Assessing the prevailing implementation issues of RFID in healthcare: A five-phase implementation model

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***Abstract*—** In healthcare, supply and demand of medical devices and equipment pose enormous challenges for material managers who have to ensure that "the right equipment" is at "the right moment" at the "point-of-need". Every year hospitals lose millions of dollar due to hoarded, lost, stolen, and misplaced medical equipment. This lack of visibility on critical medical assets has led to increase of operations inefficiencies, increase in needed resources and budgets, loss of staff valuable time, as well as delays in patient care delivery, generating patients and staff dissatisfaction and potentially affecting patient flow and safety. Radio frequency identification (RFID) is rising as an enabling technology to facilitate asset management in healthcare, where caregivers continually use thousands of medical devices across multiple clinical departments. RFID proven capabilities to automatically and capture, share and synchronize product's information, as precise as at the item-level, is giving rise to new paradigms for the management of critical and life-saving medical equipment in hospitals. Even tough RFID seems to be a very promising technology; its adoption and implementation in this sector have been hindered by the haziness of RFID projects' ROI. Through a case study at a European hospital, we intend to assess the suitability of a proposed RFID implementation model to evaluate the various implications of RFID projects, the prevailing implementation issues, as well as to investigate the anticipated benefits of such implementation.

***Keywords*—**healthcare, mobile asset management, key performance indicators, RFID implementation.

I. INTRODUCTION

THE healthcare sector faces challenges like no other industrial sector, since any mistake, any system inefficiency could put in peril people's lives. Consequently, the number one priority of healthcare systems is to ensure prompt and safe care delivery to patients. In order to do so, they need to have access to necessary human, material, informational and financial resources at the point-of-care. However, management, synchronization and alignment of diverse flows necessary to effectively operate healthcare systems is very complex. Healthcare facilities, in developed as well as in developing countries, are continuously facing a multiplicity of challenges including medical errors, lack of necessary resources, inefficient workflows, inefficient information management, process disparities, as well as a disintegrated healthcare logistics; affecting patient safety and contributing to a rise in current spending. Healthcare is going through a dramatic transformation in order to respond to the demands of the new century and fight error in medicine. The future of healthcare seems very turbulent; hence, stakeholders in this industry are prompt to pursue suitable actions and integrate best practices into their operations to overcome the myriad of challenges increasingly faced by healthcare systems, become more efficient and improve medical outcomes.

Healthcare organizations (HCOs) could achieve substantial savings by learning from and embracing technological strategies undertaken by leaders in other industries [1, p.545]. In an effort to address the core mission of healthcare organizations and reduce the occurrence and impacts of medical errors, a more advanced use of information technology (IT) at clinical and managerial levels has been suggested [2], [3], [4], [5]. Enabling technologies are perceived as strategic assets could play a pivotal role to ensure continuity of care and quality of services delivered, increase patient safety, increase the efficiency of personnel, enhance customer service, reduce organization expenditures, preserve patients' trust, successfully attain organizational goals and objectives [4], [6]–[8].

In spite of the global widespread of IT integration in many vertical markets, healthcare has traditionally lagged behind other service industries when it comes to implementing innovative IT [5], [8]–[13]. However, the implementation of several IT applications, including applications for digitizing medical records and clinical data [13], have generated documented benefits, such as the reduction of operating costs, the improvement of operational efficiencies, the increased of productivity, the automation of processes, and elimination of waste and duplication [14].

During the last decade, governments have acted as important drivers for IT adoption through the promotion of several initiatives. For instance, the NHS Connecting for Health Agency in the UK has led the National Program for IT (NPfIT), which corresponds to most substantial IT investment in England [15]. According to Natarajan [10], the US federal government has played as well an essential role in the application of health information technology (HIT). Back in 2004, President George W. Bush pointed out the need for nationwide adoption of HIT within the next 10 years [16]. In the US alone, healthcare investments in IT could result in cost savings in the order of $140 billion a year by 2014 [17].

Innovations in the field of mobile technology are opening new opportunities to prevail over some of the current pressures faced by healthcare and their applications have therefore grown considerably. Radio Frequency Identification (RFID), a wireless automatic identification technology [18], [19], is rising as the “next disruptive innovation in healthcare” [20], and is believed to be able to bring about an “industrial revolution” just like the Internet and the barcode did some decades ago [21].

The healthcare industry is becoming an important market niche for RFID implementations as it generates several potential benefits including the improvement of patient safety [22]–[28]. A wide range of RFID applications has been used in different hospitals around the world to ensure patient identification [29]–[31], medication management and safety [32], [33], specimens identification and tracking [34], blood derivatives tracking and blood supply chain management [35], newborns identification and tracking [36], staff identification and location [37], and response to mass casualty and pandemics [38], [39]. In particular, a lot of interest is given to the area of material and asset management, which is becoming the mainstream application of RFID in healthcare facilities [6], [40], [41]. The interest in RFID has not only been from academics [42]. Practitioner communities have also realized the great potential of RFID and are advocating its usage. In Mexico, the federal health-insurance program mandated manufacturers and distributors to embed RFID tags on drugs sold to the millions families covered under this insurance program [43]. Also, in the US, the Food and Drugs Administration (FDA) has advocated the use of RFID in an attempt to “improve the safety and security of the nation's drug supply” [33], [44].

Despite the importance given to RFID in this sector, there is a lack in knowledge with respect to the necessary implementation model to support its adoption and evaluate its value. We therefore aim to bridge this gap by assessing the prevailing issues, benefits, implications and limitations of implementing RFID in hospital settings to manage strategic mobile medical equipment. Consequently, the research approach privileged is a detailed *longitudinal exploratory case study*. This paper is organized as follows. In the next section, we present a brief overview of RFID and its implementation in healthcare while the third section analyses the conceptual context of this research. Section 4 provides essential information on the methodological approach. Results are presented and discussed in section 5 whereas section 6 presents some concluding observations.

II. Technical context: RFID technology

RFID is considered “the latest and most advanced” Automatic Identification technology (AIDC) [19] due to its particular capabilities to identify, locate, track and trace in real-time objects across the extended supply chain. Various technologies fall under the AIDC family, including optical recognition, biometrics, card technology, contact memory technology, bar coding and RFID technology.

Bar coding is the most commonly used technology for product identification. However, RFID is perceived as a more efficient and effective technology with many proclaiming it as the next generation barcode [45], [46]. In contrast to bar coding that allows only identification of “class of goods”, RFID permit unique “item-level” identification ensuring availability of real-time information on single physical objects or persons. However, the most distinctive difference between these technologies is that RFID is a non-line-of-sight technology [19]; hence, RFID tags do not need to be “seen” by the readers or “be” in direct presence of the reader to be detected; they only need to be within reader’s reading range. This offers particular opportunities for operational improvement in environments where several items circulate at the same time [47], as RFID open the door to simultaneous reading of numerous tags, with some authors reporting that as many as 1000 RFID-enabled items could be read in a bit over 1 minute and a half [48]. Moreover, with RFID information programmed in the tag can be overwritten as the RFID-enabled object move along its life cycle activities. Besides, RFID has the capability to cope with harsh environments, where barcodes would not endure due to their lack of durability, thus overcoming some barcoding readability issues [45], [49], [50].

