Internet of Things in healthcare: the case of RFID-enabled asset management

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Abstract: First coined by members of the RFID community in 1990s, the concept of the 'Internet of Things' is emerging as an important lever for addressing key organisational and societal challenges including megacities management, environmental management, supply chain and healthcare management. At the core of the concept, RFID technology is expected to play a vital role in terms of business value creation and realisation. Despite the high level operational and strategic potential of the technology, very few studies have been conducted on both the importance of RFID relative advantage and the RFID impact on asset management-related processes in healthcare. Filling this research gap is the main objective of this study, by assessing the importance of (a) the relative advantage of RFID in the healthcare sector and (b) the RFID impact on asset management-related processes in healthcare through a panel of experts using three rounds of the Delphi study. Finally, implications for practice and research are discussed.

Keywords: Internet of Things; RFID technology; healthcare; asset management; relative advantage.

Reference to this paper should be made as follows: Wamba, S.F. and Ngai, E.W.T. (2013) 'Internet of Things in healthcare: the case of RFID-enabled asset management', *Int. J. Biomedical Engineering and Technology*, Vol. 11, No. 3, pp.318–335.

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This paper is a revised and expanded version of a paper entitled 'Importance of the relative advantage of RFID as enabler of asset management in the healthcare: results from a Delphi study' presented at the '45th Hawaii International Conference on Systems Science, HICSS-45 2012', Grand Wailea, Maui, Hawaii, USA, January 2012.

1 Introduction

The healthcare industry is one of the largest industries in many Western countries in terms of job creation, number of employees, and expenditure. In 2008, the industry generated 14.3 million jobs in the USA, with a potential increase of almost 3.2 million new jobs between 2008 and 2018 (United States Department of Labor, 2010). In 1963, around 5% of the US Gross National Product (GNP) was allocated to healthcare expenses (Middleton, 2009), and analysts predict that this figure will increase to 20% by 2017 (Wurster et al., 2009). Similarly, Canada's total public health spending in 2000 was estimated at 6% of the country's GNP, and that it can potentially increase to almost 7.1% by 2020 (Brimacombe et al., 2001). In Australia, the total public and private healthcare expenditure was estimated at 10% of the country's GDP, that is, an annual spending of about AUS$ 65,000 million (GS1-Australia, 2010). The healthcare sector is considered by many scholars and practitioners as one of the most complex industries because it involves multiple stakeholders and challenges, including: patient safety; the ability to track and trace pharmaceuticals, medical devices, and flow of products from manufacturers to patients (GS1-Australia, 2010); and the pervasive use of error-prone methods (e.g. manual data collection and paper-based healthcare) in providing critical healthcare services (PITAC, 2004; Bang and Timpka, 2007; Agarwal et al., 2011). To overcome these challenges, the adoption and effective use of information technology (IT) is a key component of healthcare strategy. IT can facilitate the transformation of the healthcare sector (Ammenwerth et al., 2003) through better patient management, enhanced service quality, improved operational efficiency, and enhanced patient care (Bush et al., 2009, p.446). Recently, new technologies and concepts such as the 'Internet of Things' have been emerging as new tools that will broaden healthcare transformation. At the core of the 'Internet of Things' concept, Radio Frequency Identification (RFID) technology, a disruptive and open innovation (Fosso Wamba, 2011) is regarded as the next wave of IT innovation capable of helping to solve many of the healthcare challenges (Ngai et al., 2009; Oztekin et al., 2010). Indeed, recent advancements in nanotechnology, improvements in the capacity of integrated circuits, and the satisfaction of information needs in terms of accuracy have prompted renewed interest in the 'relative advantage' of RFID technology, compared with traditional Automatic Identification and Data Capture (AIDC) technology, such as bar coding. Relative advantage, which is the degree to which an innovation is better than existing practices in bringing benefits to an organisation, is considered a key innovation characteristic that may motivate the decision to adopt an innovation (Rogers, 2003, p.233). For example, RFID technology offers improved capabilities, including the identification of irrelevant line of sight, unique item-level product identification, multiple-tag product reading, enhanced data storage capability, and data read-and-write capabilities. In addition, the successful integration of RFID technology in intra- and inter-organisational business processes and information systems enables business process innovation, real-time data collection and sharing at the supply chain level, end-to-end item level tracking and tracing within the supply chain, and improved decision making. The high operational and strategic potential of RFID technology adoption are of considerable interest to academicians and practitioners. From an academic standpoint, this interest is manifested in the increased number of special journal issues on RFID in IT/IS/operation management/medical-related journals. However, very few studies have been conducted on the role of RFID technology as an enabler of improved asset management within the healthcare sector. For example, only four articles (Appendix A) came out from a search based on a combination of the following descriptors: 'Internet* of things*', IoT, 'Internet* of objects*', IoO, 'Internet* or Artefacts*' within the AIS basket of top journals considered as the primer outlet of journals in information systems: *European Journal of Information Systems* (*EJIS*), *Information Systems Journal* (*ISJ*), *Information Systems Research* (*ISR*), *Journal of AIS* (*JAIS*), *Journal of MIS* (*JMIS*), *MIS Quarterly* (*MISQ*), *Journal of Strategic Information Systems* (*JSIS*) and the *Journal of Information Technology* (*JIT*),[1] and top journals in health informatics identified by Le Rouge and De Leo (2010), and containing the following journals: *Journal of the American Medical Informatics Association* (*JAMIA*), *IEEE Transactions on Information Technology in Biomedicine* (*IEEE TITB*), *International Journal of Medical Informatics* (*IJMI*), *Journal of Biomedical Informatics* (*JBI*), *Methods of Information in Medicine* (*MIM*), *IEEE Engineering in Medicine and Biology* (*IEEE EMB*), *International Journal of Technology Assessment in Health Care* (*IJTAH*), *Medical Informatics and the Internet in Medicine* (*MIIM*), *Medical Decision Making* (*MDM*) and *British Journal of Healthcare Computing Information Management* (*BJHCIM*). Also, even if there is a growing interest in the use of RFID technology for healthcare transformation (Fosso Wamba and Ngai, 2011; Fosso Wamba, 2012), a recent analysis of peer-reviewed papers on RFID technology (Ngai et al., 2008) indicated that only 3.6% of the papers focused on issues related to the healthcare sector (17.8%, the highest frequency, pertaining to the retail sector). The present paper therefore represents an initial attempt to narrow down the existing knowledge gap observed in the literature. More specifically, this study seeks to answer the following research questions:

