Contributions to Radio Frequency Identification (RFID) research: An assessment of SCI-, SSCI-indexed papers from 2004 to 2008

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ABSTRACT

The research literature on Radio Frequency Identification (RFID) has grown exponentially in recent years. In a domain where new concepts and techniques are constantly being introduced, it is of interest to analyze recent trends in this literature. Although some attempts have been made in the past to review this stream of research, there has been no attempt to assess the contributions to this literature by individuals and institutions. This study assesses the contributions of individual researchers and institutions from 2004 to 2008, based on their publications in SCI- or SSCI-indexed journals. The findings of this study offer researchers a unique view of this field and some directions for future research.

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1. Introduction

Radio frequency identification (RFID) is a small tag containing an integrated circuit chip and an antenna, and has the ability to respond to radio waves transmitted from the RFID reader in order to send, process, and store information [40]. The advantage of RFID tags is that they use a memory storage device to store a certain amount of data such as the product identification number, price, cost, manufacture date, location, and inventory on hand [7]. As technologies continue to advance forward in antenna technology, microchip fabrication and radio spread spectrum, RFID is rapidly pushed to the existing markets with diversified applications, such as automatic tariffs payment in public transport, animal identification and tracking, and automated manufacturing and logistics control [39]. RFID has the potential to change the way we do business all around the world [32]. Many business enterprises are applying the advantages of RFID to experimental projects to improve operational efficiency and to gain a competitive advantage [4]. RFID has become a hot topic in the fields of manufacturing and logistics [25]. Given the emerging significance of RFID over the past few decades, it is hardly surprising that RFID technology and its application have attracted much attention from academics and practitioners in recent years [23].

As a field of academic inquiry, RFID has attracted numerous researchers during the last few years. In the past, there have been several attempts to review and synthesize the RFID literature, and/or to offer suggestions for other researchers (e.g., [7,23,25,32,33]). These efforts significantly consolidated the knowledge of RFID and pointed out a number of very important research directions for RFID researchers. Yet there has been no attempt to assess the contributions of individual researchers and institutions to this field of inquiry, nor has there been any attempt to assess the impact of various publications in this field. Researchers and readers of this literature are left wondering what has been researched recently, which outlets are most appropriate for publishing RFID research, who the major contributors are, and which articles have had the greatest impact on the field in recent years. Given that RFID is a well-established field, it is important to address these unanswered questions because such knowledge could give researchers a more complete view of their field, a clear idea about their potential impact on the literature, a guide in selecting their research topics and target journals, and motivation to continue making contributions to this field.

The purpose of this study is threefold. First, the primary issues of recent RFID research and the major outlets for RFID research are investigated. Specifically, the Science Citation Index (SCI)-indexed and Social Science Citation Index (SSCI)-indexed journals are ranked by the number of articles that they have published on RFID topics; the frequency of publications focusing on various topics is also reported. Second, the productivity of individual researchers and institutions in RFID research between 2004 and 2008 is assessed. This is done by tabulating the credited publications of individual researchers and institutions in SCI-indexed and SSCI-indexed journals. Third, the impact of individual publications and individual researchers on the RFID literature is assessed based on a citation analysis. In the remainder of this paper, the methodology adopted for this investigation will be described. This will be followed by a presentation of the

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results of the assessment. The paper will conclude with a discussion of the outcomes of the investigation.

2. Method

2.1. Protocol used for selecting the journal articles

The protocol for journal selection and analysis is illustrated in Fig. 1.

2.1.1. Scope of the study

As RFID research itself, this paper focuses on RFID articles published in SCI- or SSCI-indexed journals from 2004 to 2008. The rationale for a focus on SCI- or SSCI-indexed journals is that publications in such journals are likely to have the largest exposure to RFID researchers and to reflect state-of-the-art RFID research that generates a significant number of citations in the literature. While RFID research has been around for the past few decades, and many early contributions have had a major impact on the literature, the current interest is in assessing recent contributions to the RFID literature. This is because contributions between 2004 and 2008 reflect the changes in the RFID environment more closely, including but not limited to the rapid globalization of world markets and substantially increased cross-border business. It is important to keep in mind that the current study's focus on recent publications by no means implies a lack of impact of publications appearing before 2004. Rather, focusing on the contributions between 2004 and 2008 should render the results of this study more relevant to current RFID researchers.

2.1.2. Selection of papers

The RFID articles were selected through a combination of electronic and manual searches. The ABI/INFORM database was used to identify a pool of articles that might be relevant to RFID. Keywords such as "radio frequency identification" and "RFID" were used to identify electronically articles published in SCI- or SSCI-indexed journals. This method is being widely used in studies of other fields [36,41]. Although this restriction might have excluded certain papers, we can be sure that the papers identified are studies in the RFID field.

We included each paper after manual examination and confirmation of its relevance to RFID. We used the following guidelines in the confirmation process. First, as the purpose of this research was to evaluate the contribution of RFID studies, only academic research papers were considered, while journal editorials, comments on previous papers, book reviews, and magazine articles were excluded. Second, as this research was primarily concerned with research in the RFID field, studies that only mentioned the term RFID in passing were not considered to be exploring RFID-related issues and were excluded. Overall, 94 articles were identified from both searches in 44 journals between 2004 and 2008.
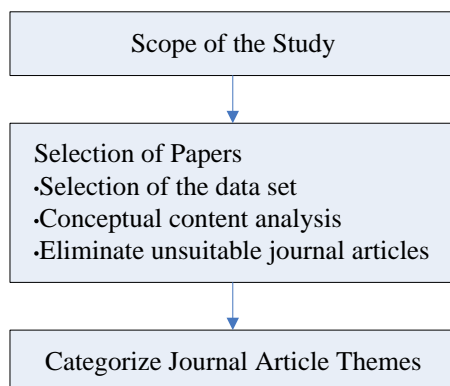

Fig. 1. Protocol used for selecting the journal articles.