The term RFID refers to a set of technologies that uses radio frequency to transmit information [19]. An RFID system consists of multiple components including RFID tags, RFID readers, and the RFID middleware. RFID tags have a chip and antenna, which allows data transmission to readers via electromagnetic radio waves. RFID tags can be classified as passive, semi-passive, and active, which are suitable for different applications. Passive tags do not have a power source; thus, rely on RFID reader’s electromagnetic field to trigger signal transmission. On the other hand, active tags have an internal power source used for signal broadcast. In recent years, hybrids RFID systems are emerging, which combine RFID with other technologies such as IR, sensors, GPS, GSM, and GPRS telecommunications [51], [52]. In a healthcare environment, various RFID technologies may share a place and play complementary roles. For instance, active RFID will be more likely used when looking at tracking mobile medical equipment [6], whereas passive tags will be often seen attached to medications and laboratories specimens [34]. Some hospitals had as well opted for hybrid solutions for various applications including patient tracking [52].

RFID readers are responsible for information retrieval and acquisition, allowing information flow between the tags and the host system by means of the RFID middleware. Readers’ antennas emit and receive radio signals activating tags and capturing the data stored in them. Readers are composed of various subsystems, including the reader API, which permits the capture of RFID tag events; the communications component that handles networking functions; as well as the event management module that oversees the data captured [53].

The RFID middleware is key element of the RFID system, which is responsible for filtering and processing the raw data gathered through readers, and then routing useable data to the appropriate existing enterprise application systems [54], such as hospital information system (HIS), and patient management systems in healthcare settings. RFID make possible to seamlessly integrate data captured through RFID hardware components with backend databases and applications, as well as decision support system, here is where the real value of implementing RFID lies [11]. It is important to take into consideration that a high volume of data would be collected through an RFID system, which could pose many challenges on existing data management systems. Hence, in order to achieve the utmost value from RFID it is critical to ensure the transformation of raw data obtained via RFID tags into useful information [55].

III. Conceptual context

A. *RFID adoption in the healthcare sector*

Healthcare facilities turn to RFID in order to better manage assets, improve inventory management, prevent newborn abductions, ensure optimal patient medication management to avoid errors, keep mentally impaired patients from walking away unnoticed, track and match blood for transfusions, track pharmaceutical supply chains to combat counterfeiting, improve business processes and workflows, and the list goes on [6], [22], [28], [56]. Studies interrelated to RFID applications and impacts in healthcare related activities are mainly case studies, conceptual papers and simulations.

Several case studies have been reported in the literature. For instance, Wang and co-authors [38], presented results from the RFID feasibility project at a Taiwanese hospital to combat SARS. The project demonstrated the feasibility of RFID in hospitals, but also highlighted the presence of technical difficulties, as well as difficulty on persuading medical professionals to accept and use the system. Kannry et al. [57] describe a study at a US hospital designed to measure the effectiveness of using RFID for bed management. Janz et al. [58] report on results from a “proof of application” and outline that RFID can support the measurement and control of workflow processes in hospitals and provide timely business intelligence for the healthcare optimistically impacting the quality of care delivered. Furthermore, some simulations have also been carried out to measure the value of RFID in this sector [59], [60].

In addition to the above mentioned empirically based articles, some conceptual papers have been published and include among others the work of Ngai et al. [27] that proposes the architecture for an RFID-based healthcare management system that is intended to reinforce patient and medication safety, improve inventory management of pharmaceuticals, as well as improve patient identification and in-hospital tracking processes. Kumar et al. [22] suggest a three-stage implementation approach for RFID adoption in healthcare environments. Tzeng et al. [61] offer a framework for evaluating the business value of RFID technology within healthcare activities drawing on the experience of five early adopters from the Taiwan healthcare industry. Aguado et al. [62] present a review paper illustrating how the application of RFID in healthcare can enable this industry to overcome existing technological and workflow limitations. Chen et al. [63] study key factors that contribute to the intention to continue using RFID. Results show that perceived usefulness of front-end interoperability and performance expectancy have significant relationships with confirmation experience; confirmation experience has a significant relationship with satisfaction, which in turn relates to intention to continue using RFID.

Though many papers point to numerous potential benefits of RFID applications in healthcare (Table I), there is still an important knowledge gap regarding the prevailing issues raised by the implementation of RFID applications in healthcare organizations and the actual measurable and realized benefits generated by such implementation. As stated by Ngai and co-authors, “the design and implementation of an RFID system is not a simple and straightforward process” [64, p.2585]; yet a number of RFID implementation frameworks have been proposed in the literature [49], [64], [65] and many RFID-based projects have been developed in a broad range of industries. For instance, Ngai et al. [64] propose an RFID implementation framework that was evaluated through a case study in the textile industry, which spans over seven stages, from project feasibility and scoping (stage 1), project team formation (stage 2), ‘AS-IS’ assessment (stage 3), process redesign (stage 4), hardware adaption to the environment (stage 5), system implementation (stage 6), to continuous improvement (stage 7). This paper intend to bridge this gap, hence an implementation model for RFID undertakings in healthcare settings is presented in details in subsequent sections.

B. *Finding value for RFID adoptions in healthcare*

IT is perceived as enabler for the improvement of care delivery, the enhancement of operational efficiency, the reduction of organizational expenses, and the achievement of competitive advantage [7]. However, creating business value from investments in such technologies has been for long a great concern to organizations and represents a prominent inhibitor factor for their adoption [66], particularly when adopting emergent technologies such as the case of RFID. It is reported in the literature that RFID could potentially offer great benefits for healthcare organizations, even outside the boundaries of a hospital to benefit the extended healthcare supply chain as well [6], [61], [67].

As demonstrated in Table I, the prospective benefits of RFID technology comprise a wide range of tangible benefits, including reduction of operation costs, reduction of manual operations, improvement of healthcare efficiency; as well as a great deal of unquantifiable benefits, making a holistic assessment of its economical profitability a very difficult task [24], [47], [48]. Accordingly, the business case behind RFID implementation is very hard to demonstrate. Many have the perception that RFID is too expensive to deploy [41], [57] since the actual cost of RFID integration is not only limited to hardware (e.g. tags and readers) and software components of the RFID system, in fact, the true investment goes well beyond that. Smith and Konsynski [68] identified a range of costs related to RFID implementation, including cost of tag and readers, cost of embedding the tag into products, cost of installing readers, cost associated to systems integration, cost of training the personnel and re-organization, as well as the cost of implementing application solutions. HCOs work with limited budgets and face great scrutiny regarding the way they use and allocate their resources. Consequently, stakeholders within the healthcare arena question whether an investment in RFID could be justified since a multitude of the benefits offered by this technology are intangible, and therefore cannot be simply measured through traditional methods (e.g. return on investment: ROI) [69], [70]. Given the intrinsic complexity to quantitatively assess the return on investment of RFID adoption projects, a significant number of organizations prefer not to get involve in early stages of the RFID adoption cycle, instead they would rather learn from the experience of early adopters, and possibly become involved during the later stages of innovation diffusion as “late majority” and “laggards” [71]. In order to ascertain the real benefits of IT implementation, Clemons [72] advocates the need to evaluate, during pre-investment stages, tangible and intangible benefits of the targeted IT implementation in order to transform these un-quantifiable benefits into financial metrics [69], [72].