1. *Compared with bar coding technology, what is the importance of the relative advantage of RFID in the healthcare sector?*
2. *What is the effect of RFID technology on asset management-related processes in the healthcare sector?*
3. *What are the top-ranked asset management-related processes associated with the adoption and use of RFID technology in the healthcare sector?*

To address these research questions, this paper draws on a review of Internet of Things with an emphasis on RFID technology, IT and RFID technology potential in asset management-related processes, as well as on a web-based Delphi study. The rest of the paper is organised as follows: Section 2 presents RFID technology. Section 3 discusses IT and RFID potential in healthcare, with a focus on asset management-related processes. Section 4 describes our research methodology. Section 5 presents the results and discussion, while Section 6 provides the conclusion and future research directions.

2 Internet of Things: the case of RFID technology

RFID is a "wireless Automatic Identification and Data Capture (AIDC)" technology (Fosso Wamba et al., 2008b, p.615) that uses radio frequencies to automatically identify individual products in real time (Poirier and McCollum, 2006). RFID technology is at the core of the so-called 'Internet of Things', which refers to the "possibility of discovering information about a tagged object by browsing an Internet address or database entry that corresponds to a particular RFID" (Calia, 2010, p.2). More broadly, the concept of the 'Internet of Things' describes the idea in which objects become part of the Internet (Velev, 2011), and therefore are able to produce, receive and share information with other objects through the network that will ultimately create smart networks (Calia, 2010). For example, an RFID-enabled product is considered as an 'intelligent' or 'smart' product (Kärkkäinen et al., 2003; Strassner and Schoch, 2004; Fosso Wamba et al., 2006; Meyer et al., 2009; Valckenaers et al., 2009; Yang et al., 2009), as it possesses a unique identity and is capable of communicating effectively with its environment. In addition, such a product can recall or store data about itself and contains a language that will allow it to display its features and production requirements. More importantly, a 'smart' product is capable of making or participating in decisions that are relevant to its own destiny (Zaharudin et al., 2002, p.8). These improved capabilities position RFID technology as an emerging inter-organisational information system with the potential to transform the entire supply chain for real-time optimisation (Curtin et al., 2007, p.88). However, the operating principle behind RFID technology is not that complex. Any basic RFID system has three main components: (a) a tag, which can be attached to or embedded in the physical product to be identified; (b) a reader and its antennas, which interact with the tag without requiring a line of sight; and (c) the middleware, which involves functions such as system management, RFID data filtering, RFID data aggregation, and interaction with intra- and inter-organisational information systems (e.g.

enterprise resource planning, warehouse management systems, logistics enterprise systems and internal and external databases); and such components help to support intra- and inter-organisational business regulations (Fosso Wamba et al., 2008a).

