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Measuring the Benefits of Tracking Medical Treatment through RFId

Abstract:

Purpose: Radio Frequency Identification (RFId) technology has great potential to improve process efficiency and effectiveness. However, due to the variety of application areas and achievable benefits, structured assessment models are needed to help managers decide whether to adopt this technology. This paper presents a structured method for evaluating the benefits enabled by RFId in medical treatment support in the healthcare industry and describes its application to an Italian case study.

Design / methodology / approach: The research undertaken for this paper formed the basis for modelling the relationship between the technology and the performance driver for the target process, and between the performance driver and the KPIs for that process. This knowledge has been formalised into 12 causal maps. A 6-step procedure is presented for estimating the benefits of using RFId technology based on these maps.

Findings: The findings are twofold: first, the knowledge represented by the causal maps; and second, the findings of the case study, which shows that efficiency benefits can cover the operative expenses of RFId adoption, but need to be integrated with effectiveness benefits in order to fully justify the investment costs.

Originality / Value: The paper provides useful information for both researchers and practitioners. As to the former, the paper addresses the lack of structured approaches for assessing the potential benefits of

RFId for product traceability at a healthcare facility. As to the latter, the proposed method can be used to help managers evaluate whether to use RFId technology in their organisation.

Keywords: RFId, healthcare, medical treatment, method, benefits evaluation

Article classification: Research Paper

1. Introduction

Nowadays, healthcare systems are facing the challenge of improving their overall performance, thereby attempting to deliver better care services in a more efficient way (Angst *et al.*, 2011). As a matter of fact, health expenditures have risen in all European countries, often increasing at a faster rate than economic growth (OECD, 2011). Increased life expectancy, new medical technologies and increased patient awareness are only some of the factors that are leading to significant growth in health expenditures (Agarwal *et al.*, 2010). In this scenario, Information and Communication Technologies (ICT) have proved to be one of the most appealing tools that can improve the quality of healthcare services and at the same time reduce, or at least control, their costs (Locatelli *et al.*, 2010; Gastaldi *et al.*, 2012).

Among the variety of existing ICT-based solutions that can support healthcare services, interest has recently risen significantly in Radio Frequency Identification (RFId) technologies (Katz and Rice, 2009). The potential of these technologies is huge (Stefansson and Lumsden, 2009; and Kvarnström and Vanhatalo, 2010), and RFId is increasingly considered a valuable tool to support operations (Mo *et al.*, 2009; Lao *et al.*, 2011) and supply chain management (Kumar *et al.*, 2009b; Fabbe-Costes *et al.*, 2009). In this regard, a recent analysis of the role played by RFId in healthcare was presented by Mehrjerdi (2011), whose work is based on reported cases from the industry. The applications cited can be divided into four main categories of use:

- *Patient identification*: RFId enables the reduction of identification errors, thus improving patient safety (Tzeng *et al.*, 2008). Most of the projects have attempted to ensure correct patient identification in the operating room (e.g. Chen *et al.*, 2009), before drug administration (e.g. Lahtela *et al.*, 2008), and to ensure secure mother-infant association;
- *Patient tracking and localisation*: active (or sometimes passive) RFId tags are used to localise patients with impaired cognitive functioning, e.g. Alzheimer (Lin *et al.*, 2008), or to track their

movements within a facility in order to improve the quality and timeliness of services provided (Lahtela *et al.*, 2008; Swedberg, 2010);

- *Asset management*: active or passive RFId tags are applied to critical assets (e.g. beds, medical devices, wheelchairs, portable electro-biomedical equipment) in order to ensure their availability in the right place at the right time (Qu *et al.*, 2011), thus reducing the time spent looking for them, improving their usage (Wicks *et al.*, 2006) and reducing losses (Davis, 2004);
- *Medical treatment support*: RFId tags can also be used to support proper medical treatment with medical items such as blood bags and organic substances, drugs, prostheses and implantable medical devices (Ting *et al.*, 2010). Some applications work by simply tracking the medical item itself, (e.g. Istituto Ortopedico Rizzoli in Italy, RFId-IPO, 2007), whereas others require that both the items and the patients be tagged (cf. patient identification) in order to ensure the accuracy of treatment process (Dzik, 2005; Sun *et al.*, 2008).

Attracted by the benefits potentially derived from these various applications, several healthcare organisations have launched a wide range of pilot projects to test RFId-based solutions. Indeed, full-scale deployment of RFId is expected to provide compelling benefits and competitive advantages to the entire healthcare industry, although several authors (e.g. Mehrherdi, 2011) suggest that some specific application areas for RFId should be examined in order to identify the technological implications and the real benefits associated with its usage. Following this recommendation, this paper focuses on medical treatment support applications, and proposes a structured methodology for evaluating the benefits enabled by RFId in this area. The paper is structured as follows. The main scientific contributions on the evaluation of RFId applications in healthcare are divided into categories in Section 2. Following the presentation of the objectives and the research methodologies in Section 3, Section 4 describes a structured method to facilitate the assessment of benefits. Section 5 provides a detailed description of the results obtained when using the method to assess benefits at a medium-sized Italian hospital. Finally, Section 6 presents the conclusions.