TABLE I
POTENTIAL RFID BENEFITS IN HEALTHCARE

Benefit type	Benefits	References
Direct / Tangible	-Increased patient safety	[4], [22], [24], [29], [35], [55], [56], [60], [62], [67], [70], [75]
	-Improved patient identification and location in case of health crisis	[28], [38], [39]
	-Increased patient satisfaction	[22], [23], [55], [56], [70], [75]
	-Enhanced clinical services quality	[4], [22], [23], [55]
	-Cost savings	[6], [22], [23], [55]
	-Improved asset visibility, and utilization	[6], [23], [28], [55]
	-Improved inventory management	[4], [22], [28]
	-Improve drug management and administration	[6], [23]
	-Improved healthcare supply chain	[55]
Indirect / Intangible	-Improved business process and workflows	[4], [6], [22], [56], [58] [60], [61], [70], [75]
	-Improved information flow and visibility	[6]
	-Reduced clinical staff frustration	[6], [67], [74]
	-Gained competitive advantage	[70], [75]

Even though the business value of RFID adoption in healthcare still somewhat uncertain, some studies have investigated the expected benefits or anticipated advantages that RFID can offer to healthcare organizations. Let us mention the work of Evans and Piechowski [73] that identified that most of US healthcare industry believed that RFID technology could improve patient safety, business process and productivity. Castro et al. [6] discuss how RFID holds the potential to improve visibility and management of critical mobile assets, to eliminate non-value added activities and to generate intelligent processes. Wang et al [38] highlight three potential benefits of RFID adoption in Taiwan hospitals, including reduction of cost and time, improvement of patient safety and medical services. Zhou and Piramuthu [24] point some unquantifiable benefits of RFID such as safety and security, as well as better tolerance for longer payback periods. Castro et al. [6], [74] discussed how a better level of visibility of assets contribute to intangible benefits such as the reduction of clinical staff frustration, and the improvement of organizational climate and work conditions. Other authors have discussed the potential of RFID to enhance customer satisfaction, gain competitive advantage, improve patient safety, improve patient satisfaction, as well as refine business process [70], [75]. Indeed, Tzeng et al. [61] accentuates in the potential to derive business value from RFID applications through refining business processes and expanding the business model in healthcare organizations. Through an evaluation of a RFID implementation process model in healthcare, Bahri [67] outline that RFID will make possible for the hospital to enhance patient care, ensure the security of its doctors, nurses, administrative staff and patients, and make better the working environment for nurses and administrative staff. Roh et al [48] discusses that various intangible advantages could come from innovative use of a technology, such as RFID, including the creation of new business processes.

C. IT performance evaluation in healthcare

The focal point of healthcare organizations is patients' safety and well-being, which represents a key determinant of the quality of healthcare services; conversely, many patients are receiving poor or inadequate quality care [11], [76]. Multiple issues, including inefficient inventory management and control, deficient products and assets tracking, lack of visibility of information, as well as disrupted workflows and processes are greatly affecting the overall performance of healthcare operations. Healthcare systems are very complex in nature. The prevailing norms, practices, and culture characterizing this sector have an impact on efforts to increase system performance [10]. Moreover, the distinct differentiation of professional groups into subcultures based on occupation and skills is vivid proof of it. Each group has its own mind set in terms of priorities, outcomes and quality of care; consequently, they may give dissimilar importance to different aspects of quality [10], [11], which could in turn represent a barrier to the promotion of safety and performance improvements in healthcare [10].

Performance measurement offers a unique opportunity for decision makers, since it gives them an opportunity to ensure health system improvement and accountability [77]. Although integrating an effective performance measurement system into an organization is essential in order to align its operations with its strategic objectives; many organizations are not successful at addressing this issue [78]. In the healthcare context, the performance of support services, such as material and asset management, is perceived to have an impact on the overall performance of the health system, and consequently the performance of care delivery [79]. HCOs could possibly be able to enhance their patient care performance by working on "efficiency and cost reduction" targets [80]. Asset managers concur that real-time operational, economic and asset life key performance indicators (KPIs) are vital for topnotch asset management [81].

Previous work on the assessment of the impact of RFID has been mainly carried out in the supply chain management context in other sectors [82]. From a supply chain perspective, many authors have explored the subject of performance measurement, including the work of [83] and [84]. However, given the discussed particularities of this sector, many of the indicators identified and measure in other industries are not applicable within the context of healthcare.

Moreover, when investigating the area of asset management, there is paucity in terms of a framework for asset management performance measures; consequently, there is not a guide or reference model for medical equipment asset management performance measures and evaluation, particularly when evaluating the impact of integrating RFID technology to such processes. Purbey et al. [78] shed light on evaluation of performance measurement systems for healthcare processes presenting a framework for the selection of a suitable performance measurement system, which proposed to measure performance from a multi and interrelated perspective that is efficiency, effectiveness and flexibility. A study by Chowdhury et al. [11] highlights the importance of considering measures such as efficiency, acceptability, equity and quality to evaluate the performance of health service delivery. According to the authors, efficiency plays a very significant role in performance improvement since it reflects whether an organization is making the best use of its available resources, such as best use of available medical equipment in hospital facilities.

When evaluating performance related to asset management activities at HCOs, productivity of materials resources needed to deliver care is pertinent. According to Smith et al. [77] productivity of operations within healthcare involves the degree to which the resources used by the health system are used in an efficient manner. Indeed, measures such as "*equipment utilization rate*", "*equipment order turnaround*", "*equipment shrinkage*" are of relevant importance for material managers and hospital's stakeholders since it reflects whether or not valuable assets such as medical equipment are fully utilized for the benefit of patient care delivery and for the financial health of the hospital.

IV. Methodology

RFID implementation in healthcare cannot yet be grounded in theory and remains under investigated [27], [56], [57], [61]. As the overall research objective here is to gain a better understanding of RFID implementation in healthcare organizations, the research design clearly falls in the realms of exploratory research. The research was conducted over two years at one hospital (hereinafter referred to as "*hospital A*").

With some 180 medical specialists and approximately 30 medical units, *hospital A* is nearly 100% Wi-Fi and has adopted medical information systems. In order to manage assets inventory, maintenance and repair, the hospital relies on various enterprise applications, and uses a barcoding. Hospital management demonstrated interest in the implementation of an RFID-based mobile asset tracking system to improve the management of critical medical devices.

In order to allow triangulation and strengthen the validity of the results [85], multiple sources of evidence were analyzed:

1) Analysis of internal documents such as clinical and non-clinical procedures and directives;
2) Multiple on-site observations;
3) Panel studies (same focus groups over a period) and semi-structured on-site interviews over multiple points in time (two year period);
4) Continuous analysis of data generated by RFID tags and the corresponding information from the asset tracking system.

The research design therefore combined both unobtrusive and obtrusive data collection methods that generated large amounts of qualitative and quantitative data. For instance, the quantitative data provided by the RFID-based mobile asset tracking system (1317 tags readings) corresponds to a rather efficient and unobtrusive data collection method to assess the value of the RFID-based mobile asset tracking system. On the other hand, the obtrusive data collection methods such as the semi-structured interviews and the focus groups allowed the researchers to gain additional insights into the existing legacy systems, the needs and requirements for the future RFID system, and the priorities and divergent issues prevailing at each stage of the RFID implementation process from the perspective of the different groups of participants and stakeholders.