3 Enabling healthcare asset management using RFID technology

IT is a critical enabler of healthcare transformation. Some scholars have even suggested that the adoption and effective use of IT in the healthcare sector is "a critical goal of a 21st-century healthcare system" (Menachemi and Brooks, 2006, p.79). IT can be used to support various activities within the healthcare sector, including the tracking of blood bags, monitoring of drug allergies (Cresswell and Sheikh, 2008), access to patient record transactions (Lu et al., 2005), improvement of healthcare decision making and healthcare resource allocation (Palacio et al., 2009), and the facilitation of individual patient reminders and alerts (Medicare Payment Advisory Commission, 2004). In addition, IT offers prospects for the integration of patient information to promote quality of care and enhance efficiency (Palacio et al., 2009). More important, IT is critical in all decisions related to "managing, processing, retaining, and making accessible large amounts of disparate data to multiple end users" (Cresswell and Sheikh, 2008, p.1113). Thus, IT and other emerging technologies are considered "the biggest levers… that will re-make healthcare for the 21st century" (Flower, 2004, p.42). For example, IT not only allows for the fundamental re-design of end-to-end healthcare processes, but also fosters the "transition from institution-centric to patient-centric applications" (Demiris et al., 2008, p.8); it therefore cultivates better collaboration among healthcare stakeholders in providing improved healthcare services to patients (Demiris et al., 2008).

Compared with other methods such as bar coding, RFID technology offers a more improved mechanism for patient identification, tracking and tracing within healthcare facilities (Fisher and Monahan, 2008; Iadanza et al., 2008). It is a viable means for reducing errors in patient care, such as order errors, errors related to adverse drug effects and allergies, patient-medication mismatches, and medication dosage errors (Menachemi et al., 2007; Thuemmler et al., 2007; Iris et al., 2009; Tu et al., 2009; Oztekin, et al., 2010). Analysts estimate that between 6% and 12% of medication errors in the US result from the ingestion of drugs by patients who are known as allergic to such drugs, as indicated in their medical records (Cresswell and Sheikh, 2008).

In the context of asset management within the healthcare sector, RFID technology can be used to facilitate the tracking and tracing of pharmaceutical products to avoid the consumption of counterfeit drugs (Booth et al., 2006). Counterfeit medications represent not only a threat to patient safety because they may contain dangerous ingredients (Fuhrer and Guinard, 2006), but also important financial losses for pharmaceutical firms (Dahiya, 2008). For example, analysts estimate that about 10% of the pharmaceutical products worldwide are counterfeit (Lefebvre et al., 2011), accounting for almost US$ 75 billion in financial losses for pharmaceutical firms in 2010 (Dahiya, 2008). The fight against this problem explains why US regulatory organisations (e.g. Food and Drug Administration) and states (e.g. California) issued a mandate to pharmaceutical firms to adopt a unique identifier (or e-Pedigree) for each pharmaceutical product that will be used along the supply chain to attest to the origin of the said product. More broadly, RFID technology facilitates the tracking and tracing of critical assets (e.g. infusion pumps, wheelchairs) within the healthcare supply chain (Symonds et al., 2007; Bendavid et al., 2010). In addition, the same technology can be used to support all steps related to the blood transfusion process (e.g. identification of blood bags at the collection point, tracking and tracing from the collection point to the healthcare facility) (Kebo et al., 2010). Finally, the adoption and effective use of RFID in the healthcare sector can facilitate the development of predictive maintenance strategies for medical equipment, and therefore enhance proper equipment servicing (Van Oranje et al., 2009).

Despite such claims, very few studies have been conducted on the relative advantage of RFID technology and its role as an enabler of improved asset management within the healthcare sector. The present study represents an initial attempt to address this issue.