2.1.3. Categorize journal article themes

According to the method proposed by Ngai et al. (2008) [25], RFID literature is classified into four main categories: technological issues, applications areas, policy and security issues, and other issues. Each of these categories is divided into several sub-categories. The 94 articles in the pool were content-analyzed to uncover the major topical areas of RFID research. Examined by title, abstract, and content, articles were then assigned to one of the following sub-categories. Each article was classified into one of these sub-categories on the basis of its primary topic. It should be recognized that some articles investigated multiple topics. Because this classification system does not allow an article to be classified into more than one topic area, it does not reflect the topical variations within an article. Rather, it is meant to capture the primary topics investigated in the 94 articles.

2.1.3.1. RFID technology. A typical RFID system consists of tags and readers, application software, computing hardware, and middleware. We focus our attention on the articles that pertain directly to the RFID system, including tags, readers, antennae, and communications infrastructure, but exclude the literature on computer software. We divide the technology category into the following sub-categories.

(1) Tags and antennae: An RFID tag consists of an integrated circuit with memory, which is essentially a microprocessor chip. The antennae are the conduits for the communication of data between the tag and the reader. This area focuses on RFID chips and tag antennae.
(2) Reader: An RFID reader is a device that can read data from and write data to compatible RFID tags. To ensure the compatibility of the communication, the tag and reader must work at the same specified working frequency and comply with specific regulations and protocols. Papers related to this section aimed at RFID readers design to ensure the compatibility of the communication.
(3) Communication infrastructure: This category includes articles on the relevant communication criteria and protocols, safeguards, and network connectivity issues.

2.1.3.2. RFID applications. RFID is an emerging technology that has been successfully applied in supply chain management, manufacturing, and logistics, but its range of application extends far beyond these areas. Based on the various industry areas that are featured in the reviewed literature, we sub-classify this category as follows.

(1) Animal detection
(2) Building management
(3) Enterprise feedback control
(4) Food safety warranties
(5) Health
(6) Library services
(7) Logistics and supply chain management
(8) Museums
(9) Retailing
(10) Manufacturing
(11) Casinos

2.1.3.3. Policy and security issues. The literature in this category is mainly divided into three broad sub-categories, namely, privacy, security, and standardization.

(1) Privacy: Studies of RFID privacy and protection issues, and especially those that examine RFID in relation to existing human rights policies, constitutional protection, and data protection law, are therefore included in this section.
(2) Security: Security concerns revolve around vulnerabilities and the protection of confidential data from unauthorized access and manipulation.

(3) Standardization: The creation and adoption of official standards can powerfully accelerate the adoption of new technology [3].

2.1.3.4. Other issues. This category includes publications that discuss other aspects of RFID technology, we sub-classify this category as follows.

(1) Customer: The key to a successful RFID application is how it considers the equation from the consumer's point of view [8].
(2) Implementation: This area concerns the various steps of implementation of RFID, and related problems, conditions of success, and reasons for failures.
(3) Management: This section focuses on RFID as a management tool, showing what changes and what remains constant in a company's business organization.
(4) Literature Review: An RFID literature review is a body of text that aims to review the critical points of knowledge about RFID topics.

2.2. Total contributions and credited contributions

To assess the productivity of individual researchers in RFID research, both the total author appearances and the well-established "adjusted author (credited) and institution appearances" methods were adopted. These methods have been used in assessing author and institutional contributions to marketing research (e.g., [34]), advertising research (e.g., [15,41]), international business research (e.g., [18]), finance research (e.g., [14]), and adult education research (e.g., [31]). In this study, the number of articles that an author has published as either a single author or as a coauthor constitutes the total contributions of that author. As for credited contributions, if a published article has a single author, the author is credited for one (1) publication. If an article has two authors, each author is credited with half (0.5) a publication. If an article has three authors, each author is credited with one-third (0.333) of a publication. The same formula applies to articles with four or more authors. An author's total credited contributions is the sum of his or her credited publications for all articles that he or she authored or coauthored in the pool of the 94 identified RFID articles.

To assess the contributions of institutions to RFID research, however, only credited contributions were used. In contrast to individual author names, which would never appear more than once on a published article, institution names could appear more than once on the same published article, if, for example, two or more faculty members from the same institution coauthored the article. As a result, the total appearances method should not be used for assessing the contributions of institutions, to avoid double (or triple) counting of the institutions for the same articles. Thus, institutions whose faculty members authored or coauthored an article are credited for the same portion of a publication for which their faculty members are credited. For example, if a faculty member of an institution coauthored one of the 94 articles with two other authors from other institutions, the first institution is credited for one-third (0.333) of the publication. If two faculty members of the same institution coauthored an article, the institution is credited for one publication (0.5 + 0.5). The same method applies in a similar way to articles coauthored by any other combination of coauthors. An institution's total credited contributions is the sum of its credited publications for all articles that its faculty members authored or coauthored in the 94-article pool that is the focus of this study.