Special attention was also paid to acquire an in-depth understanding of workflows within the hospital. A process-based approach was retained for several reasons. First, it provides "a more dynamic description of how an organization acts" [86, p. 2]. Second, it is known to be particularly pertinent for RFID project [50]. As noted by Murphy [87], "only when an organization fully understands its business processes, then RFID could be truly effective". Third, the process-based approach proved to be a valuable graphical tool for anchoring discussions, especially in focus groups, for reaching a consensus among research participants; for instance, when deciding on the technological scenario to be selected, or for validation purposes; for instance, when validating existing business processes. These processes were modeled using a drill-down approach with Aris Toolset software from IDS Scheer.

The thirty-one (31) participants represent key managers, professionals, medical and non-medical staff as well as technical specialists from nine (9) organizations (Table II). Members of the research team from one research center and from two universities are considered as participants because they played different roles ranging from full participants (when building the technological scenarios) to participants as observers (when mapping actual business processes).

TABLE II
PROFILE OF PARTICIPANTS

Entities	Type of participants		Number of participants
Hospital A	Top-management	-Hospital director	1
	Medical technical department	-Manager -Biomedical engineers	3
	Medical units	-Manager for ward A & B - Team manager (A & B) -Team manager for other medical wards -Head nurses	8
	ICT departments	-Manager - automation -Manager- ICT -Technical expert	3
	Central storage room	-Supervisor -Clerk	2
Total			**17**
Hospital association	Chairman		1
Four TPs	Top managers, technical experts and professionals from TPs (technological partners)		8
UBRC	Director of UBRC (University-based research center)		1
Two universities	Professors and PhD candidates		4
Total			***14***

V. RESULTS AND DISCUSSION

Results from the case study are presented in a linear manner following five consecutive phases, namely pre-feasibility, feasibility, RFID scenario building and validation, implementation in a real-life setting, and benefits assessment, although iterations between these phases have occurred. These five phases are in line with the implementation model recently proposed by [64]. The main results obtained from each phase are summarized in Table III.

A. Pre-feasibility

The main objectives that could be derived from an RFID-enabled mobile asset management system were discussed in the first focus group. Consensus on the hospital needs concerning critical assets was rapidly reached on the following objectives:

1) Need to *improve real-time monitoring and management* of mobile assets, including assets availability rate, utilization rate, status information, and real-time localization;
2) Need to *reduce delays in patient care* by responding more efficiently and faster to emergencies and unpredicted critical events, and therefore improve patient care;
3) Need to *improve productivity and efficiency* by reducing the time hospital staff, including physicians, nurses, technicians, etc., spends in locating misplaced assets;
4) Need to *improve communication and decisions activities* by keeping up-to-date equipment status on maintenance, sterilization, decontamination, etc.;
5) Need to *reduce overbuying, unnecessary rentals, and under-utilization* of hospital assets;
6) Need to *eliminate costly replacement* of lost or stolen medical equipment.

Mainly, the overriding concern expressed by participants deals with the improvement of the quality of healthcare services, either directly as noted from objective 2 or indirectly as implied by objectives 1, 3 and 4. Cost effectiveness objectives, namely objectives 5 and 6 are placed in second rank.

The development of strategic alliances among technological and non-technological partners proved to be based on their respective competences, resources and strengths. However, the technology partners' readiness was the factor that contributed the most to the hospital's decision to go ahead with the RFID project.

As all participants wished to minimize financial and time investments in the RFID-based project, they agreed to limit the scope of the project to *one type of mobile assets* and *three hospital units*. Participants from the hospital felt that *infusion pumps* would be particularly pertinent and rather strategic for the *hospital A*. Infusion pumps are expensive equipment that are used all across the hospital, cost over € 1,500 each, and are considered as "high-risk" medical equipment given the high level of threat any failure could represent to patient's health. The main problems with the infusion pumps at hospital A relate to the fact that they are continually misplaced, hoarded, or hidden around the hospital; rendering them very difficult to find and restock. According to hospital participants, lack of visibility on their location and status results in continual shortage of infusion pumps, which in turn entails several significant drawbacks, including consuming staff time on unnecessary equipment search, delaying care delivery, and postponing maintenance and repair activities. Furthermore, some thirty (30) infusion pumps have disappeared over from the last few years, representing a 25 percent shrinkage rate and resulting in additional pumps purchase.

The decision was also easily reached to limit the RFID project to two medical wards (Ward A and Ward B) where the availability of infusion pumps is considered critical. According to information validated with wards team managers, approximately 90% of patients treated in Ward A, a 35-beds surgical recovery unit, require an infusion pump for delivering fluids, medication or nutrients while Ward B, an orthopedics unit with 40 beds, is a slightly larger unit where infusion pumps are necessary for the treatment of 60% of its weekly patients. As infusion pumps are stored in a central storage unit, the participants felt strongly that this latter unit should also be included in the pilot project as well. The central storage unit of *hospital A* furnishes medical units and departments with all necessary general and medical supplies. With regards to the medical equipment, the central storage room is responsible for warehousing activities, including receiving, put away, and picking of equipment, for distributing the equipment to wards, and for restocking it from wards.

TABLE III
MAIN RESULTS OF RFID IMPLEMENTATION

Implementation phase	Main decisions	Prevailing issues
Pre-feasibility	- Defining main objectives - Selecting technological and non-technological partners - Circumscribing the scope of the RFID pilot project - Appoint a project champion	- Improvement of the quality of healthcare services as the overriding concern. - Readiness of technological partners Low initial time and money investments. - Limit pilot to one mobile asset and three hospital units - Limit pilot to an optimal physical layout to cut down the costs of RFID infrastructure
Feasibility	- Selecting critical asset management activities related to infusion pumps for the RFID pilot project - Validating the existing business processes for the selected asset management activities and identifying areas of improvement - Assessing the functional and technical requirements of the RFID pilot project, including the level of granularity and precision	- Cleavage between administrative concerns versus clinical concerns - Limit opportunity evaluation to two critical activities: warehousing and usage - Evidence of some operational inefficiencies - Cleavage between and within the different perspectives - Limit the functional requirements to tracing and tracking, with an added functionality on status (in-use versus no- in- use) - Limit costs of RFID infrastructure by maintaining *visibility at a ward level* - Ensure scalability of chosen RFID solution
RFID scenario building and validation	- Assessing the gap between the existing situation (AS IS) and the RFID-enabled situation (TO BE) - Validating the elements of the proposed infrastructure for the RFID-based Wi-Fi asset management solution - Validating the technological scenario	- Easily reached consensus
Implementation in a real-life setting	- Defining modalities and agreement for RFID system deployment - Agreeing upon pilot duration among partners - Ensuring training of key personnel to achieve system appropriation	- Technological partners agreed to lend to *hospital A* all components of the RFID-enabled asset-tracking platform (e.g. tags, software), and carry on all necessary system integration at no cost. - Consensus reached on initial pilot duration; thus, as project advanced new datelines were set to ensure vast data collection. - Easily reached consensus among participants
Benefits assessment	- Determining specific benefits of RFID for asset management - Analyzing of KPIs - Determining limitations of current available technology	- Define a KPIs framework for asset management - Envision a technological solution where the RFID tags would be an integrated element of the medical equipment