4 Method and data collection

This exploratory study intends to examine the relative advantage of RFID technology to assess the potential effect of the technology on asset management-related processes in the healthcare sector. We follow with an assessment of the relative importance of such an effect. Given the exploratory nature of this investigation and the scarcity of related previous studies, a web-based Delphi technique was used to collect data on the assessments made by RFID experts regarding factors related to the relative advantage of RFID and asset management in the healthcare sector. In this study, an expert is "an individual who has acquired knowledge in a specific domain (e.g. RFID technology) gradually through a period of learning and experience" (Okoli et al., 2010, p.5). The Delphi technique is a viable method for achieving the objectives of this study (Snyder-Halpern, 2001; Okoli and Pawlowski, 2004; Nakatsu and Iacovou, 2009); it is suitable for studies that are constrained by the availability of historical data (De Haes and Van Grembergen, 2008). Moreover, the technique "lends itself especially well to exploratory theory building on complex, interdisciplinary issues" (De Haes and Van Grembergen, 2008, p.446). The Delphi technique was developed by Rand Corporation (Steinert, 2009) as an interactive technique for achieving consensus from a group of experts (Melnyk et al., 2009) by "structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" (Linstone and Turoff, 1975, p.3). The technique allows for the (a) anonymity of respondents to reduce the effect of dominant individuals; (b) iteration and controlled feedback through multiple rounds to reduce noise; and (c) statistical group response to ensure that the opinion of each panellist within the group of experts is represented in the final response (Dalkey, 1969, p.24). Finally, the Delphi technique is highly relevant to our study because it is "a particularly valid choice when the problem does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis" (Sasser and Bartczak, 2004, p.2218).

On the basis of an early study of Van Oranje et al. (2009), a review of academic papers, white papers and industry reports focusing on RFID technology, as well as several discussions with experienced academicians and practitioners, we generated and included a list of 12 processes related to the relative advantage of RFID and ten processes related to RFID-enabled asset management applications in the healthcare sector in the research questionnaire. For example, the vast majority of items used for RFID-enabled asset management applications were drawn from an early study by Van Oranje et al. (2009). Thereafter, a pilot test of the questionnaire was conducted among five RFID technology researchers to confirm validity, as well as verify the accuracy of the definitions of all the items in the questionnaire.

Three rounds of the Delphi study were run. In the first round, a random sample of 85 respondents was drawn from an aggregate list of authors who have submitted papers on RFID technology to different international conferences and for various special issues of academic journals. A personalised invitation email that explains the objectives of the study, the approximate time required to complete the survey, and the potential number of rounds in the study was sent to each of the respondents. Of the 85 invited authors, 61 agreed to participate. However, only 41 retrieved questionnaires were valid because 20 questionnaires were either incorrectly or insufficiently accomplished (response rate = 67.21%). In the second round, one participant who failed to complete the first round expressed his willingness to participate, bringing the number of respondents to 42. In the third round, 28 panellists participated.

In the first and second rounds, the panellists were asked to evaluate the 12 processes related to the relative advantage of RFID and ten processes related to RFID-enabled asset management in the healthcare sector using a five-point Likert scale (1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, and 5 = strongly disagree).

5 Results and discussion

Among the respondents, 71.4% were doctorate degree holders; the others held master's (14.3%), MBA (7.1%) and bachelor's degrees (4.8%) (Table 1). In terms of business association, 76% of the respondents were from the academic field, 20% from the healthcare sector, and 2% from the consulting and research field (Table 1).

Table 1 Respondent profile-based on round 2

Demographic categories	*Frequency*	*Percentage*
Level of education		
Doctorate degree	30	71.4
Master's degree	6	14.3
MBA degree	3	7.1
Bachelor's degree	2	4.8
Others	1	2.4
Total	42	100
Business association		
Academia	31	75.6
Consulting	1	2.4
Healthcare	4	9.8
Healthcare services provider	1	2.4
Research	1	2.4
Government	1	2.4
Academia & consulting	1	2.4
media	1	2.4
Total	41	100

Table 1 Respondent profile-based on round 2 (continued)

Demographic categories	*Frequency*	*Percentage*
Level of knowledge of RFID technology		
I am an RFID technology expert	12	28.6
I have a good knowledge of RFID technology	24	57.1
I have some knowledge of RFID technology	6	14.3
Total	42	100

In terms of the level of knowledge about RFID technology, 57.1% of the respondents claimed to have 'good knowledge about RFID technology', 28.6% claimed to be 'RFID technology experts', and 14.3% acknowledged having 'some knowledge about RFID technology'. Overall, more than 85% of the respondents had good knowledge of RFID technology (Table 1).