2.3. Citation analysis

Citation analysis is the formal quantitative analysis of the literature produced by a field and the relationships among people as evidenced by whom they cite in their published articles [19]. In particular, in academic disciplines where the importance of publication and citation is high, the bibliographic references used in research documents can be an important mirror of how people in a field construe it [19]. Citations in a journal article are a measure of the extent to which the author(s) of the article considered the cited works useful to their own research and to the development of their own field of knowledge [6]. Thus, the number of citations that a published journal article has received (that is, the number of other publications that cited the article) is a good measure of the impact that the article has had on the literature. Indeed, citation counts are widely accepted as a superior ranking criterion in comparison with individual opinions regarding the impact of an article on the social science literature. It is noteworthy, however, that citation analysis is sometimes subject to criticism on the grounds of such possibilities as negative citations, self-citations, and a bias that favors methodological articles. Moreover, the number of citations that an article has received does not reveal the underlying reason for the citation, nor does it show the topical areas on which the citing articles are focused. Nevertheless, the citation count of an article is a reflection of the interest that other social science researchers have had in the cited article [18].

The SCI and SSCI are widely accepted around the world as the most authoritative measures of the impact of an article on the related literature [41]. They have been frequently used in articles published in major academic journals to assess the impact of articles on research literature. An article that has a significantly higher count than another article is believed to have had a more significant impact on the related literature [18].

To assess the impact of an individual author on RFID research, the SCI or SSCI citations of all articles in the 94-article pool that he or she had authored or coauthored were summed up into the total SCI or SSCI citations for that author. The total SCI or SSCI citation score for an author is a measure of his or her cumulative impact on the RFID literature. For example, if an author has published three articles in the 94-article pool, the total citation count for the author is the sum of the SCI or SSCI citations of the three articles. Thus, an article's total SCI or SSCI citations measure the article's overall impact, whereas an author's total SCI or SSCI citations for his or her article in the 94 articles in this study's pool measure the author's impact on RFID literature.

In the current study, the Institute for Scientific Information (ISI) Web of Science database was used to assess the impact of each RFID article and its author(s). Thus, for each article in the 94-article pool, its SCI or SSCI citations were obtained from the ISI Web of Science database. A researcher's total SCI or SSCI citations were computed as the sum of the SCI or SSCI citations of all the articles in the 94-article pool that the researcher authored or coauthored.

3. Results

3.1. Frequency of RFID research in journals

Table 1 presents the total number of RFID research articles published in each of the 44 journals targeted in this study between 2004 and 2008. As is shown, we found that 45.75% of the 94 RFID-related articles published in the 44 SCI- or SSCI-indexed journals from 2004 to 2008 appeared in the following "top five" journals: International Journal of Production Economics (twelve articles, or 12.77%); Production and Operations Management (ten articles, or 10.64%); Communications of the ACM (nine articles, or 9.57%); Industrial Management & Data Systems (eight articles, or 8.51%); and Computer Networks (four articles, or 4.26%). The International Journal of Production Economics and Production and Operations Management appear to be the most popular outlets for RFID research. Furthermore, there are 70 articles published in SCI-indexed journals, 16 articles published in SSCI-indexed journals, and 8 articles published in both SCI- and SSCI-indexed journals. It's obvious that the

Table 1
Number of RFID articles published in SCI- or SSCI-indexed journals (2004–2008).

Journal	Number of articles	Percentage of total
International Journal of Production Economics	12	12.77%
Production and Operations Management	10	10.64%
Communications of the ACM	9	9.57%
Industrial Management & Data Systems	8	8.51%
Computer Networks	4	4.26%
Library Hi Tech	3	3.19%
Supply Chain Management	3	3.19%
Assembly Automation	2	2.13%
Computers & Security	2	2.13%
Decision Sciences	2	2.13%
Decision Support Systems	2	2.13%
IEEE Spectrum	2	2.13%
IIE Transactions	2	2.13%
Journal of Manufacturing Systems	2	2.13%
Technovation	2	2.13%
Other 29 journals	1	30.85%

articles published in SCI-indexed journals take the vast majority in the 94 articles.

3.2. Frequency of RFID research by topics

Table 2 presents the frequency of the topical areas researched in the 94 articles. As shown in Table 2, the top most researched topics is RFID applied in logistics and supply chain management (twenty articles, or 21.28%). RFID applied in retailing (eight articles, or 8.51%) and implementation of RFID (eight articles, or 8.51%) are the next two most frequently researched topics. Communication infrastructure and privacy issue are primarily researched in seven articles (7.45%), respectively.

3.3. Top individual contributors to RFID research

Table 3 shows the top individual contributors to RFID research based on total contributions between 2004 and 2008. As can be seen, Ngai, E.W.T. and Lee, H. are the top two contributors to the RFID research realm, each with three or more publications. Angeles, R., Cheng, T.C.E., Dallery, Y., Gaukler, G.M., Hausman, W.H., Huang, G., Lai, K.-H., Mickle, M.H., Moon, K.L., Rekik, Y. and Sahin, E. round out the top thirteen individual contributors category, each with two publications.

Table 2
Frequency of RFID articles by topical areas (2004–2008).