2. Literature Review

Since RFId technologies are receiving more and more attention from both academics and practitioners, the number of papers addressing the evaluation of RFId projects is growing. Whereas early papers in this field mainly dealt with technological issues, e.g. tags and reader performance, attention subsequently turned to the value (i.e. cost, benefits) of RFId-based solutions (Fosso Wamba, 2011; Ngai *et al.*, 2008). Using the classification framework presented by Miragliotta *et al.* (2009), Table 1 lists the available papers in the literature that deal with the topic of RFId enabled benefits in the healthcare industry:

- *Qualitative analyses of the value of RFId,* which describe the strategic implications of applying RFId technologies, provide a classification and usually a qualitative evaluation of the benefits, and sometimes address the implementation process and the ensuing issues (e.g. Dzik, 2005);
- *Quantitative studies based on empirical evidence*, which seek to provide both a classification and a quantitative evaluation of the benefits associated with RFId adoption, relying mainly on case and field studies (e.g. Lewis et al., 2010);
- *Quantitative studies based on structured models*, which aim to develop analytical and simulation models to assess the impact of RFId on performance. Most of the models focus on a limited subset of benefits and do not include a comprehensive evaluation of the profitability of the investment (e.g. Van der Togt *et al.*, 2011).

However, a review of the literature shows that most of the quantitative analyses are based on trial projects of limited scope, and structured assessment models are not only still few in number, but are also mainly focused only on asset management. The final result is that limited guidance is available to healthcare facilities that are considering whether to adopt RFId technologies or not, especially with regard to the more complex implementation scenarios.

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3. Objectives and Research Methodologies

This paper presents a general method that aims to increase knowledge about the potential benefits of using RFId technologies within the healthcare domain, in particular for *medical treatment support*, which has still received limited attention (cf. Section 2). Specifically, the approach proposed in this paper is intended to help managers identify the whole range of achievable benefits, and to understand the main drivers explaining the origin of the benefits themselves, thus helping them to conduct a quantitative evaluation. The research programme was carried out as part of the activities conducted by the RFId Solution Center, the research centre at Politecnico di Milano, Italy, devoted to applied research on RFId (www.rfidsolutioncenter.it).

In order to reach the stated goals, the research program was divided into three phases in which ad hoc methodologies were used.

The first phase was devoted to identifying the most critical performance indicators affected by the introduction of RFId-based solutions in healthcare. Using information from the abovementioned in-depth literature review, the main Key Performance Indicators (KPIs) affected by the adoption of RFId technologies were identified.

The second phase was devoted to developing a structured method for evaluating the benefits of RFId projects in the medical treatment support area. This phase consists of two methodological stages: the first stage is to generate a set of cause-effect maps that highlight, for each previously identified KPI, the set of drivers that affect performance level, while the second stage is to follow a structured 6-step procedure to quantitatively evaluate the impacts of RFId application .

Finally, in the third phase of the research programme, the model was used to assess the benefits to an Italian hospital interested in evaluating the implications of the introduction of an RFId-based smart cabinet to better track and manage medical treatment using implantable medical devices. The well-established case study methodology (Yin, 2003) was used with a twofold purpose: firstly, to validate the usefulness and quality of the proposed assessment approach and, secondly, to help hospital managers to make decisions. The research team conducted nine face-to-face interviews with people working in the hospital (doctors, nurses and purchasing officers from the hospital pharmacy), and collected internal documents on inventory management policies (e.g. reports on orders, product utilisation, inventory levels). The method described in phase 2 was used along with this information to quantify the impact of using the smart cabinet to support the medical treatment process.

4. The proposed method

4.1 Method overview

The proposed method is intended to be used to assess the value of RFId-enabled medical treatment support applications in terms of improving process KPIs, and economic value. As mentioned in Section 3, the method consists of two stages. The first stage focuses on business performance improvements due to RFId adoption; the relationship between RFId adoption and Key Performance Indicators was formalised through a set of cause-effect maps, which will be discussed in detail in Section 4.2. The second stage is a 6-step procedure based on the proposed cause-effect maps that helps decision makers to make use of the maps with respect to a specific situation, and to quantitatively assess the value of the RFId option (cf. Section 4.3).

4.2. Cause-effect maps to establish performance impacts

Based on the literature review conducted in the first phase of the study (cf. Section 2), the KPIs that can be improved by using an RFId-enabled application supporting medical treatment were identified; these KPIs were divided into two main groups, according to their nature: efficiency and effectiveness performance indicators.

Efficiency KPIs refer to cost reductions enabled by typical features of RFId technologies, e.g. the automation of identification activities. These characteristics allow the retrieval of more accurate information in a timely manner, with a positive impact on process accuracy and visibility. The efficiency KPI considered were:

- *Inventory holding costs* (Kinsella, 2003; Lee and Lee, 2010), which include all of the expenses for carrying stock. RFId-based solutions can reduce this cost mainly by reducing the average stock level within the hospital;
- *Inventory control costs* (DeHoratius and Raman, 2008; Panos and Freed, 2007), which are due to the execution of periodic inventory checks. With the enhanced visibility provided by RFId technologies, both the frequency and the unit time needed for this process can be reduced;
- *Ordering costs* (Prater *et al.*, 2005; Tu *et al.*, 2009), which include all of the expenditures incurred when placing an order (e.g. cost of preparing the order, communication cost). Prompt identification of what is needed and the automation of non-value-added activities (i.e. data entry) are the main sources of value related to the implementation of RFId-based solutions;
- *Recall costs* (Sounderpandian *et al.*, 2007), which comprise all of the expenses associated with recalling a product, in relation to both the supplier-hospital relationship (recall campaign notification, batch identification and removal) and the hospital-patient one (specification of those patients on whom the specific device was used, check-up visit, and potential surgery). RFId technology can help to quickly identify the batch of products affected by a recall, allowing an

immediate hold to be put on those items. At the same time, hospital staff can immediately identify those patients affected by the recall;

