shipment	12	12	12	12	12	12	12	12	12	12	12
SC	0	60	120	180	240	300	360	420	480	540	600
HC	6,362	6,362	6,362	6,362	6,362	6,362	6,362	6,362	6,362	6,362	6,362
TheftC	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954	1,954
MisplC	3,680	3,680	3,680	3,680	3,680	3,680	3,680	3,680	3,680	3,680	3,680
TRC	*11,996*	*12,056*	*12,116*	*12,176*	*12,236*	*12,296*	*12,356*	*12,416*	*12,476*	*12,536*	*12,596*
P_{Tot}	99.53%	99.53%	99.53%	99.53%	99.53%	99.53%	99.53%	99.53%	99.53%	99.53%	99.53%
Scenario 3											
No. of orders	1,691.5	176.9	123.3	103.2	88.6	79.9	72.8	67.5	63.2	59.2	56.4
No. of shipment	250.8	137.9	103.6	89.4	78.9	71.9	66.2	62.0	57.7	54.5	52.5
SC	0	689	1,036	1,340	1,578	1,798	1,986	2,170	2,309	2,452	2,627
HC	1,276	1,770	2,050	2,303	2,499	2,699	2,891	3,060	3,219	3,397	3,527
RFIDC	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434
TRC	*5,710*	*6,893*	*7,520*	*8,077*	*8,511*	*8,931*	*9,311*	*9,664*	*9,962*	*10,283*	*10,588*
P_{Tot}	99.1%	99.3%	99.3%	99.4%	99.4%	99.4%	99.4%	99.5%	99.5%	99.5%	99.5%

Table IX. Analytical model output of the sensibility analysis

	λ										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Scenario 1											
No. of shipment	12	12	12	12	12	12	12	12	12	12	12
SC	0	59.5	119	178.5	238	297.5	357	416.5	476	535.5	595
HC	6,700	6,700	6,700	6,700	6,700	6,700	6,700	6,700	6,700	6,700	6,700
TheftC	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903	1,903
MisplC	3,806	3,806	3,806	3,806	3,806	3,806	3,806	3,806	3,806	3,806	3,806
TRC	*12,409*	*12,468.5*	*12,528*	*12,587.5*	*12,647*	*12,706*	*12,766*	*12,825.5*	*12,885*	*12,944.5*	*13,004*
Scenario 3											
No. shipments	1,707	178	124	104	89	81	73	68	64	60	57
SC	0	888	1,238	1,551	1,779	2,004	2,188	2,369	2,530	2,666	2,817
HC	1,202	1,719	2,058	2,285	2,510	2,692	2,869	3,026	3,180	3,341	3,466
RFIDC	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434	4,434
TRC	*5,636*	*7,041*	*7,731*	*8,271*	*8,723*	*9,130*	*9,491*	*9,829*	*10,145*	*10,441*	*10,717*

model seems acceptable, being the gap with *TRC* obtained through simulation very small. As expected, the analytical model tends to overestimate transportation costs (SC), due to the difficulty in distinguishing between numbers of orders and numbers of shipments. In fact, the number of orders does not correspond to the number of shipments. An order is placed every time the inventory position ($IP=$ on hand+on order) reaches the reorder point s_i. If this happens more than one time in a day, orders can be grouped in a single shipment. This occurs especially when the order quantity is small with respect to the daily demand, that is, when λ decreases. All these interactions generate a non-linear relation between the network coefficient λ and the total shipment costs, as shown in Figure 5. This complication is not taken into account by the analytical model.

In scenario 1 it is evident how λ only affects the shipment costs in a linear way. On the contrary, being all the policies parameters independent from λ, the holding costs are constant, as thefts and misplacements costs. The network coefficient λ greatly affects the CR policy (scenario 3). Indeed, λ influences not only the cost per shipment $A'=\lambda A$, but also Q_i and as a consequence the number of orders (equal to D_i/Q_i).

The required service level ($P=99.9$ per cent) is approximately respected both in scenarios 1 and 3. This is due to the assumption related to the demand distribution. In fact, reorder points and order-up-to levels are calculated assuming a normal distribution for the demand during the uncertainty period, which is equal to the lead time L for CR policy, and to $R+L$ for the PR policy. However, in the simulation model, the daily demand is assumed to be exponentially distributed.