Topical areas		Number of articles	Frequency
RFID technology	Tags and antennae	3	3.19%
	Reader	3	3.19%
	Communication infrastructure	7	7.45%
RFID applications	Animal detection	3	3.19%
	Building management	1	1.06%
	Enterprise feedback control	2	2.13%
	Food safety warranties	1	1.06%
	Health	1	1.06%
	Library services	4	4.26%
	Logistics and supply chain management	20	21.28%
	Museums	1	1.06%
	Retailing	8	8.51%
	Manufacturing	4	4.26%
	Casinos	1	1.06%
Privacy and security	Privacy	7	7.45%
	Security	3	3.19%
	Standardization	3	3.19%
Others	Customer	5	5.32%
	Implementation	8	8.51%
	Management	4	4.26%
	Literature review	5	5.32%

Table 3
Top contributors to RFID research based on total number of publications in SCI- or SSCI-indexed journals (2004–2008).

Author	Total number of publications	Rank
Ngai, E.W.T.	5	1
Lee, H.	3	2
Angeles, R.	2	3
Cheng, T.C.E.	2	3
Dallery, Y.	2	3
Gaukler, G.M.	2	3
Hausman, W.H.	2	3
Huang, G.	2	3
Lai, K.-H.	2	3
Mickle, M.H.	2	3
Moon, K.L.	2	3
Rekik, Y.	2	3
Sahin, E.	2	3
Other 222 authors	1	14

There are 222 authors who contributed one publication each on RFID in the 2004–2008 period.

Table 4 presents the list of top individual contributors to RFID research based on their total credited contributions. As can be seen, Angeles, R. is the top contributor to this field based on total credited contributions, followed by Ngai, E.W.T. and Lee, H. From Tables 3 and 4, it appears that there is a group of researchers who have been active in RFID research and have frequently published RFID articles in SCI- or SSCI-indexed journals.

3.4. Top institutional contributors to RFID research

Table 5 shows the top institutional contributors to RFID research based on their total credited contributions. Hong Kong Polytechnic University and Stanford University are the top two institutional contributors, with 3.5 or more total credited contributions. University of New Brunswick Fredericton, Naval Postgraduate School, Indiana University, Ecole Centrale Paris and Arizona State University have 2.0

Table 4
Top contributors to RFID research based on total credited publications in SCI- or SSCI-indexed journals (2004–2008).

Author	Credited number of publications	Rank
Angeles, R.	2.000	1
Ngai, E.W.T.	1.500	2
Lee, H.	1.333	3
Attaran, M.	1.000	4
Ayoade, J.	1.000	4
Chien, H.-Y.	1.000	4
Dew, N.	1.000	4
Eckfeldt, B.	1.000	4
Graafstra, A.	1.000	4
Heese, H.S.	1.000	4
Lekakos, G.	1.000	4
Mehrjerdi, Y.Z.	1.000	4
Muir, S.	1.000	4
Peslak, A.R.	1.000	4
Piramuthu, S.	1.000	4
Ranky, P.G.	1.000	4
Roberts, C.	1.000	4
Stajano, F.	1.000	4
Wyld, D.C.	1.000	4
Yu, S.-C.	1.000	4
Gaukler, G.M.	0.833	21
Hausman, W.H.	0.833	21
Moon, K.L.	0.750	23
Dallery, Y.	0.583	24
Huang, G.	0.583	24
Mickle, M.H.	0.583	24
Rekik, Y.	0.583	24
Sahin, E.	0.583	24
Other 207 authors	<0.583	

Table 5
Top institutional contributors to RFID research (2004–2008).

Institution	Credited number of publications	Rank
Hong Kong Polytechnic University	6.250	1
Stanford University	3.500	2
University of New Brunswick Fredericton	2.000	3
Naval Postgraduate School	2.000	3
Indiana University	2.000	3
Ecole Centrale Paris	2.000	3
Arizona State University	2.000	3
National Tsing Hua University	1.667	8
Athens University of Economics and Business	1.667	8
University of North Texas	1.500	10
University of Pittsburgh	1.333	11
University of Michigan	1.333	11
University of Cambridge	1.333	11
Oklahoma State University	1.333	11
University of Washington	1.125	15
University of Hong Kong	1.083	16
Other 101 institutions	<1.083	

total credited contributions, while National Tsing Hua University, Athens University of Economics and Business and University of North Texas have more than 1.5 but fewer than two total credited contributions.

It is worth noting that five institutions in U.S., two institutions in China (including Mainland China, Taiwan, and Hong Kong), two in Europe, and one in Canada are among the top 10 institutional contributors to RFID research. Although these institutions outside the United States have made significant contributions to this field, it appears that U.S. institutions are the most frequent contributors to RFID research in the current study's targeted journals. It is also interesting to note the conspicuous absence of some elite research schools among the top-ranked institutional contributors based on total credited contributions.

3.5. Most cited RFID research articles

The 94 RFID research articles were ranked based on the total citation count. Table 6 lists the names of the authors of the most cited RFID articles published between 2004 and 2008, the journals in which they were published, the article titles, the number of citations of the articles, and their rankings. The most cited RFID research article is Ni et al. [26]. Rounding out the top ten are Angeles [1], Roberts [33], Prater et al. [30], Wu et al. [40], Ohkubo et al. [27], Ngai et al. [24], Günther and Spiekermann [12], Hou and Huang [16], and Hsi and Fait [17]. From Table 6, it is apparent that the most cited RFID research articles were published in SCI- or SSCI-indexed journals. These are the leading journals that published high-impact RFID articles from 2004 to 2008. Also noteworthy is that although the number of citations of the top-ranked RFID articles received is impressive, most citation counts are relatively modest. Other than the top 10 most cited articles, the articles listed in Table 6 received 18 or fewer citations.