- *Maintenance Repair and Operations (MRO) costs* (Ng *et al.*, 2006; Ramudhin *et al.*, 2008), which are due to the expense of products consumed, but which do not include the core facility area (e.g. office supplies such as ink and paper). Greater automation enabled by RFId-based solutions prevents over- consumption of these items at the hospital;
- *Theft costs* (Tu *et al.*, 2009; Twist, 2005), which represent the cost of items that have been illegally removed from the hospital. An RFId-based solution can help identify suspicious movements in a timely manner and prevent such events;
- *Labour costs* (Kumar *et al.*, 2009a), which refer to the costs generated by doctors' and nurses' operating activities. An RFId-based solution increases employee productivity, reducing the amount of resources needed to perform specific tasks or, at least, reducing the extra hours paid;
- *Insurance costs* (Ferrer *et al.*, 2010; Lindkvist and Elmualim, 2009; Ngai *et al.*, 2008), which are due to the hospital's need to ensure full or limited compensation for accidental damages.

Effectiveness KPIs are mainly impacted by improvements in visibility, traceability and process control (Caridi *et. al.*, 2010), which are achieved through automation of the data gathering activities enabled by RFId. The selected KPIs are:

- *Patient satisfaction* (Tu *et al.*, 2009), which represents the patients' view of the service provided. RFId usage can improve the service level provided in terms of time dedicated and perceived security of the treatment process;
- *Staff satisfaction* (Fleisch and Tellkamp, 2005), which represents the employees' view of their working experience. Thanks to RFId technologies, workers can achieve greater job satisfaction, concentrating on value-added activities with fewer worries about unintentional errors;

- *Clinical risk* (Ferrer *et al.*, 2010; Oztekin et al., 2010), which refers to the probability of incurring incidents related to hospital practices. The risk assigned to a specific healthcare facility can be drastically reduced by using an RFId-based solution, because of the potential to noticeably reduce errors and improve the overall quality of treatment;
- *Knowledge management* (Vercellis, 2009), which deals with the organisation's ability to identify, create, organise and distribute different forms of knowledge. An RFId-based solution improves the hospital's ability to gather a large amount of useful data, thus developing analyses and reports that can help improve common knowledge.

Using these 12 KPIs, the research team investigated how RFId could improve these measures of process performance: this was done by clearly identifying the relationships between "performance drivers" and "KPIs" through the concept of "RFId enablers". For the sake of clarity, "performance drivers" are defined as those factors that determine the value of a KPI through positive or negative effects, while the RFId features (e.g. automation) that affect "performance drivers" are called "enablers". These relationships have been described in 12 cause-effect maps, one for each KPI, which were purposely constructed to be generally applicable to healthcare facilities interested in evaluating RFId-based solutions for medical treatment support. Therefore, they may be used in their general forms, or they might need to be customised to reflect the specific context that characterises a particular hospital before being used. The maps allow the identification of those KPIs that may benefit from RFId technologies, and they clarify the reasons for the KPI improvements, thus supporting managers' confidence in the results.

For the sake of brevity, only the cause-effect map for inventory holding cost is shown in Figure 1. An explanation of each of the inferred cause-effect relationships shown on Figure 1 is provided in Annex 1, while the remaining 11 cause-effect maps are available upon request.

——— INSERT FIGURE 1 AROUND HERE ———

4.4. Procedure for evaluating performance improvement

As stated previously, the proposed procedure for the evaluation of RFId-enabled benefits consists of six steps:

1. *Qualitative evaluation of the impact on KPI*: an initial evaluation of the impact of the RFId system on each KPI is performed on the basis of the general relationships shown on the standard cause-effect maps;
2. *Selection of a subset of KPIs to be analysed in-depth*: based on the objectives of the healthcare facility's managers and on the output from the qualitative analysis (cf. Step 1), a subset of the most interesting KPIs to be analysed in greater depth is selected;
3. *Cause-effect map customisation*: for the selected KPIs, the general causal map should be customised according to the application context, in order to focus in on the performance drivers that represent a real contribution to the KPI for that specific healthcare facility;
4. *Development of ad hoc analytical models for quantitative assessment of the impacts on the selected KPIs (if needed)*: depending on the nature of the selected KPIs, one or more *ad hoc* models may be developed in order to quantify the related benefits. The customised cause-effect maps represent the framework to be followed in the development of the analytical model, as they allow to take all performance drivers into account;
5. *Application of the models to quantitatively assess the impacts on the selected KPIs*: the quantification of the benefits is carried out using the *ad hoc* models, if developed (cf. Step 4), or - when available - on the basis of common managerial knowledge, i.e. existing standard models;

6. *Estimation of the overall impact (qualitative and quantitative)*: the results of the qualitative and quantitative analyses are combined in order to evaluate the overall impact of the RFId-based solution, and to support healthcare managers in the decision-making process with a complete overview of the impacts of the solution. An analysis of the capital and operational expenditures related to the RFId-based solution is also provided.

This method (i.e. the combination of the general causal maps plus the 6-step customised evaluation procedure) can be helpful to managers as it provides a baseline that takes into consideration the specific healthcare processes and suggests how baseline performance can be exceeded through prioritisation and adaptation. By using this method, even managers with little experience of the technology or of quantitative analyses can not only easily identify the benefit areas, but also identify the type of assistance needed to perfect the assessment.