The flow of mobile medical equipment (including the infusion pumps) within the three units retained for the pilot study is displayed in Fig. 1. Taking into consideration the physical layout of the chosen pilot zone, the general disposition of the two medical units is well fitted for minimizing the complexity and the costs of an eventual RFID infrastructure, a primary concern for the technological partners that was not equally shared by the other participants. Indeed, wards A and B are co-located on the same floor, sharing a common entrance hallway and access to elevators, which are the only two points of entrance to these two units. When storage room's clerks distribute infusion pumps to Wards A or B, they will access these wards by either of these two entrance points. Moreover, when either of these units needs an infusion pumps and that there is a stock-out at central storage room; their first choice for procuring their required equipment is the other ward; hence, nurses from ward A will try to find an available pump in ward B and vice versa before looking at other units. The storage room is located in a different floor at a different hospital wing.

Various authors agree that the presence of project champions represents a chief factor in facilitating new technology adoption process [5], [49]. It was highly important to define at an early stage of the project a project champion among the hospital management participating staff. The latter, it is consider a valuable strategy to successfully deal with issues that may rise due to necessary process redesign and resistance to change. The manager of medical technical department was the link between researchers and technological partners with the strategic and operational staff at the hospital.

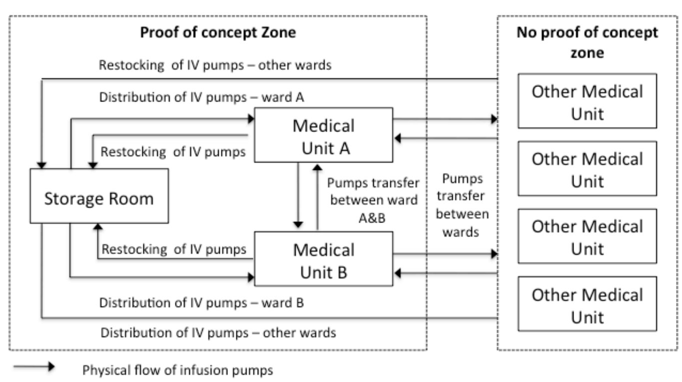

Fig. 1 Flow of infusion pumps at hospital A

B. Feasibility

From the internal documents and the on-site observations and interviews, asset management related to infusion pumps covers five broad activities: procurement, warehousing, usage (point of care), maintenance and repair, and, final disposal or recycling. However, participants retained only warehousing and usage activities to be targeted by the RFID pilot project (indicated in grey in Fig. 2). Activities such "maintenance and repair", and "disposal and recycling" although implied by the previously agreed objective (Objective 4: Need to improve communication and decisions activities by keeping up-to-date equipment status on maintenance, sterilization, decontamination, etc.) were discarded. Strong arguments were made by team leaders to focus on the clinical dimension of the pilot project; one team leader stated "the most critical questions we should be asking are: how many pumps do we have and how are we going to use them?" The more managerial and operational issues such as maintenance were second ranked for the pilot project; though poorly maintained, contaminated or even broken infusion pumps are of no use. Cleavage between administrative perspective and the clinical perspective became apparent.

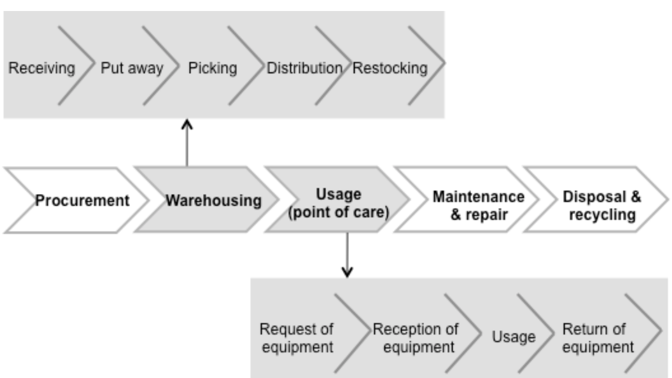

Fig. 2 Asset management activities related to infusion pumps

Once the focus on warehousing and usage activities was agreed upon, prevailing importance was given by participants to two aspects: *first*, the assessment of existing operational inefficiencies and, *secondly*, the requirements of the RFID application to overcome such inefficiencies.

"AS IS" business processes were mapped by researchers and validated with key personnel to ensure reliability of the data collected from on site-observations and the semi-structured interviews. Existing processes were analyzed in order to find areas of opportunity for improvement, such as eliminating unnecessary manual activities or duplications. Several operational inefficiencies affecting mobile asset management were then identified. Inefficiencies such as recurrent inventory shortages at central storage room, service delays since infusion pumps are unavailable on demand, asset sub-utilization, wasted staff time since biomedical engineers, storage room clerks and nurses spend time searching for equipment, were caused by the lack of visibility of equipment location and the presence of information "silos" among hospital services.

The above inefficiencies also arise from some discrepancies between the "formally established processes" (or the way it is supposed to be done) and the "actual processes" (or the way it is actually done). Several comments are symptomatic of the cleavage between the clinical and non-clinical perspectives: for instance, according to personnel from the central storage room and the medical technical department, "nurses are not using the infusion pumps properly; they drop it, etc., so they get out of order often and therefore are not available. In case of breakdowns, nurses are supposed to call us; instead, nurses usually put the equipment in the corridor with a paper that says "defected" and it can stay in the corridor for up to four days and nobody does anything, until finally someone calls. Everybody thinks that they are so busy that no one makes time for that."

Cleavage also exists within the *non-clinical perspective*, for instance, staff from the central room storage reported that "the biggest problem is the delay of the technical medical department to do the maintenance. In some occasions, they have 20 to 25 pumps left in the technical department and no one is fixing them." As for the *clinical perspective*, the different professional groups do not put a uniform front either. For example, the team leader from Ward A made the following comment "the shortage of infusion pumps could be a consequence of an inappropriate usage of the equipment, since sometimes nurses use pumps for patients that could be treated manually". This is echoed in another similar comment from one physician, "Nurses use the pump for everything. There is a number of pumps used by patients that not necessary need one, nurses use them for everything because it is easy for them." Consequently, various team managers agreed that from a clinical perspective some protocols should be established in regards to the usage of critical equipment with team leaders from wards A and B commenting "they should establish some rules of who can use it (pump) and for what kind of treatment", this view is shared by other colleagues with one other team leader stating that there is a need to "determine that we will use the pumps only in specific situations".

The following proposition was made by the four technological partners: The deployment of an RFID solution that allows the identification, location, and tracking would resolve to a certain level some of the above mentioned inefficiencies and would directly resolve issues concerning lack of equipment location visibility. Consensus was easily reached to retain such a proposition, which basically represented the overall statement of the functional requirements of the RFID pilot project. Indeed, available information regarding equipment location will permit staff to look for equipment at a known location, thus reducing time devoted to search, and will allow it restocking at the storage room, thus increasing service responsiveness. The only issue is that having information on equipment location does not guaranty its availability. If an asset is located but it is in use, staff will have to continue looking for an available one. As a result, knowing the status of the infusion pump, in use or not in use, will have a direct impact on most of the inefficiencies noted previously and was retained as an additional functional requirement of the RFID pilot project.