Tables 2 and 3 provide an overview of the key analytical points related to the ranking of items associated with the relative advantage of RFID and RFID-enabled asset management in the healthcare sector, respectively. The 'rank' column presents the ranking of all items classified using the mean ranking in the second round of the Delphi study (the reference round for the ranking).

Table 2 Ranking of processes related to RFID relative advantage

		Round 1 (n = 41)		*Round 2 (n = 42)*		*SD variation*
Rank	*Relative Advantage Items*	*Mean*	*SD*	*Mean*	*SD*	
7	Improved accuracy	1.950	0.999	1.860	0.952	–0.047
11	Improved company image	2.540	0.790	2.550	0.815	0.025
6	Improved data capacity	1.820	0.874	1.830	0.863	–0.011
4	Improved firm internal and external co-ordination of material flows	1.700	0.608	1.660	0.575	–0.033
8	Improved management decisions	2.020	0.790	2.000	0.765	–0.025
2	Improved operational efficiency	1.620	0.586	1.590	0.547	–0.039
5	Improved visibility	1.760	0.943	1.690	0.897	–0.046
1	Improved traceability	1.450	0.639	1.440	0.634	–0.005
3	Provided real-time information access and exchange	1.590	0.591	1.600	0.587	–0.004
9	Reduced error rates	2.220	0.936	2.190	0.943	0.007
12	Reduction in the number of employees	2.820	0.675	2.880	0.678	0.003
10	Improved collaboration with business partners	2.420	0.781	2.440	0.808	0.027
	Kendall's W	0.304		0.338		
	Chi-Square	127.263		144.793		
	Asymp. Sig.	0.000		0.000		

Table 3 Ranking of processes related to asset management applications

		Round 1 (n = 41)		Round 2 (n = 42)		SD variation
Rank	*Asset Management Items*	*Mean*	*SD*	*Mean*	*SD*	
1	Asset identification of blood bags	1.410	0.547	1.400	0.544	–0.003
5	Asset tracking and tracing for access control and inventory shrinkage decrease	1.490	0.675	1.500	0.672	–0.003
1	Asset tracking and tracing for expiration date and restocking	1.410	0.591	1.400	0.587	–0.004
4	Asset tracking and tracing to avoid procedure delays	1.460	0.778	1.450	0.772	–0.006
1	Inventory management	1.410	0.547	1.400	0.544	–0.003
6	Maintenance of medical equipment	1.630	0.662	1.620	0.661	–0.001
8	Materials tracking to avoid left ins	1.710	0.782	1.690	0.780	–0.002
7	Ensure proper equipment servicing	1.660	0.617	1.640	0.618	0.001
10	Detect tampered or unacceptable drugs	1.730	0.708	1.710	0.708	0.000
9	Provide ePedigree	1.750	0.732	1.700	0.740	0.008
	Kendall's W	0.08	0.07			
	Chi-Square	25.966	23.200			
	Asymp. Sig.	0.002	0.006			

The 'mean' and 'SD' columns represent the means and standard deviations of the items, respectively, for each round. Finally, the column labelled as 'SD variation' shows the differences in standard deviations between the two rounds. Variations in standard deviations (SD) and the Kendall coefficient of concordance (W) were used to assess the level of consensus among members of the Delphi study panel. With regard to SD, the "lower the standard deviation is, the higher is the consensus; thus, a 'perfect consensus' on an issue has a standard deviation of zero" (Park et al., 2006, p.424).

Furthermore, a reduction in SD during the Delphi process shows a high level of consensus among the panel members (Park et al., 2006). For W, a value of $W \geq 0.7$ indicates strong consensus among the panel members; $W = 0.5$ indicates moderate consensus; $W < 0.3$ shows weak consensus (Schmidt, 1997; Nevo and Chan, 2007); and $W < 0.1$ reflects very weak consensus (Schmidt, 1997).