5. Application of the Method: An Italian case study

5.1. Case Study Introduction

The structured method described in the previous section has been used to evaluate a possible RFId-based solution to improve medical treatment practices within the hemodynamic department at the Policlinico San Matteo in Pavia (northern Italy).

The Policlinico has more than 3,000 beds and serves 2.3 million people. The medical treatment assessed is hemodynamic surgery: in this department, 5.5 surgeries are performed on average every day, but this value is highly variable because of the need to perform emergency surgeries as well. The information and material flows between the “hospital pharmacy”, the “department pharmacy” and the “operating room” (cf. Figure 2 and Figure 3) were examined, with a specific focus on: the department pharmacy stock replenishment process, the department pharmacy receiving process, the operating room stock replenishment process and the product use process. Not all of the products handled at this facility were included in the study, but only a specific subset of valuable and critical items (e.g. pacemakers, rotablator devices, stents and catheters).

The RFId-enabled solution studied was the introduction to the operating room of two smart cabinets and the placement of a desktop RFId reader in the department pharmacy, which can instantly identify and record any medical items consumed or supplied. The smart cabinet is equipped with RFId technology in order to automatically identify the items removed from or added to the cabinet located in the operating room. The cabinet was built using a passive HF RFId technology (Mode 2), with 15 antennae required to monitor a single cabinet. In developing the right solution, it some specific operational issues had to be accommodated, such as not interfering with the X-Ray machine installed in the room or overcoming the issues created by metallic packaging on some products. This RFId scenario required item-level tagging: an RFId tag was applied to every medical device included in the study.

——— INSERT FIGURE 2 AROUND HERE ———

The RFId solution described above enables total visibility on stock, automates the replenishment process and allows real-time tracking of medical items consumed for each surgery performed. Focusing on inventory management, currently, nurses check operating room inventory levels visually and replenish the stock by themselves as needed (Figure 2). Once or twice a month (depending on the product) the nurses generate replenishment orders for the hospital pharmacy. The availability of accurate inventory level data (both for the department pharmacy and the operating room) in a shared database made possible by using RFId technology improves this process by providing a reliable information source and triggering the replenishment process whenever needed (Figure 3). Moreover, this database can also store all of the information about items that was previously listed in the operating room report, thus allowing better tracking of these expensive products.

——— INSERT FIGURE 3 AROUND HERE ———

5.2. Application

Step 1: Qualitative Evaluation of the impact on KPIs

In order to identify the enablers associated with the use of RFId, the researcher team investigated different processes through face-to-face interviews and on-site observations (cf. Section 3). Thus, they assessed the impact of the RFId-based solution on the KPIs based on the standard cause-effect maps (cf. Section 4.2). In the efficiency performance area the KPIs most affected are those related to inventory management (i.e. inventory holding cost, inventory control cost) and the ordering process (i.e. ordering cost). The reason for this is related to the poor visibility that characterises the current scenario, which leads to numerous periodic inventory checks in order to identify current levels of stock and, if necessary, put in a request for replenishments. The other efficiency KPIs were not deemed relevant for this particular hospital: the current overall expense for MRO items is very low and recalls or thefts are not frequent; even the department contribution to labour and insurance is minimal when compared to the total, hence these performance indicators are not critical. Among the effectiveness KPIs, the most interesting is clinical risk, which represents a very crucial issue. In this case, the RFId-based solution helps because it automatically records consumptions and links all devices used in an operation directly to a specific patient. With regard to the other effectiveness KPIs, the satisfaction of both staff and patients embodies hospital objectives, as well as knowledge management, but at a lower priority level with respect to clinical risk reduction.

Step 2: Selection of a subset of KPIs to be analysed in-depth

Based on the results of the qualitative analysis (cf. step 1), the board decided to start investigating the inventory management area, postponing quantification of the benefits in the clinical risk area. Thus, the following steps in the study focused on evaluating the achievable benefits in this performance area.

Step 3: Cause-Effect map customisation

Due to the decision of the hospital board, this activity was performed for the inventory holding cost cause-effect map, shown above in Figure 1. In this example the space cost was removed because it is not affected by the RFId-based solution. Indeed, the hemodynamic department studied is characterised by a single storage room plus cabinet used in the operating room. The storage room cannot be removed or reduced as it holds several medical items other than those affected by the RFId application and, moreover, the empty space cannot be used to store different products. The cabinet will be replaced with an RFId-based cabinet, resulting in no space cost differential. No other maps were customised.

Step 4: Development of analytical (ad hoc) models to quantitatively assess the impacts on the selected KPIs

In order to quantify the benefits related to the selected KPIs (i.e. inventory holding cost, inventory control cost and ordering cost) the research team analysed the inventory management process to determine (i) which activities would be most affected by the introduction of the RFId-based solution and (ii) in what way. The costs related to each KPI were then calculated by analysing the relevant cost subcomponents, which are shown in the related cause-effect maps. The techniques used to estimate these values depend on which inventory management model is used, i.e. fixed time period model (FT, which is the model currently used at the hospital given the current level of visibility on inventory) and the economic order quantity model (EOQ, whose adoption is enabled by the increased reliability of inventory data due to the adoption of the RFId-based solution). Thus, the inventory holding cost was evaluated using these standard models, notwithstanding a few adjustments that were needed to meet some specific hospital requirements. In addition, the research team developed an *ad hoc* model for the evaluation of both inventory control and ordering costs. Table 2 introduces the nomenclature used throughout this paper, while the *ad hoc* model equations are presented below. The annual ordering costs