The technological feasibility of the RFID future implementation was carried out by technological partners and university-based researchers, who worked closely with IT and technical staff at *hospital A*. Moreover, opportunities and constraints in the selected zones (wards A and B, central storage room) were examined. Knowledge of the environment where the implementation will take place permits to evaluate different factors; including possible installation issues and potential interference of objects, as well as to eliminate certain technological choices that would not be suitable in such environments. An RF finger printing of specific areas of the hospital was undertaken using a spectrum analyzer in order to measure possible interference and Wi-Fi coverage at specific areas at *hospital A*. From the site surveys, it was noticed that Wi-Fi coverage was weak inside rooms at wards A and B; hence, room-level visibility of IV pumps would implied installation of additional Wi-Fi access points, with the necessary wiring, etc. Participants agreed that for the scope of the pilot project *visibility at a ward level* will be sufficient; thus, only information of whether or not a specific infusion pump is inside ward A or B at a given time will be available.

Finally, particular consideration was given to the selection of a "scalable solution" that would permit to use the foreseen RFID infrastructure in order to improve management of other mobile asset, as well as for additional applications according to the eventual needs of the *hospital A*, for instance, possible applications of RFID to help with the identification and location of mentally challenged patients and staff was regarded as an area of interest.

C. RFID scenario building and validation

Scenarios integrating RFID technologies were modeled using a drill-down approach with Aris Toolset and validated in an iterative manner with participants. Once scenarios were built, a gap analysis between the “AS IS” situation and the “TO BE” situation was performed for all activities pertaining to warehousing and usage (see Fig. 2). Fig. 3 displays an example of the gap analysis for two integrated activities, namely “picking” and “distribution”, which falls under the broad set of warehousing activities.

The analysis of the existing processes performed during the previous phase (feasibility) permitted to identify actual “pain points” and evaluate opportunity zones within all analyzed processes. For instance, when analyzing activities involved in the “As-is picking” and “As-is distribution” processes, participants determined that among the existing activities, four (4) activities were not adding value and therefore were suitable candidates for improvement (Fig. 3). Today, when there is a request for an IV pump, the warehouse clerk needs to go to the location of their designated shelf to validate whether or not they have an available pump (activity 1), implying unnecessary staff movement. Also, in order to keep their inventory system updated, clerks need to scan bar codes attached to pumps, scan sheet containing destination wards bar codes, and then link the equipment to the user ward (activities 4,5,6), demanding additional manipulation of equipment and adding labor time to the distribution process.

Various technological scenarios were built for each process in order to make the most of the potential opportunities of RFID to lessen identified “pain points”, which are at the source of inefficiencies of core existing business processes. Fig. 3 depicts one of the RFID-enabled scenarios (TO BE) built for activities involved in the “picking” and “distribution” processes. As illustrated on the “To Be” process, the areas of opportunity assessed when evaluating the existing situation could be effectively improved with RFID integration. For instance, warehouse clerks would not need any longer to go to the dedicated shelf to validate if there is a pump available; instead, he will have assess to real-time information about pumps availability through the asset tracking system. Various activities could be eliminated since real-time information on warehouse inventory will be seamlessly collected through the RFID-enabled asset tracking system. Activities such as “register exit of pump in WMS” and “update inventory levels in WMS”, activity 7 and 8 respectively, could be now performed automatically as tagged assets leave storage room.

This portrays only some of the opportunities evaluated during the RFID scenario building and validation stage, since various scenarios were built not only for the “To-be picking” and “To-be distribution” processes, but also for the rest of the “warehousing” and “usage” activities.

Gap analysis of “As-is” vs “To-be” processes permitted to evaluate the capabilities of RFID to increase productivity and quality of operations, validate some of the numerous expected benefits, as well as assess possible technological limitations of RFID-enabled scenarios. Once the “To Be” scenario to be deployed was agreed upon, technology partners worked closely with hospital’s ICT team in order to determine system architecture requirements necessary to support the new processes integrating RFID. For instance, verify whether exiting Wi-Fi infrastructure could support scenario implementation or if changes were needed. Since there was no Wi-Fi connectivity available in the storage room, the IT team at the hospital agreed to ensure Wi-Fi coverage at that particular location. All requirements were discussed and agreed upon. Consensus was easily reached for all decision points pertaining to this third phase.

D. Implementation in a real-life setting

During this phase, the “To-be” processes of the retained scenario were reproduced and integrated into real processes at hospital A. Initially, partners agreed on a six-week pilot testing for the deployed application. This very short period seemed preferable since the technological partners were lending at no cost the elements required by the RFID infrastructure.

However, as the project evolved, the proof of concept ended up running over seven (7) months. The longer duration of the pilot project permitted to collect more vast unobtrusive data than originally planned.