The cumulative citation count tends to favor articles that were published in earlier years (as they have more years in which to receive citations), so it may not be the best indicator of an article's impact on the literature. To better gauge the relative impact of an article, the number of citations needs to be adjusted for the number of years the article has been available for citation. Table 7 shows the ranking of the most cited RFID articles based on citations per year. Based on this table, the top ten high-impact articles are Ni et al. [26], Roberts [33], Ngai et al. [24], Gaukler and Hausman [10], Angeles [1], Wu et al.[40], Lee and Özer [20], Ngai et al. [25], Prater et al. [26], and Gaukler et al. [11]. Table 8 shows abstracts for the top ten high impact articles. The research methods they used included qualitative research such as prototype system and general review, and quantitative research such as those that used static model and analytic models. Table 9 shows methodology and category of the top ten high impact articles.

3.6. Most cited RFID researchers

To identify the most cited RFID researchers, total citation counts were used. Table 10 shows the most cited RFID researchers who had published at least one RFID article between 2004 and 2008, based on their total citation counts. As can be seen, Angeles, R. is the most cited RFID researcher, followed by Ngai, E.W.T., Roberts, C., Frazier, G.V., Prater, E., Reyes, P.M., Lin, T.-R., Nystrom, M., Wu, N.-C., and Yu, H.-C. Not surprisingly, most of these authors are also ranked among the top individual contributors to RFID research. Clearly, for the period of 2004 to 2008, they are among the top scholars in RFID and represent the core intellectual pool of the field.

Table 6
Most cited RFID articles by cumulative SCI or SSCI citations (2004–2008).

Author(s)	Journal	Article title	Citations	Rank
Ni, L.M., Liu, Y., Lau, Y.C. and Patil, A.P. (2004)	Wireless Networks	LANDMARC: Indoor Location Sensing Using Active RFID [26]	60	1
Angeles, R. (2005)	Information Systems Management	RFID technologies: Supply-chain applications and implementation issues [1]	43	2
Roberts, C. (2006)	Computers &Security	Radio frequency identification (RFID) [33]	33	3
Prater, E., Frazier, G.V. and Reyes, P.M. (2005)	Supply Chain Management	Future impacts of RFID on e-supply chains in grocery retailing [30]	30	4
Wu, N.-C., Nystrom, M., Lin, T.-R. and Yu, H.-C. (2006)	Technovation	Challenges to global RFID adoption [40]	29	5
Ohkubo, M., Suzuki, K. and Kinoshita, S. (2005)	Communications	RFID privacy issues and technical challenges of the ACM [27]	23	6
Ngai, E.W.T., Cheng, T.C.E., Au, S. and Lai, K.-h. (2007)	Decision Support Systems	Mobile commerce integrated with RFID depot technology in a container [24]	22	7
Günther, O. and Spiekermann, S.(2005)	Communications of the ACM	RFID and the perception of control [12]	21	8
Hou, J.-L. and Huang, C.-H. (2006)	Industrial Management & Data Systems	Quantitative performance evaluation of RFID applications in the supply chain of the printing industry [16]	20	9
Hsi, S. and Fait, H.(2005)	Communications of the ACM	RFID enhances visitors' museum experience at the Exploratorium [17]	19	10
Smith, J.R., Fishkin,K.P., Jiang, B., Mamishev, A., Philipose, M., Rea, A.D., Roy, S., and Sundara-Rajan, K. (2005)	Communications of the ACM	RFID-based techniques for human-activity detection [35]	18	11
Eckfeldt, B. (2005)	Communications of the ACM	What does RFID do for the consumer? [8]	17	12
Lee, H. and Özer, Ö. (2007)	Production and Operations Management	Unlocking the Value of RFID [20]	17	12
Gaukler, G.M., Seifert, R.W. and Hausman, W.H. (2007)	Production and Operations Management	Item-Level RFID in the Retail Supply Chain [11]	15	14
Ranky, P.G. (2006)	Assembly Automation	An introduction to radio frequency identification (RFID) methods and solutions [32]	14	15
Other 79 articles			<14	

Table 7
Most cited RFID articles by SCI or SSCI citations per year (2004–2008).

Author(s)	Journal	Article title	Citations/ Year	Rank
Ni, L.M., Liu, Y., Lau, Y.C. and Patil, A.P. (2004)	Wireless Networks	LANDMARC: Indoor Location Sensing Using Active RFID [26]	12.00	1
Roberts, C. (2006)	Computers and Security	Radio frequency identification (RFID) [33]	11.00	2
Ngai, E.W.T., Cheng, T.C.E., Au, S. and Lai, K.-h. (2007)	Decision Support Systems	Mobile commerce integrated with RFID depot technology in a container [24]	11.00	2
Gaukler, G.M. and) Hausman, W.H. (2008	IIE Transactions	RFID in mixed-model automotive assembly operations: Process and quality cost savings [10]	11.00	2
Angeles, R. (2005)	Information Systems Management	RFID technologies: Supply-chain applications and implementation issues [1]	10.75	5
Wu, N.-C., Nystrom, M., Lin, T.-R. and Yu, H.-C. (2006)	Technovation	Challenges to global RFID adoption [40]	9.67	6
Lee, H. and Özer, Ö. (2007)	Production and Operations Management	Unlocking the Value of RFID [20]	8.50	7
Ngai, E.W.T., Moon, K.L., Riggins, F.J. and Yi, C.Y. (2008)	International Journal of Production Economics	RFID research: An academic literature review (1995–2005) and future research directions [25]	8.00	8
Prater, E., Frazier, G.V. and Reyes, P.M. (2005)	Supply Chain Management	Future impacts of RFID on e-supply chains in grocery retailing [26]	7.50	9
Gaukler, G.M., Seifert, R.W. and Hausman, W.H. (2007)	Production and Operations Management	Item-Level RFID in the Retail Supply Chain [11]	7.50	9
Bottani, E. and Rizzi, A. (2008)	International Journal of Production Economics	Economical assessment of the impact of RFID technology and EPC system on the fast-moving consumer goods supply chain [5]	7.00	11
Tzeng, S.-F., Chen, W.-H.and Pai, F.-Y. (2008)	International Journal of Production Economics	Evaluating the business value of RFID: Evidence from five case studies [38]	7.00	11
Hou, J.-L. and Huang, C.-H. (2006)	Industrial Management and Data Systems	Quantitative performance evaluation of RFID applications in the supply chain of the printing industry [16]	6.67	13
Lee, L.S., Fiedler, K.D. and Smith, J.S. (2008)	International Journal of Production Economics	Radio frequency identification (RFID) implementation in the service sector: A customer-facing diffusion model [21]	6.00	14
Ohkubo, M., Suzuki, K. and Kinoshita, S. (2005)	Communications of the ACM	RFID privacy issues and technical challenges [27]	5.75	15
Other 79 articles			<5.75	