(1) that the hospital has to pay are determined by the unit order costs (composed of labour and fixed costs) multiplied by the frequency of the reordering process. Of course, the frequency differs according to the inventory management model used. Similarly, annual inventory control costs (2) depend both on the frequency of controls and unit control costs (determined by labour expenses).

$$C_{o,p,x} = \left(Ta_{o,p,x} * Clab_h + FC_{p,x}\right) * F_{o,p,x} \qquad (1)$$

$$C_{ic,p,x} = Ta_{ic,p,x} * Clab_h * F_{ic,p,x} \qquad (2)$$

——— **INSERT TABLE 2 AROUND HERE** ———

As stated previously, to calculate the inventory holding costs, standard models with few adjustments were used: therefore, to calculate the annual holding costs (3) for a *p* product, it is sufficient to add the yearly amount of its subcomponents, which are: insurance, obsolescence and capital costs. According to the customised map (cf. step 3) the fourth inventory cost component, i.e. space cost, was not included as it is not differential for the hospital.

$$C_{ih,p,x} = C_{ins,p,x} + C_{obs,p,x} + C_{fin,p,x} = c_{ih,p,x} * AI_{p,x} \qquad (3)$$

Where:

$$C_{a,p,x} = c_{a,p,x} * AI_{p,x} \qquad a = ins, obs, fin \qquad (4)$$

The average inventory level is determined by the sum of working and safety stock, calculated using the standard model formulations. An in-depth analysis of the existing articles and their rate of consumption (daily demand) was carried out for each product category, in order to identify whether increased visibility can permit a reduction in stock; however, there are some products, most importantly rotablators and pacemakers but also certain models of stents and catheters, for which stock cannot be reduced due to internal agreements regarding emergency service level: for the sake of clarity, these categories have been defined as “untouchable”. The achievable benefits were assessed by comparing the best stock levels calculated with the current ones.

STEP 5: *Application of the models to quantitatively assess the impact on the selected KPIs*

In order to assess the impact on inventory holding costs (reduction of the stock levels due to greater visibility on consumption and available stock inside the cabinet) and on ordering costs (reduction of processing time), the proposed model was initialised using hospital data (Table 3).

——— INSERT TABLE 3 AROUND HERE ———

As previously stated, the pacemaker and rotablator device categories were assumed to be “untouchable” with respect to current stock levels; nonetheless, the daily demand for catheters and stents is sufficiently high to allow some room for improvement, and therefore a maximum 45% reduction over the current inventory levels has been estimated by the researchers. These limitations on inventory reduction impacted the achievable benefits, however the safety requirements of the healthcare process were necessarily given priority over the financial benefits.

Table 4 presents the annual cost reduction that can be achieved by using this technology given the two different inventory management scenarios.

——— INSERT TABLE 4 AROUND HERE ———

In the fixed time period scenario, the hospital can save more than 18% of its current expenses, and could achieve an even better result by using an economic order quantity model (savings of up to 27%). If the hospital continues to manage its inventory using its current approach, it can reduce the holding cost related to the products included in the study by 16%. This result is a combination of the 40% savings obtained considering only the “touchable” categories and the null savings on “untouchable” medical items. As stated previously, additional benefits could be achieved with an EOQ scenario, where the inventory holding cost can be decreased by 32% (in this case it is almost 50% for the catheters and stents categories). The main factors responsible for this result are the zeroing of the obsolescence cost and an equal reduction in insurance and capital costs respectively. It is even possible to achieve an important reduction for the inventory control process, due to the elimination of inventory checks: in both scenarios the hospital can save up to 83% on this process. Savings related to the ordering process are minimal in the FT model (1.54%), while they are non-existent in the EOQ model (the specific expense is increased by 114%). In general, excellent results can be achieved in both scenarios, although there is a greater impact using the EOQ model, despite the increased ordering cost.

Step 6: Evaluation of the overall impact (qualitative and quantitative)

The estimated initial investment for the technological solution proposed is €17,000, which includes two smart cabinets, a desktop RFId reader and all of the expenses needed for the software integration and optimisation process. There are also some operative expenditures totalling €2,300 annually, mostly tag purchases, which are comparable to the operative benefits expected. Therefore, the benefits calculated previously are not sufficient to cover the investment required to realise the project. This means that an evaluation of clinical risk reduction and other effectiveness performance indicators identified in Step 1 is needed, in spite of the managers’ priorities identified during the qualitative assessment steps. Although these results are representative of this particular hospital setting, similar results have been obtained in many other businesses (cf. Balocco et al., 2011), where the monetary benefits derived from efficiency gains are insufficient to recover the initial investment made to adopt the technology.

Evaluation of the method

The case study was conducted by the research team whose aim was to help the managers make a decision about the adoption of the RFId technology. The input data required was gathered with help from both the managers and employees at the hospital. The researchers checked with the managers that the method and the results were in line with their expectations. According to the feedback acquired, the method was relatively easy to use, since the information required to create the causal maps was available, and users found the causal maps very helpful when making their decisions. Hospital staff (both employees and managers) were involved in the application of the methods, and, therefore the results were shared, making them aware of the benefits of this technology and thereby reducing one of the typical barriers to technology adoption (i.e. lack of understanding of the benefits) . One of the main advantages of the method is that it helps hospital managers not only to assess, but also to understand, the benefits, using their considerable knowledge of the processes and involving them from the start in assessing the impacts of the technology.