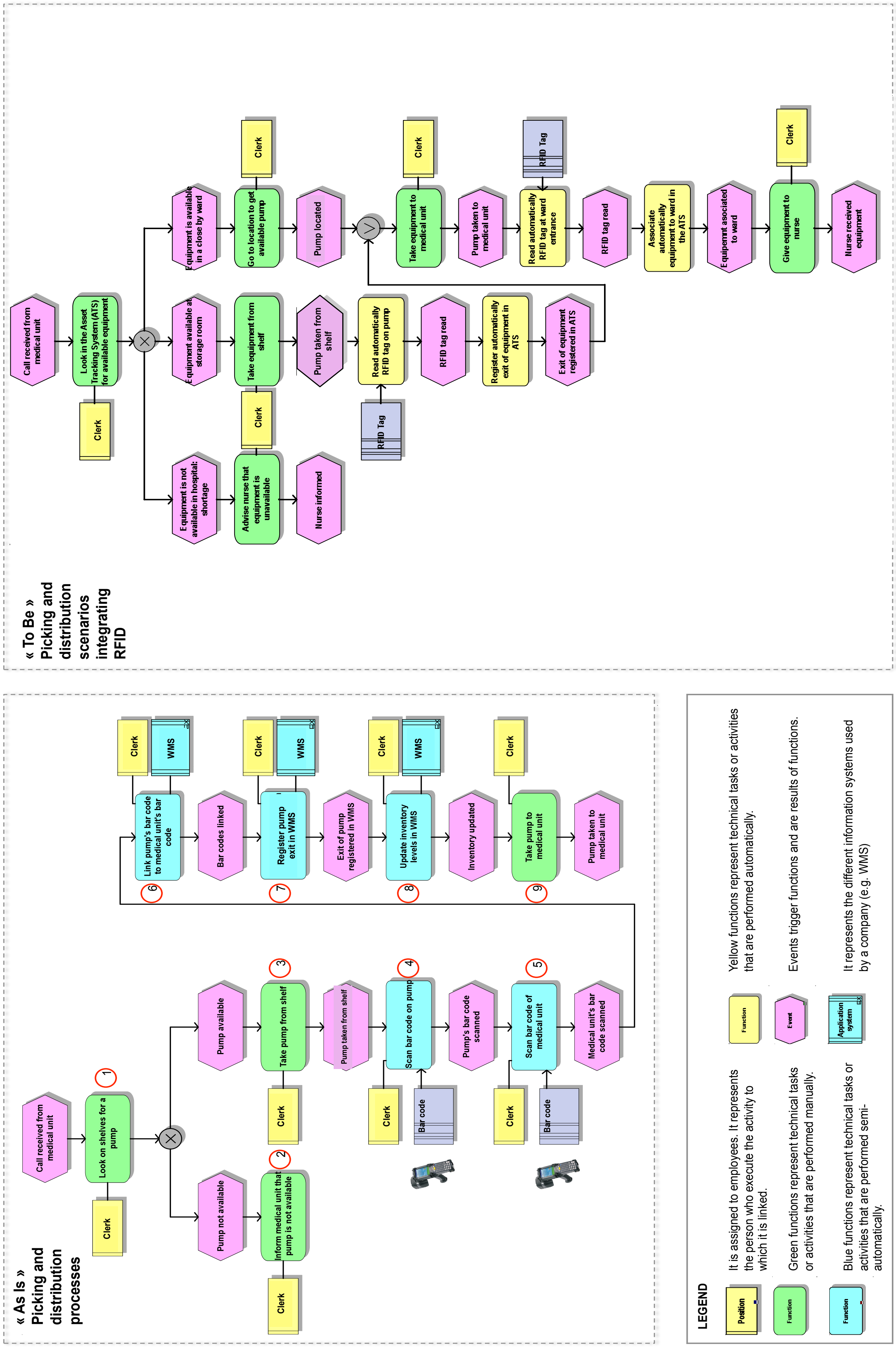

Fig. 4 Gap analysis: As Is vs To Be picking and distribution processes

Fig. 4 depicts the RFID-based asset tracking system as implemented at hospital A. As illustrated on this figure, the RFID-based asset tracking system as implemented at hospital A included various Wi-Fi access points and exciters, numerous Wi-Fi-based RFID active tags, one tracking engine, and one enterprise tracking software.

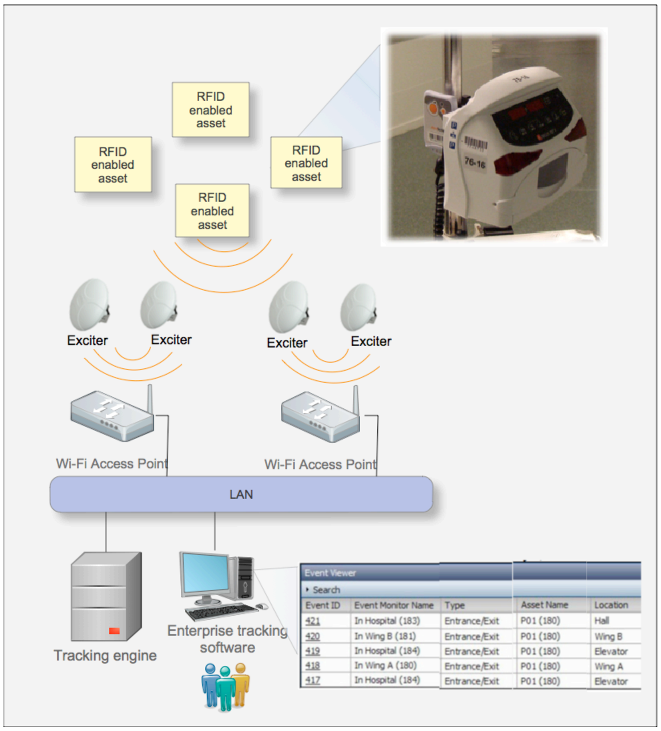

Fig. 4 RFID-enabled asset tracking system

Actual deployment of retained scenario included among others the following activities:

- *Site survey*: prior to the deployment of the RFID-enabled platform, a general site survey was carried out by technical experts, researchers, and appointed staff to verify installation of previous requested elements such as power sockets, additional access point at storage room, etc.;
- *Physical mounting of system elements*: mounting of exciters at all determined locations at ward A, ward B and storage room was performed, ensuring that both exciters and power adapters for the exciters were securely mounted;
- *Software configuration and integration*: carried out by technical partner staff with support from hospital's ICT department;
- *Tag-positioning test*: perform in order to identify best RFID tag position to ensure that tags would be readable and would not interfere with equipment handling and usage;
- *Tag programming and activation*;
- *Test runs*: performed by technical experts from the technological partner team to ensure tags readings and exciters functionality.

A sample of tagged pumps was used to test the system and carry out all necessary system tuning. Once the system was tested and tuned, the rest of the tags were ready to be mounted on infusion pumps. Forty infusion pumps were tagged and were assigned an identifier between 1 and 40; hence, each tagged pump has a corresponding asset name between P01 and P40 in the asset tracking system.

A system demonstration was given to key participants, including among others the manager for wards A & B, and the technical department manager. Participants were able to see the movement of the tags within the proof of concept zone, for instance:

- Through the exciter placed at wards A and B hallway entrance, it was possible to have information of equipment as it enters and leaves these wards;
- The exciter in front of elevator doors allows to record information of the infusion pumps as they enter and leave these wards through the elevators;
- The exciters at the entrance of wards A and B detect and record any RFID-enabled pump as it enters or exits wards A or B, providing visibility on asset used by either ward and offering information to record equipment transfers between wards A and B as well.

In order to facilitate system appropriation by users, system training was given by technology partners to key personnel at the hospital premises. These trained personnel will in turn be in charge of operational staff training, including nurses. Staff training was undoubtedly necessary to support RFID implementation and to motivate the personnel to use and benefit from the opportunities brought by the technology. For instance, nurses were trained particularly on usage of tags push bottoms, so that information regarding pumps status (in use vs. not in use) could be collected. Technical medical manager was trained on asset-tracking functionalities, data collection techniques and reports generation, among others.

E. Benefits assessment

During a seven-month period, participants monitored the RFID deployment, and collected and analyzed the unobtrusive data generated by the asset management system in order to substantiate the anticipated benefits of such implementation.

Hospital personnel could have real-time access to information about the location of any RFID-enabled pumps as they move through the pilot zone over time. Further, information collected through this system, over the pilot period, permitted to have visibility not only of the location of tagged pumps at a certain period of time, but to have information about their utilization, movement (enter/exit ward), and inter-service transfers. The information collected allows hospital administrators and equipment manager to have a global vision of the utilization of their equipment park. For instance, the system registers provides information on the total utilization "in days" of each pump used in ward A and/or ward B during the pilot project. From the analysis of these data a variation on the total days in use of the RFID-enabled pumps can be noticed, with some pumps having a higher utilization rate than others.