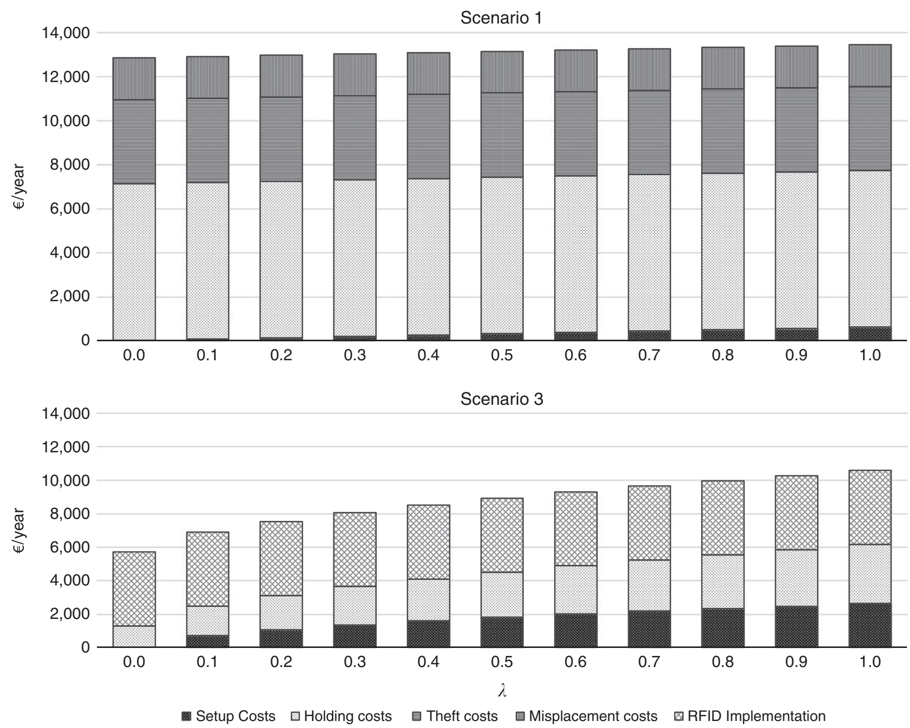

Figure 5.
Periodic review and continuous review total annual cost composition

During the period $R+L$ (scenario 1) the normal approximation can work due to the Central Limit Theorem; on the contrary during the lead time, which is just equal to two days, this assumption generates some inaccuracies.

RFID implementation is convenient for low value of the network coefficient even without considering costs related to misplacements and thefts, as reported in Figure 6, which shows the cost composition for the two different policies varying on λ value. The larger costs in scenario 3 are related to RFID implementation, which, as described in Section 4, are for the majority fixed. Thus, it is reasonable to believe that, considering a greater number of products lines with respect to the case study, the CR policy should be even more convenient with respect to the PR policy.

Note also that increasing the number of companies in the networks should result in decreasing λ, even if distances between them are large. Indeed, it is well known that the savings obtainable by a round trip, instead of a two-ways trip from each company, increases (see Figure 7). In a network perspective total cost per shipment decreases because each new company determines an increase of only one side in the polygon that represents the round trip of Company 1. In other words, the length increment of the total round trip due to an extra-company is only equal to one side of the triangle instead of two sides related to the traditional two-way trip.

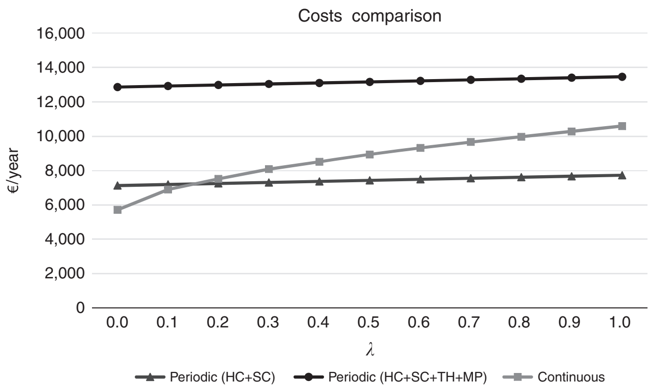

Figure 6.
Total annual costs comparison

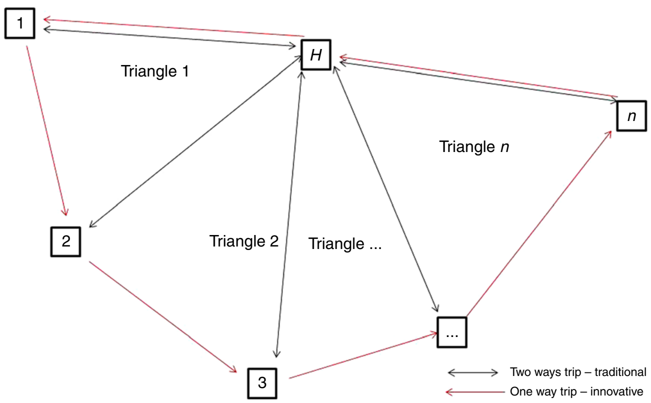

Figure 7.
Roundtrip vs two-way trips

7. Summary

Within the healthcare sector, in which it is necessary to reduce uncertainties related to inventory management, the ability to implement a policy for inventory management without an additional cost burden represents a great accomplishment.

The business model described in this work provides an integrated supplying service for the operating room that proved to be less expensive than traditional models, while maintaining an adequate service level to the patient. In fact, the presence of RFID technology allows the implementation of a CR policy, which is known to reduce the uncertainty period with respect to PR policies. Consequently, relevant savings related to holding costs are achievable. At the same time, the collaborative network of suppliers allows the sharing of transportation costs. In this way, the costs connected to shipments, which are typically high in CR policy, are limited.

Implementation of the RFID factor also permits tracking of all the materials of the OT with no work increase for nurses or surgeons. Moreover, the personnel employed in logistics activities would be relieved from tasks that, as previously documented, do not relate to their core-competencies.

Repeating this model with data related to other configuration permits supporting the VDO in the choice of advantageous inventory management policy.

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 CR 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 1 to the hospital.

This model can be used not only for healthcare network management but also for all the networks in which daily supplies are considered. For example, in the food sector there are many enterprises which provides their products daily.

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