The main drawback of the method is the need to develop "ad hoc" models (as shown in Step 4) in order to assess the benefits, which makes it difficult to use without support from researchers/consultants, as specific expertise is required to develop analytical models. In order to make the method more accessible, standard models should be developed so that it can be applied in complete autonomy by the final users.

6. Conclusions

This paper presents a method for investigating the impact of RFId-based solutions on medical treatment support in the healthcare context. A structured method was developed, which furthers the scientific research effort invested in this topic to-date, and which fully supports the management team in the decision-making process. The purpose of this work was to remedy the existing lack of structured approaches concerning the evaluation of the potential benefits of using RFId technology for medical treatment support within a healthcare facility. In order to do so, the existing literature was reviewed and analysed, a complete set of causal maps was developed, and a 6-step procedure was defined to support the decision-making process. The method proved to be a useful tool that can be used by managers to identify the performance indicators affected by the introduction of RFId, and to choose which ones to analyse more closely, based on their relative importance and the potential magnitude of their impact.

However, the proposed method has a few limitations. One limitation is related to the correlation between the technology itself (i.e. the design of the specific tag + reader + antenna solution) and its economic impact. In this work it has been assumed that 100% reading accuracy is always achieved, while this may not be true in reality and should therefore be taken into account when modelling the relationship between RFId enablers and performance drivers. A second limitation is that the methodology does not include an explicit method for combining monetary and non-monetary benefits (such as effectiveness improvements). Although several papers in the literature deal with multi-objective decision-making, this limitation could be explicitly addressed to better match the method with the managerial skills in the healthcare industry.

The next phase of the research programme involves extending the method to other application areas from amongst those listed in Section 1 (patient identification, patient tracking and localisation, asset management). The authors believe that the proposed 6-step procedure can easily be adapted for the evaluation of RFId-based solutions in the other application areas, although new cause-effect maps will need to be developed.

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Annex 1

——— INSERT TABLE A1 AROUND HERE ———

Table 1. Literature Review on RFId Benefits in Healthcare

Application area	*Author*	*Article contribution*		
		Qualitative approach	*Quantitative analyses based on empirical evidence*	*Quantitative studies based on structured assessment models*
Patient identification	Cavalleri *et al.*, 2004	X		
	Wicks *et al.*, 2006	X		
	Fuhrer and Guinard, 2006	X		
	Liao *et al.*, 2006	X		
	Sun *et al.*, 2008		X	
Patient tracking and localisation	Cangialosi *et al.*, 2007	X		
	Marjamaa et al., 2006		X	
	Tzeng *et al.*, 2008		X	
	Chen *et al.*, 2009		X	
Asset management	Fry and Lenert, 2005		X	
	Mun *et al.*, 2007		X	
	Kumar *et al.*, 2009c			X
	Laskowski *et al.*, 2010			X
	Oztekin *et al.*, 2010		X	
	Qu *et al.*, 2011			X
Medical treatment support	Dzik, 2005	X		
	Lewis *et al.*, 2010		X	
	Van der Togt *et al.*, 2011			X

Table 2. Nomenclature

Parameter	*Description*
A	Set of possible inventory cost elements (a), i.e. insurance (ins), obsolescence (obs) and capital cost (fin)
P	Set of possible product categories (p), i.e. stent, catheter, pacemaker, rotablator
X	Set of possible inventory management models (x), i.e. fix time period (FT), economic order quantity (EOQ)
Z	Set of possible processes (z), i.e. inventory holding (ih), inventory control (ic) and ordering (o)
$AI_{p,x}$	Product *p* mean inventory level in the *x* inventory management model
$C_{a,p,x}$	Yearly cost element *a* per product *p* category when the *x* model is adopted
$C_{z,p,x}$	Yearly cost of process z per product *p* category when the *x* model is adopted
$Clab_h$	Hourly labour cost
$F_{z,p,x}$	Process *z* frequency for product *p* category when the *x* model is adopted
$FC_{p,x}$	Fixed ordering cost for product *p* orders when the *x* model is adopted
O_p	Set of items belonging to the *p* product category
$Ta_{z,p,x}$	Time needed for labour activities in the *z* process for product *p* category when the *x* model is adopted

Table 3. Input Data

Input parameter	*Device*			
	Catheter	*Rotablator*	*Pacemaker*	*Stent*
Average value [€/unit]	30	700	1,200	840
Average daily consumption [unit/day]	6.73	0.18	0.94	6.85
Daily consumption deviation [unit/day]	3.36	0.33	0.89	3.01
As is average inventory level [unit]	300	12	30	200
Max allowed stock reduction (due to service level constraints)	45%	0%	0%	45%
Hospital average lead time [days]	1.5	1.5	1.5	1.5
Supplier average lead time [days]	3.25	3.25	3.25	3.25
Hospital Lead time deviation [days]	0	0	0	0
Supplier Lead time deviation [days]	0.5	0.5	0.5	0.5
Unit insurance cost [€/unit]	0.3	7	12	8.4
Obsolete items [unit/year]	10	0	0	0
Time needed for inventory control [hours/control]	3	0.25	0.5	1
Days between two inventory controls [working days]	130	130	130	130
Time needed for ordering process [hours/order]	0.3	0.3	0.3	0.3
Fixed time ordering period [days]	10	10	10	20

Table 4. Hospital Benefits

	FT Scenario	*EOQ Scenario*
Total cost reduction	2,000€ (18%)	3,000€ (27%)
Inventory holding cost reduction	1,600€ (16%)	3,300€ (32%)
Insurance cost reduction	*300€ (13%)*	*700€ (30%)*
Obsolescence cost reduction	*300€ (100%)*	*300€ (100%)*
Capital cost reduction	*1,000€ (13.51%)*	*2,300€ (30%)*
Inventory control cost reduction	400€ (83%)	400€ (83%)
Ordering cost reduction	0€ (1.54%)	–700€ (–114%)