4. Discussion, limitations, suggestions and future studies

4.1. Discussion

This study represents the first attempt to assess the contributions to RFID research by individual and institutional contributors in the period from 2004 to 2008. It also assesses the impact of individual articles and individual authors on the RFID literature based on SCI or SSCI citation analysis. The implications of the study are discussed below, in the hope of offering some concluding remarks about the RFID literature.

First, the journals that published the largest number of RFID research articles are the International Journal of Production Economics, and Production and Operations Management. Six of the top 15

Table 8
Abstracts of top 10 cited RFID articles by SCI or SSCI citations per year (2004–2008).

Author(s)	Article title	Abstract
Ni, L.M., Liu, Y., Lau, Y.C. and Patil, A.P. (2004)	LANDMARC: Indoor Location Sensing Networks Using Active RFID [26]	This paper presents LANDMARC, a location sensingprototype system, that uses RFID technology for locating objects inside buildings.
Roberts, C. (2006)	Radio frequency identification (RFID) [33]	Some see RFID as the inevitable replacement for bar codes. Increasing demand brings increasing concern on privacy and security. Clearly there are considerable work to be undertaken before RFID becomes as pervasive as bar codes, though the tempo of change is increasing rapidly.
Ngai, E.W.T., Cheng, T.C.E., Au, S. and Lai, K.-h. (2007)	Mobile commerce integrated with RFID depot technology in a container [24]	The authors present the findings of a case study on the development of a RFID prototype system. It's depot technology is integrated with m-commerce in a container. A system architecture, capable of integrating mobile commerce and RFID applications, is proposed.
Gaukler, G.M. and Hausman, W.H. (2008)	RFID in mixed-model automotive assembly operations: process savings and quality cost savings [10]	This research shows how to characterize the potential and operational benefits of RFID in a complex assembly system. Both process savings and quality (rework) savings are included in the presented model, and it shows that process savings and quality cost savings are strongly interdependent.
Angeles, R. (2005)	RFID technologies: Supply-chain applications and implementation issues [1]	This article provides an introduction to the technology, several case examples, and implementation guidelines for managers based on published reports.
Wu, N.-C., Nystrom, M., Lin, T.-R. and Yu, H.-C. (2006)	Challenges to global RFID adoption [40]	This paper explores the existing challenges and obstacles to RFID's quick adoption. the potential resolutions and approaches to the challenges, and the migration strategies to expand the RFID industry.
Lee, H. and Özer, Ö. (2007)	Unlocking the Value of RFID [20]	This paper argues that there is a huge credibility gap of the value of RFID, a void exists in showing how the proclaimed values arrive at, and how those values can be realized. The paper shows that this credibility gap must be filled with solid model analysis, and therefore presents a great opportunity for the Production and Operations Management research community.
Ngai, E.W.T., Moon, K.L., Riggins, F.J. and Yi, C.Y. (2008)	RFID research: An academic literature review (1995–2005) and future research directions [25]	In this paper, the authors present a literature review of 85 academic journal papers that were published on this subject between 1995 and 2005.
Prater, E., Frazier, G.V. and Reyes, P.M. (2005)	Future impacts of RFID on e-supply chains in grocery retailing [26]	The focus of this paper is on RFID research within the context of the grocery industry. It also outlines the market drivers that affect the way the grocery approaches RFID. Specific areas of research industry on RFID should be undertaken to provide the grocery industry better with managerial insights into this technology's application.
Gaukler, G.M., Seifert, R.W. and Hausman, W.H. (2007)	Item-Level RFID in the Retail Supply Chain [11]	Within the context of this retail supply chain, the authors present analytic models of the item-level RFID benefits to both supply chain partners.

Table 9
Methodology and category of most cited RFID articles by SCI or SSCI citations per year (2004–2008).