Thus, we observe a high convergence of consensus in eight of the 12 processes related to the relative advantage of RFID and in seven of the ten processes related to asset management among the Delphi panel members. In addition, we reach perfect consensus among the panel members with regard to the process 'detect tampered or unacceptable drugs' in asset management.

Using the Kendall coefficient of concordance from Tables 3 and 4, we can conclude that the level of consensus among the panel members with regard to the relative advantage of RFID is weak ($W = 0.304$ in Round 1; $W = 0.338$ in Round 2) and statistically significant for both rounds ($\chi^2 = 127.263$, $p = 0.000$; $\chi^2 = 144.793$, $p = 0.000$). For the processes related to asset management, the level of consensus among the panel members is very weak ($W = 0.08$ in Round 1; $W = 0.07$ in Round 2) and statistically significant for both rounds ($\chi^2 = 25.966$, $p = 0.002$; $\chi^2 = 23.200$, $p = 0.006$).

Table 4 Ranking of processes related to RFID relative advantage by panel type

	Round 1: Rank		*Round 2: Rank*	
	Non-Healthcare practitioners (n_1 = 35)	*Healthcare practitioners (n_2 = 5)*	*Non-Healthcare practitioners (n_1 = 36)*	*Healthcare practitioners (n_2 = 5)*
Improved accuracy	7	2	7	2
Improved company image	11	7	11	7
Improved data capacity	6	4	6	3
Improved firm internal and external co-ordination of material flows	4	6	4	6
Improved management decisions	7	7	8	7
Improved operational efficiency	3	2	3	2
Improved visibility	5	7	5	7
Improved traceability	1	1	1	1
Provided real-time information access and exchange	2	4	2	3
Reduced error rates	9	10	9	10
Reduction in the number of employees	12	12	12	12
Improved collaboration with business partners	10	10	10	10
Kendall's W	0.311	0.372	0.350	0.372
Chi-Square	109.583	20.468	127.112	20.468
Asymp. Sig.	0.000	0.039	0.000	0.039

More important, all the top five processes related to the relative advantage of RFID reflect high levels of consensus. These are 'improved traceability' (1st), 'improved operational efficiency' (2nd), 'provided real-time information access and exchange' (3rd), 'improved firm internal and external co-ordination of material flows' (4th), and 'improved visibility' (5th).

We also generate a high level of consensus for the top five processes related to asset management; however, three processes are tied at first place: 'asset identification of blood bags' (1st), 'asset tracking and tracing for expiration date and restocking' (1st), 'inventory management' (1st), 'asset tracking and tracing to avoid procedural delays' (4th), and 'asset tracking and tracing for access control and decreasing inventory shrinkage' (5th).

Furthermore, we were interested in determining the level of agreement between the panel groups (e.g. healthcare practitioners vs. non-healthcare practitioners) or intra-panel agreement. For example, intra-panel agreement was used to examine problems in the interplay of development and IT operations in system development projects (Iden et al., 2011). Tables 4 and 5 show a weak and statistically significant level of consensus among the two distinct groups of panel members with regard to processes related to the relative advantage of RFID for the two rounds of the Delphi study.

Table 5 Ranking of processes related to asset management by panel type

	Round 1: Rank		*Round 2: Rank*	
	Non-Healthcare practitioners (n_1 = 35)	*Healthcare practitioners (n_2 = 5)*	*Non-Healthcare practitioners (n_1 = 36)*	*Healthcare practitioners (n_2 = 5)*
Asset identification of blood bags	1	7	1	7
Asset tracking and tracing for access control and inventory shrinkage decrease	4	6	4	6
Asset tracking and tracing for expiration date and restocking	2	5	2	5
Asset tracking and tracing to avoid procedure delays	5	2	4	2
Inventory management	3	2	3	2
Maintenance of medical equipment	9	1	9	1
Materials tracking to avoid left ins	6	8	7	8
Ensure proper equipment servicing	9	2	9	2
Detect tampered or unacceptable drugs	6	9	7	9
Provide ePedigree	8	10	6	10
Kendall's W	0.093	0.585	0.083	0.585
Chi-Square	25.91	21.066	23.835	21.066
Asymp. Sig.	0.002	0.012	0.005	0.012

For non-healthcare practitioners, we have $W = 0.311$, $\chi^2 = 109.583$, $p = 0.000$ in Round 1 and $W = 0.350$, $\chi^2 = 127.112$, $p = 0.000$ in Round 2; for healthcare practitioners, we have $W = 0.372$, $\chi^2 = 20.468$, $p = 0.039$ in Round 1 and $W = 0.372$, $\chi^2 = 20.468$, $p = 0.039$ in Round 2.