Table A1. Explanation of assumed cause-effect relationships in Cause-effect map #1

Arrow beginning	*Arrow tip*	*Type of impact*	*Description*
Automation	Time spent for the reordering process	–	A higher automation level can reduce the manual activities carried out in the reordering process (e.g. product identification) and therefore the required time
Computerisation	Time spent for the reordering process	–	A higher computerisation level (e.g. data automatically available) can help perform some activities without human intervention, thus reducing the total time required
Computerisation	Order processing lead time (supplier)	–	An increased computerisation level can reduce the order processing lead time because most of the elaborations can be done in a shorter time even by the supplier
Time spent for the reordering process	Cost of placing an order	+	An increased automation of the process allows a reduction in the cost of placing an order
Time spent for the reordering process	Procurement Lead Time	+	The longer it takes to process an order, the later an order is filled
Order processing lead time (supplier)	Procurement Lead Time	+	The longer it takes to process an order, the later the supply is fulfilled
Cost of placing an order	Ordering cost	+	The cost of placing an order contributes to the total ordering cost
Cost of placing an order	Re-order frequency	–	The more expensive placing an order is, the more a hospital tries to reduce the number of orders placed
Procurement Lead Time	Safety stock	+	The longer it takes to obtained a product, the greater the safety stock level is, in order to handle emergencies
Re-order frequency	Order quantity	+	Given a constant demand, more orders are placed, less quantity is ordered each time
Order quantity	Working stock	+	The smaller the order quantity is, the less is stored
Inventory visibility	Average Inventory level	–	Inventory visibility allows a better control on stock, diminishing the overall level
Inventory	Demand	+	A better knowledge about stock movements (actual demand

visibility	forecast accuracy		data) is essential for accurate demand forecast
Demand forecast accuracy	Average Inventory level	–	A better knowledge about product allows a better purchase planning process, which has the consequence to reduce stock as well
Inventory visibility	Alert for unemployed products	+	A better control on stock movements can effectively alert for unemployed products
Inventory visibility	Check on expiration date	+	A better control on stock movements can effectively alert for almost expired products
Check on expiration date	Total waste	-	Effective alerts for almost expired products can reduce the total waste collected by the hospital, since the unemployed item can be replaced or used
Alert for unemployed products	Total waste	–	Effective alerts for unemployed products can reduce the total waste collected by the hospital, since the unemployed item can be replaced or used
Total waste	Obsolescence cost	+	The amount of waste produced (lost products) affects the obsolescence cost financed by the healthcare facility
Average Inventory level	Obsolescence cost	+	The more products are stored, the less funds are available for other investments
Avg. Inventory level	Space cost	+	The more products are stored, the more space is required
Avg. Inventory level	Capital cost	+	Capital invested in inventories cannot be used for other investments
Avg. Inventory level	Insurance cost	+	The more products are stored, the higher the overall insurance cost is
Obsolescence cost	Inventory holding cost	+	Obsolescence cost is a component of the inventory holding cost
Space cost	Inventory holding cost	+	Space cost is a component of the inventory holding cost
Capital cost	Inventory holding cost	+	Capital cost is a component of the inventory holding cost
Insurance cost	Inventory holding cost	+	Insurance cost is a component of the inventory holding cost