Reference for Most Cited Article	Research Methodology Used	Category 1	Category 2	Category 3	Category 4
Ni, L.M., Liu, Y., Lau, Y.C. and Patil, A.P. (2004) [26]	Prototype system		√		
Roberts, C. (2006) [33]	General review				√
Ngai, E.W.T., Cheng, T.C.E., Au, S. and Lai, K.-h. (2007) [24]	Prototype system	√			
Gaukler, G.M. and) Hausman, W.H. (2008) [10]	Static model				√
Angeles, R. (2005) [1]	General review		√		
Wu, N.-C., Nystrom, M.,Lin, T.-R. and Yu, H.-C. (2006)[40]	General review				√
Lee, H. and Özer, Ö. (2007) [20]	Analytic model			√	
Ngai, E.W.T., Moon, K.L., Riggins, F.J. and Yi, C.Y. (2008) [25]	General review				√
Prater, E., Frazier, G.V. and Reyes, P.M. (2005) [26]	General review		√		
Gaukler, G.M., Seifert, R.W. and Hausman, W.H. (2007) [11]	Analytic model		√		
Bottani, E. and Rizzi, A. (2008) [5]	Questionnaire survey		√		
Tzeng, S.-F., Chen, W.-H. and Pai, F.-Y. (2008) [38]	Case study				√
Hou, J.-L. and Huang, C.-H. (2006) [16]	Interview and questionnaire survey		√		
Lee, L.S., Fiedler, K.D. and Smith, J.S. (2008) [21]	Case study				√
Ohkubo, M., Suzuki, K. and Kinoshita, S. (2005) [27]	General review			√	

Note: Category 1: RFID technology; Category 2: RFID applications; Category 3: policy and security issues; Category 4: other issues.

most cited RFID articles, based on cumulative citations per year, came from these journals. This could be because of the broader nature of these journals, which makes it more conducive for researchers to cite the articles published in these journals. To enhance the likelihood of making a major impact on the literature, RFID researchers may have to select research topics that have broader appeal and to target less-specialized journals to publish their work. This study highlights the fact that the majority of research has been published in more technical publications such as SCI-indexed journals. However, as the focus shifts from the technical issues to the business issues, and as RFID begins to be applied to various locations along the value chain, we should expect to see more RFID research published in management and business publications such as SSCI-indexed journals.

Second, with regard to the topical areas of research, it is evident that issues related to logistics and supply chain management, and RFID applied in retailing continue to form a major topic in RFID research. Because of the nature of electronic identity to any object, RFID technology can help companies succeed in moving goods around efficiently, to cut costs, and to deliver a wealth of information that

Table 10
The most cited researchers in RFID based on total citations.

Author	Total citations	Rank
Angeles, R.	45	1
Ngai, E.W.T.	41	2
Roberts, C.	33	3
Frazier, G.V.	30	4
Prater, E.	30	4
Reyes, P.M.	30	4
Lin, T.-R.	29	7
Nystrom, M.	29	7
Wu, N.-C.	29	7
Yu, H.-C.	29	7
Cheng, T.C.E.	28	11
Lai, K.-H.	28	11
Gaukler, G.M.	26	13
Hausman, W.H.	26	13
Kinoshita, S.	23	15
Ohkubo, M.	23	15
Suzuki, K.	23	15
Au, S.	22	18
Günther, O.	21	19
Spiekermann, S.	21	19
Hou, J.-L.	20	21
Huang, C.-H.	20	21
Lau, Y.C.	20	21
Liu, Y.	20	21
Ni, L.M.	20	21
Patil, A.P.	20	21
Other 209 authors	<20	

helps companies more efficiently predict and respond to customer demand [2,37]. This technology promises to offer both process freedoms and near-perfect information visibility throughout the supply chain across different industries [1]. Many business enterprises are applying the advantages of RFID to experimental projects to improve operational efficiency and to gain a competitive advantage [4]. It is not surprising to find that issues attract more research attention. Implementation of RFID is also a major research topic in the RFID literature, reflecting scholars' continued curiosity about this issue. To implement RFID, enterprises will have to resolve issues of technology development, international standards and regulations, and costs [40]. Given the complexity of implementation, it can be expected that much more research is needed in this area. Considering the fact that the creation and adoption of official standards can powerfully accelerate the adoption of new technology [3], it is surprising to find that issues related to RFID standardization did not attract more research attention.

Third, RFID research has attracted a large number of researchers from around the world during the 5 years covered by this study. Indeed, researchers from North America, Asia, and Europe have made contributions to this field of inquiry. Yet RFID remains a relatively underresearched field: only 94 research articles were published in the 2004–2008 period in 44 SCI- or SSCI-indexed journals, suggesting an average of less than three articles published per year in 44 journals. Moreover, because of the limited number of studies on the topic, the overall SCI or SSCI counts are relatively modest, even for the most cited articles in the area. Clearly, given the increasing importance of RFID in the era of globalization, more and better research needs to be conducted in the future. In addition, based on the names of individual contributors, it appears that there are proportionally more international scholars who have made significant contributions to RFID research. This shows that there is a wide institutional base that supports inquiries in the field. It appears that great potential exists for cross-national collaboration on RFID research. After all, collecting international data is relatively challenging and expensive. Cross-national collaboration could conceivably ease the data collection task and foster synergy among researchers.

Fourth, yet the proportion of scholars who have made contributions to RFID research and who are working outside the United States is relatively low. Perhaps the varying research traditions and unfamiliarity with publishing in English journals explain this outcome. It is worth noting that Chinese institutions are the next most frequent contributors to RFID research. China has successfully encouraged foreign investment with an open door policy. This has resulted in larger and more complex networks of R&D, manufacturing and service operations, and supply chains, all of which address the increasing desire for investment in China [22]. These developments

have placed tremendous pressure on firms in China to improve their operational performance based on new IT systems. This may be one reason that the number of RFID research papers increased in China.