For the two groups, the following processes are ranked at the same level: 'improved traceability' (1st), which is the most important process related to the relative advantage of RFID technology; 'improved collaboration with business partners' (10th) and 'reduction in the number of employees' (12th), which are the two less important processes related to the relative advantage of RFID technology. This ranking is consistent with the early ranking from the entire panel group.

With regard to processes related to asset management applications, a very weak and statistically significant level of consensus is observed among the non-healthcare panel members for the two rounds of the Delphi study ($W = 0.093$, $\chi^2 = 25.91$, $p = 0.002$, for Round 1 and $W = 0.083$, $\chi^2 = 23.835$, $p = 0.005$), but a moderate consensus is achieved among the healthcare members for the two rounds of the Delphi study ($W = 0.585$, $\chi^2 = 21.066$, $p = 0.012$, for Rounds 1 and 2). This may suggest that for more specific (e.g. 'core') processes related to asset management in the healthcare sector, there is an enhanced common understanding of the potential effects of RFID-enabled smart healthcare asset management among the healthcare panel members. One implication of this observation may be the need to carefully select panel members when assessing the effects of RFID technology in a specific business context.

This is in line with the observations of Prater et al. (2005, p.134), who suggest that the study and discussions on RFID-enabled organisational transformation should be conducted within a specific business domain (e.g. retailing, healthcare) because the business effects of the applicability of RFID technology are influenced by its environment.

For the panel of non-healthcare practitioners, the top five asset management-related processes that may benefit from RFID technology as determined in Rounds 1 and 2 are as follows: ‘asset identification of blood bags’ (1st), ‘asset tracking and tracing for expiration date and restocking’ (2nd), ‘inventory management’ (3rd), ‘asset tracking and tracing for access control and decreasing inventory shrinkage’ (4th), and ‘asset tracking and tracing to avoid procedural delays’ (5th in Round 1 and 4th in Round 2).

For the panel of healthcare practitioners, the top five asset management-related processes that may benefit from RFID technology as determined in Rounds 1 and 2 are as follows: ‘maintenance of medical equipment’ (1st), ‘inventory management’ (2nd), ‘asset tracking and tracing to avoid procedural delays’ (2nd), ‘ensure proper equipment servicing’ (2nd), and ‘asset tracking and tracing for expiration date and restocking’ (5th) (Table 5).

Our results are consistent with early studies on the relative advantage of RFID technology when dealing with counterfeit medicines (Lefebvre et al., 2011). In fact Lefebvre et al. (2011) observe that ‘added intelligence’, ‘data sharing between partner’ and ‘real time data collection’ were among the top advantages of the technology. Similarly Fosso-Wamba et al. (2009) found that the relative advantage capabilities of RFID such as ‘data accuracy’, ‘information visibility’ and ‘track and trace’ were among the factors that mattered ‘most’ when exploring the potential of RFID technology. However, Wang et al. (2010) found that relative advantage was not an important discriminator for adoption in the manufacturing industry (e.g. help lower inventory costs, quick data capture and analysis and reduce paperwork). Similarly Soon and Gutiérrez (2010) found that relative advantage of RFID was not a ‘decisive influential factor’ when exploring RFID adoption in New Zealand’s supply chains (e.g. manufacturing, logistics service and retail businesses). These conflicting results require further studies on the relative advantage of RFID technology within various sectors.

In terms of RFID-enabled asset management applications, our results are consistent with the results of prior research on the topic (Van Oranje et al., 2009). Indeed Van Oranje et al. (2009) found that ‘asset identification of blood bags’ and ‘asset tracking and tracing to avoid procedure delays’ were among the most important applications to improve quality of care, while ‘inventory management’, ‘asset tracking and tracing for expiration date and restocking’ and ‘asset tracking and tracing for access control and inventory shrinkage decrease’ are among the most important applications to contain healthcare costs.