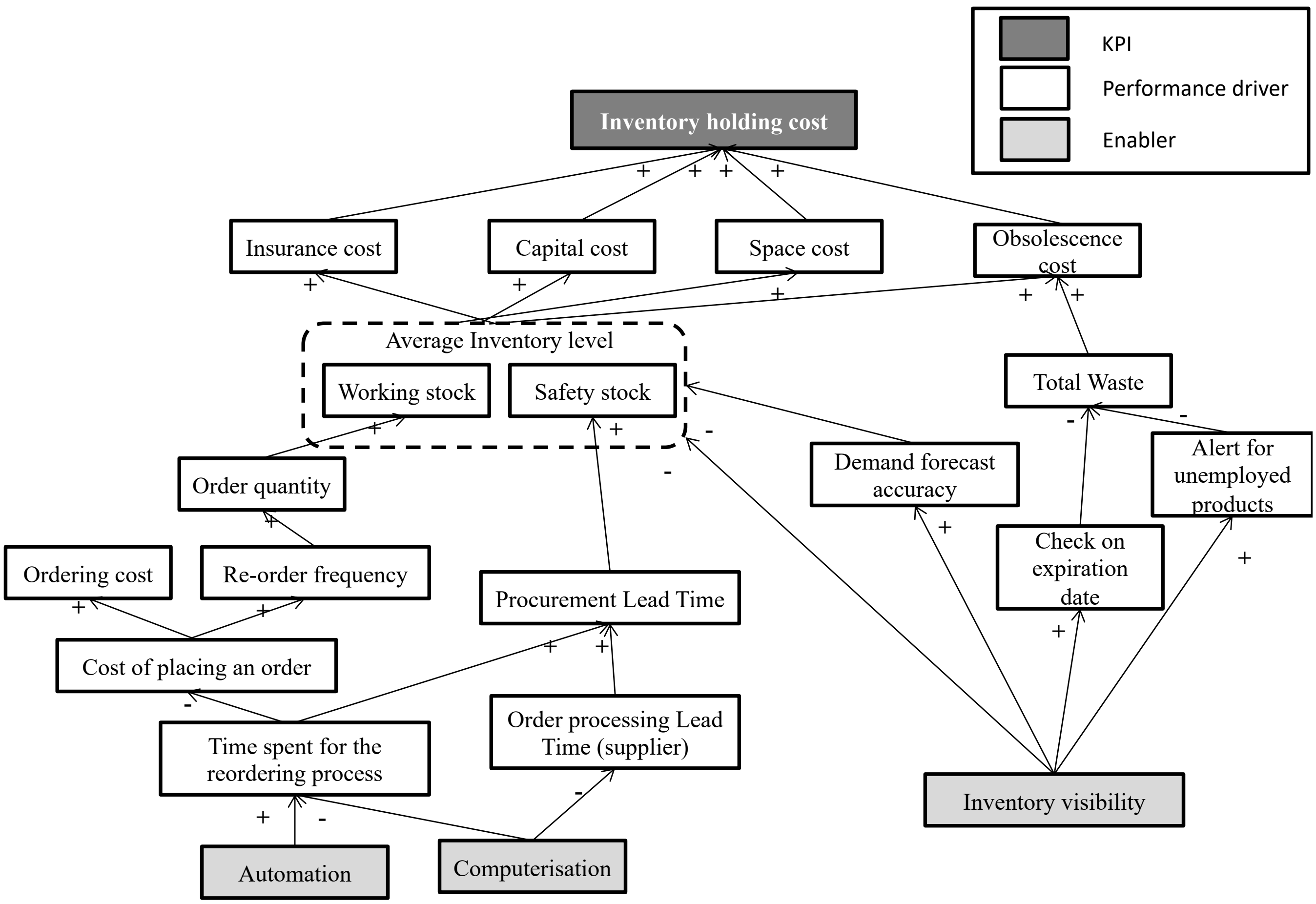

Figure 1: Cause-effect map #1 - The Inventory Holding Costs

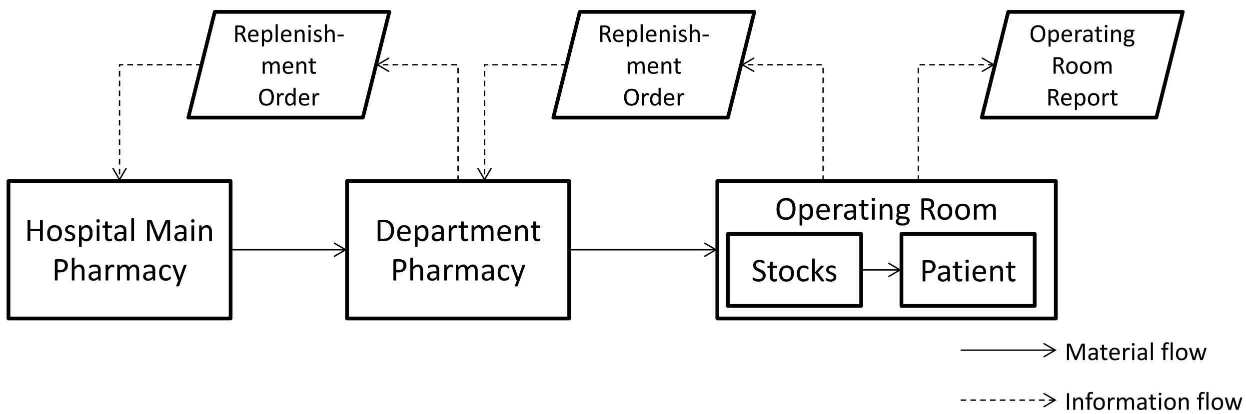

Figure 2: “As Is” Material and Information Flows

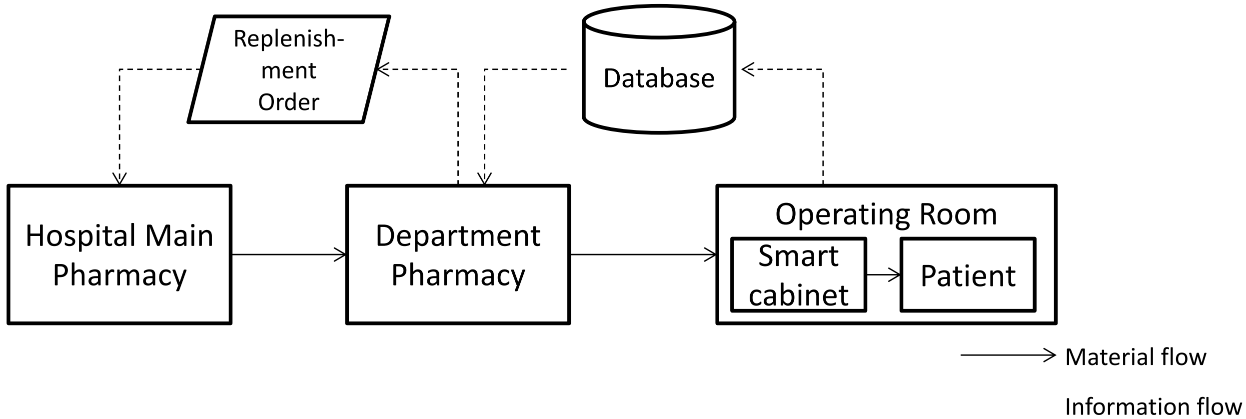

Figure 3: “To Be” Material and Information Flows