Fifth, many elite research institutions do not appear to emphasize inquiries in RFID. On the other hand, scholars from elite research institutions certainly have the capacity to make a major impact on the RFID literature. It is hoped that more scholars from elite research schools will pay more attention to RFID research and make their contributions to advancing knowledge in this field.

Sixth, there is a core group of scholars who have made multiple and frequent contributions, either as single authors or coauthors, in the period covered by this study, and who have had a major impact on the RFID literature, based on their citations. They are thought leaders in the field, and their scholarship has had a significant impact on those who identify themselves as RFID researchers. It would be very beneficial if more new scholars could join this group, as it would be an indication of the sustained growth of the discipline as an academic field of inquiry.

Finally, several articles stand out as the most influential in the RFID literature, based on their citations. Although the present study is not capable of delineating the nature of studies that cited these articles, or the rationale behind these citations, these most frequently cited articles do reflect the core knowledge in RFID research. Those articles with relatively high citations per year will undoubtedly continue to shape the future directions of RFID research.

4.2. Limitations

Several limitations of this study need to be kept in mind in attempting to interpret its findings. First, the current study did not include articles published before 2004. It is not the authors' intention to downplay the contributions made by scholars who published prior to 2004. Instead, the focus on the period from 2004 to 2008 was intended to keep the task manageable and to stay relevant to current RFID researchers. Second, the current study did not include all academic journals that may publish RFID articles; only SCI- and SSCI-indexed journals were included. Although chances are slim that articles published in journals other than those targeted in this study would have a major impact on RFID research, it was not the intention of this study to ignore the contributions of other journals. Third, the SCI or SSCI citation count, while popular and broad based, does not account for citations by articles published in journals not indexed by the SCI or the SSCI. Thus, the reported citation counts in this study might slightly underestimate an article's total citation count in the academic literature. Fourth, non-English publications are not considered in this survey to determine the effects of different cultures on the development of RFID technology and applications. We believe that RFID technology and applications in addition to those discussed in this article have been publishing and developed in other areas and languages. Finally, a major limitation of this article is the authors' limited ability in presenting an overall picture of this subject. For example, what happens to topics that do not fit this taxonomy, other academic journals/magazines, practical articles and reports are not included in this survey, etc.

4.3. Suggestions

(1) An RFID system can collect data from hundreds or thousands of goods simultaneously. It can generate a large throughput of data, and requires considerable computing power and system integration to collect and process all the data [40]. New decision support tools are required to convert RFID data into useable information. Most current tools cannot handle the amount and the real-time aspects of such data [5].

(2) The adoption of an RFID system along an entire supply chain will benefit multiple companies. Industry supply chains can be quite long and can often cross international borders [40]. It is a huge challenge to confront the vast systems integration and IT tasks ahead of us [5]. In order to achieve this goal, an entire RFID infrastructure must first be established [28].

(3) Our review illustrates the articles focusing on the technical issues rather than issues related to realizing business value or impact on inter-organizational relationships. It is likely that as the technical issues related to RFID technology are solved, the business issues will emerge as particularly salient in the coming decade [25]. As the technology matures, we should see more attention being paid to less developed research areas.

(4) There are many challenges that need to be overcome to expedite the widespread implementation of RFID. One of the greatest challenges is to bridge the gap between practitioners and researchers. There is a need to provide useful guiding principles for practitioners to implement RFID, and we believe that future research effort is needed in this area.

(5) There are three major advantages of developing international standards for RFID systems. First of all, a common RFID standard will ensure interoperability among tags and readers manufactured by different vendors and allow for seamless interoperation across national boundaries [9]. Secondly, due to compatibility and exchangeability, the demand for RFID components and equipment will be high which can bring the cost down [29]. Thirdly, an internationally accepted RFID standard will facilitate the growth of the worldwide RFID market [13]. However, there is no global public body to govern the frequencies that are used for RFID, and in principle each country can set its own rules [25]. An international unified standard needs to be set up and multiple-protocol readers need to be developed that could work with different RFID standards are being developed.

4.4. Future studies

In an effort to expand upon this current study's findings, future studies could conduct the following suggested extension of current methodology. Using a well articulated method, content analysis of the selected journal articles is suggested. An example of such a method would be the use of a grounded approach that focuses on the main conceptual emphasis of each article and its objectives. The steps involved are shown in the following:

(1) Develop a conceptual classification from the literature rather than imposing a preexisting classification system or taxonomy of categories.

(2) Having at least two researchers analyze the journal articles and develop their own classification of categories.

(3) Analyze journal articles by looking at the article title, abstract, keywords, article objectives, and a conceptual review of its content.

(4) Match the category lists of the researchers.

(5) Resolve inconsistencies between the classification systems arrived at by the researchers.

(6) Finalize classification system and have the researchers classify the journal articles using this system.

(7) Check the level of reliability in the classifications between the two researchers.

Different classification/taxonomy methods should be implemented on this subject in order to broaden our horizons.

5. Conclusions

The main purpose of the present work is to examine the articles, authors, institutions, and journals that have had the most impact on the development of the RFID field of research. Even if this survey only

gives a static picture of a very dynamic area, several lessons can be drawn, and the study can still fill an apparent gap in the RFID literature. It broadens and enriches our understanding of developments in RFID research. In addition, the current research contributes to the field by providing future research directions with potential significance. Finally, even if the variety of journals in which articles related to RFID are published shows that this phenomenon captures the attention of several research communities, very few multidisciplinary studies seem to have been conducted on the subject.

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