6 Conclusion, limits and future research directions

We used a modified web-based Delphi study to explore the drivers and challenges of RFID adoption, a key technology at the core of the ‘Internet of Things’ concept in the healthcare sector. More specifically, we asked the Delphi panel to assess a list of 12 processes related to the relative advantage of RFID and ten processes related to RFID-enabled asset management derived from the literature. A 5-point Likert scale was used by the panellists in the evaluation. Results show that all the top five processes related to the relative advantage of RFID reflect high levels of consensus. These are ‘improved traceability’ (1st), ‘improved operational efficiency’ (2nd), ‘provided real-time information access and exchange’ (3rd), ‘improved firm internal and external co-ordination of material flows’ (4th), and ‘improved visibility’ (5th). We also yield a high level of consensus for the top five processes related to asset management; however, three processes are tied at first place: ‘asset identification of blood bags’ (1st), ‘asset tracking and tracing for expiration date and restocking (1st), ‘inventory management’ (1st), and finally ‘asset tracking and tracing to avoid procedural delays’ (4th), ‘asset tracking and tracing for access control and decreasing inventory shrinkage’ (5th).

For the intra-panel agreement (e.g. healthcare practitioners and non-healthcare practitioners), results indicate a weak and statistically significant level of consensus among the two distinct groups of panel members with regard to the relative advantage of RFID for the two rounds of the Delphi study. With regard to asset management-related processes, although a very weak and statistically significant level of consensus is observed among the non-healthcare panel members for the two rounds of the Delphi study, a moderate and statistically significant level of consensus is achieved among the healthcare members for the two rounds of the Delphi study. This result may suggest that for more specific processes related to asset management in the healthcare sector, there is an enhanced common understanding of the potential effects of RFID-enabled smart healthcare asset management among the healthcare panel members. An implication of this observation may be the need to carefully select panel members when assessing the effects of RFID technology in a specific business context.

This study provides a list of processes related to the relative advantage of RFID and processes related to RFID-enabled asset management in the healthcare sector. This study may serve as a starting point for future research on the effect of RFID technology in the said sector. Similarly, the same list may serve as a complete checklist for healthcare managers as they explore the potential of RFID technology. Future research can build upon our list to assess the effect of RFID as an enabler of healthcare asset management at the focal firm level (e.g. within one healthcare facility) and at the inter-firm level (e.g. between multiple healthcare facilities). Furthermore, it would be interesting to examine the effect of improved RFID-based healthcare asset management on healthcare staff performance, service quality, operational efficiency, patient satisfaction and patient care. Finally, further research must be conducted to assess the cost-benefit of RFID-enabled healthcare asset management projects at the focal firm and inter-firm levels.

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Note

1 Senior Scholars' Basket of Journals: http://home.aisnet.org/displaycommon.cfm?an=1&subarticlenbr=346

Appendix A Articles on the 'Internet of Things' gathered from the AIS basket of journals and the list of top health informatics journals

Reference	*Objectives*	*Methodology*	*Key Findings*
Baars et al. (2009)	Based on the insights from the case studies, an evaluation framework is introduced and combines with the benefit evaluation to determine the multifaceted benefits from deployment of RFID.	Case Study	The paper presents an evaluation framework which considers accounting the entire evaluation process (identification, forecast and assessment) to identify the benefits of RFID.
Se-Joon and Yan (2006)	The paper focuses on finding the factors influencing the adoption of multipurpose information appliances beyond the work settings and how these factors affect the user intentions to adopt these technologies.	Survey	The investigation on mobile data service utilising an adoption model incorporating adoption drivers (general technology perceptions, technology-specific perceptions, user psychographics, social influence and demographics) is proposed and tested.
Eriksson and Ågerfalk (2010)	The paper elaborates on the problems of descriptive identifier, identifier selection, and identifier control by exploring the meaning of the identifier construct from a technical, institutional, ontological, and information infrastructural perspective.	Conceptual/Developmental	The principles guiding the design of identifiers in order to avoid lock-in situations, inefficiency, and quality problems in information infrastructures are provided.
Istepanaian and Zhang (2012)	The paper provides a review reflecting a spectrum of recent advances in m-health technologies and the role of the emerging mobile and network technologies (4G) in m-health systems and applications.	Review	The concept of 4G health in relation to the long-term evolution of m-health is reviewed. The challenges to be addressed are summarised; they include globalisation and the potential options of decreasing healthcare disparities and inequality levels, the development of the best applicable 4G health ecosystem, social medicine challenges, privacy and security challenge and future mobile technologies beyond 4G.