TABLE IV
RFID-ENABLED ASSET MANAGEMENT: MAIN KPIS

KPI LEVEL	KPIS AND MEASURE ORGANIZATIONAL GOAL
Essential KPIs: Quality of healthcare service	KPI-1: % of patients needing to be assigned an IV pump. Measured as the percentage of patients needing to an IV pump relative to all patients within measurement period. KPI-2: % of patients being assigned an IV pump. Measured as the percentage of patients being assigned an IV pump relative to all patients needing an IV pump within measurement period. KPI-3: % of patients needing to be assigned an IV pump, but not being assigned one.
Primary KPIs	KPI-4: % of available infusion pumps in the central storage room at a given time. KPI-5: % of time that one particular IV pump is available in the central storage room at a given time. KPI-6: Average % of time that IV pumps are available in the central storage room at a given time. Measured as average time that infusion pumps are in inventory. KPI-7: % of available IV pumps. Measured as the percentage of IV pumps not in used relative to all available IV pumps. KPI-8: Average utilization/usage time of IV pumps. Measured as the average time (e.g. in hours) that IV pumps are used. KPI-9: Average non-stop utilization/usage time of IV pumps. Measured as total hours of IV pumps non-stop usage. KPI-10: % of IV pumps in use in each ward at a given time. Measured in terms of total IV pumps used at a specific ward at a given time. KPI-11: Projected vs actual IV pumps utilization/usage. Measures of how well the utilization of pumps can be predicted. KPI-12: IV pump's transit time. Measured by the number of minutes (or hours) from the time an IV pump leaves the central storage room to the time it arrives at the ward. KPI-13: IV pumps stock-outs per period. Measured as the number of times where a demand cannot be met due to the absence of the required inventory. KPI-14: % of IV pumps incorrectly located. Measured as the percentage of IV pumps incorrectly located relative to all IV pumps. KPI-15: % IV pumps shrinkage. Measured as the percentage of IV pumps that cannot be accounted for inventory. KPI-16: IV pump's inventory accuracy: physical stock against system stock. Measured in terms of the accuracy in IV pumps physical stock against system stock. KPI-17: Value of IV pumps stolen from inventory. Measured as the monetary value of IV pump stolen from inventory. KPI-18: IV pumps inventory value. Measured as the monetary value of IV pump total inventory. KPI-19: % of IV pumps transferred between wards. Measured as the percentage of pumps being moved between wards. KPI-20: % of IV pumps returned to storage room after usage. Measured as the percentage IV pumps returned to the storage room relative to all IV pumps assigned to the ward within measurement period. KPI-21: Average number of IV pumps requested by a specific ward during a given period.
Other Critical factors	KPI-22: Customer satisfaction level (ward) KPI-23: Staff morale (clerks, nurses, doctors) KPI-24: Improved work environment KPI-25: Enhanced eemployee motivation KPI-26: Inter-units relation KPI-27: Storage room image and reputation KPI-28: Hospital good image and reputation KPI-29: Improved organizational teamwork KPI-30: Technological edge KPI-31- Improved communication and control KPI-32: Improved management of information about assets (infusion pumps) KPI-33: Improved accuracy of decisions KPI-34: Improved patient satisfaction KPI-35: Intellectual Capital

For instance, pump 29 (P29) and pump 34 (P34) were in use in either Ward A or B during about 130 days (each). On the contrary, there were some pumps that were only used in the proof of concept zone for only 20 days or less, as was the case for P36 (20 days), P12 (18 days), and P10 (1 hour). Moreover, there were eleven pumps that never passed through the area of the proof of concept (P02, P04, P08, P11, P18, P22, P25, P27, P40), and consequently, there is no record of their location and utilization history during this period. The later, is a reality common to many hospitals as asset managers and staff are overwhelmed by the lack of information on assets.

Through a literature review, a set of key performance indicators (KPIs) related to the asset activities were identified with the objective of evaluating the possibility and potential of the proposed RFID solution to provide necessary information for KPIs measurement, as well as to evaluate whether RFID could positively impact asset management performance.

The unobtrusive information available through the RFID location system could be used to evaluate medical equipment performance. For instance, the information obtained concerning infusion pumps utilization history and length of usage could be used to measure indicators related to the "usage" activity of medical equipment, including indicators such as equipment utilization rate, number of equipment that are not in used, at a ward, but that replenishment has not taken place, number of equipment been used at a ward at a certain period, as well as total number of equipment requested by a ward, among others.

Table IV presents core KPIs related to receiving, put away, picking, distribution, restocking, and usage activities within the context of medical equipment management were analyzed. Being able to measure these metrics is of chief importance for material managers and hospital stakeholders since it will provide them with the necessary information to evaluate the whether their clinical critical assets are utilized, maintained and manage at the levels necessary to ensure operations productivity and well as quality care delivery. However, the relative importance of these KPIs widely differs between the different stakeholders. For instance, the manager of one of the wards stated that "after all, the most crucial objective is to know the location of the infusion pumps", discarding at the same time the importance of some previously agreed objectives (phase 1) such as operational issues such as keeping up-to-date equipment status on maintenance, sterilization, or decontamination and administrative issues such as overbuying, unnecessary rentals, under-utilization of hospital assets and elimination of costly replacement of lost or stolen medical equipment.

The analysis of KPIs also revealed that the nurses did not systematically register the status of the infusion pumps that they use. The information on pumps utilization, from the moment it is assigned to the patient to the moment it is not in use any longer, is therefore inadequate in some cases. Nurses and other participants then envisioned a technological solution where the RFID tags would be an integrated element of the medical equipment, so that information could be collected flawlessly.

VI. Conclusion

The palpable paucity of established and structured RFID implementation frameworks to guide healthcare managers led us to propose a five-phase implementation model. The results presented in this paper offer valuable insights for top managers in hospitals and IT specialists responsible for RFID implementation.

First, the detailed longitudinal field research allows us to document the prevailing issues related to RFID implementation in a hospital setting. The most significant issues are not technological but are mainly organizational, as they seem to arise from the presence of diverging perspectives. The empirical evidence presented in this paper demonstrates a cleavage between the administrative and clinical perspectives but also within the clinical perspective. However, divergences also run deep within each perspective (for instance, nurses vs. doctors) and between the technologists in the hospital (ICT managers, biomedical engineers, and maintenance specialists) and the administrators. It is therefore critical to better understand these organizational issues and, for managers and IT specialists, not to underestimate them.

Second, empirical evidence shows that the process of RFID implementation is indeed highly iterative. Participants revisited and modified previously agreed steps. For instance, the benefits assessment and the analysis of KPIs (phase 5) led to reconsider the stated objectives (phase 1) and the retained technological scenario (phase3). Such iterations, although inevitable, are also time-consuming. By carefully assessing all implications of each phase on subsequent phases, some iteration may be prevented.

Third, the results also prove that benefits are derived from RFID implementation. The new RFID-enabled processes provide information on assets availability rate, utilization rate, and real-time localization. Information on asset status could however be improved, either by increasing the nurses awareness to the new technology or by integrating RFID tags in the design of infusion pumps. Both options may require some time. KPIs represent an effective tool to formally evaluate and assess the benefits derived from RFID implementation.

RFID represents a new paradigm for asset management in healthcare. It increases in productivity through elimination of search delays from the staff and impacts the care dimension. Indeed, accessibility to critical resources allows care professionals to respond more efficiently and faster to clinical events, and therefore improves patient care and the patient experience. Other strategic objectives targeting cost effectiveness can be as well be derived from such implementation thanks to a potential reduction of overbuying and or replacement, unnecessary rentals, and under-utilization of hospital assets.

Acknowledgment

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