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Determining technology trends and forecasts of RFID by a historical review and bibliometric analysis from 1991 to 2005

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Abstract

Radio frequency identification (RFID) has been identified as one of the ten greatest contributory technologies of the 21st century. This technology has found a rapidly growing market, with global sales expected to top US $7 billion by 2008. An increasing variety of enterprises are employing RFID to improve their efficiency of operations and to gain a competitive advantage. To shed light on RFID trends, and contributions, a historical review and bibliometric analysis are included in this research. The bibliometric analytical technique was used to examine this topic in SCI journals from 1991 through November of 2005. Also, a historical review method was used to analyze RFID innovation, adoption by organizations, and market diffusion. From the analysis of the study's findings, supply chain management (SCM), health industry, and privacy issues emerge as the major trends in RFID. Also, the contributions of the RFID industry and forecasts of technological trends were also analyzed, concluding that RFID will be more ubiquitously diffused and assimilated into our daily lives in the near future.

Keywords: RFID; Historical review; Bibliometric

1. Introduction

The advantage of radio frequency identification (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. This information can quickly be read by a wireless scanner, so RFID can process large volumes of multiple data sets at the same time and improve efficiency of operations by using identification tags to accurately monitor processes for time, place and person. This technology has been adopted by and diffused into a variety of enterprises to achieve cost-savings and increased efficiency. Many business enterprises and the health industry are applying the advantages of RFID to experimental projects to improve operational efficiency and to gain a competitive advantage (Bilge and Ozkarahan, 2004). RFID has been identified as one of the ten greatest contributory technologies of the 21st century.

Many information systems are old, do not meet existing demands, and will soon become obsolete. Therefore, technology is evolving on an almost daily basis and managers must continuously look for new ways to utilize resources (Kodama, 2005). Therefore, it is anticipated that it will become increasingly important for organizations to create new ways of thinking and job processing (Carayannisa and Coleman, 2005). Organizations are not only investing in knowledge capital and information technology (IT) to improve their operational weaknesses (Macpherson, 2005), but managers are also trying to resolve sequential operational crises. They are devoting resources and knowledge to reconfiguring and creating innovative new structures and systems in order to overcome the crises (Li, 2005), pursue more efficient operations (Munday et al., 2005), and gain an economic advantage (Szántó, 2005). Therefore, organizations are integrating learning and teamwork cohesion with innovative technologies to adapt to the changing needs of the business

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environment (Lloréns Montes et al., 2005). Creativity and innovation are leading customers into new experiences and creating new needs (Rose-Anderssen et al., 2005). Thus, to survive, organizations are counting on the integration of innovative technologies with business management processes (Kumar et al., 2005).

Enterprises are applying advanced information systems to strengthen managerial ability to enhance organizational change and growth for better operations (Lin, 1991). Hospital administrators are aware that using new technologies is essential to surviving and succeeding in the competitive heath care environment (Uslay et al., 2004). Therefore, the health care industry is also beginning to employ RFID to solve operation problems such as fighting drug counterfeiting (Koleszar, 2004) and tracking blood products from donor to patient, and are applying new innovative systems and models to meet knowledge and economic demands (Cooke, 2004). Hospitals are adopting RFID tags to prevent medical errors by ensuring the delivery of correct medicine dosages to patients (Cline, 2004). The US Food and Drug Administration expects drug makers to have RFID tracking in place by 2007 for nearly all pharmaceuticals to control counterfeiting (Gebhart, 2004), and it is even testing the technology on several types of viruses. There are RFID-enabled resource and workflow management solutions being designed to optimize asset utilization, reduce operating costs, and improve care quality in the healthcare industry (Kohn and Henderson, 2004), and for a variety of other medical applications (Costlow, 2004). Hospitals are utilizing RFID for tracking injection IV bags, blood bags, cancer medicine, and wounded soldiers and their treatment.

In this paper, we explored RFID technological trends and forecasts by means of bibliometric and historical reviews from 1991 through November, 2005 to elucidate the RFID technology trends in adopting enterprises, contributions that RFID is making, and forecasts for RFID growth.

2. Material and method

All documents used in this study were accessed from the database of the Science Citation Index (SCI), obtained by subscription from the ISI, Web of Science, Philadelphia, PA, USA. In this study, we only discuss the papers published in the period beginning 1991 because there were less data regarding RFID prior to that year.

To shed light on RFID trends and contributions, both a bibliometric analysis and a historical review were conducted in this research. For the bibliometric analysis, the SCI was systematically searched for RFID-related materials published from 1991 through November, 2005. Selected documents included "RFID" or "radio frequency identification" in the title, abstract, or key words. Analyzed parameters included authorship, patterns of international collaboration, journal, language, document type, research address, number of times cited, and reprint author's address. Citation analysis was based primarily on the impact factor as defined by the *Journal Citation Reports* (JCR) and on *Citations Per Publications* (CPP), which are used to assess the impact of a journal relative to the entire field and is defined as the ratio of the number of citations the publication has received to the length of time since publication. A historical review was also performed. The historical method proposes that historical phenomena can be rich and complex and that we can gain a better understanding by reviewing and investigating the time(s), place(s) and context(s) in which events occur and develop. The historical method was employed in investigating the initiation and development of RFID as documented in publications in the SCI from 1991 to November, 2005.

For a longitudinal literature review, we employed bibliometric and historical review methods to explore RFID technological trends, and based on this review, we forecast possible future developments.

3. Results and discussion

3.1. RFID historical analysis

The key words "RFID" or "radio frequency identification" were used to search SCI entries from 1991 to 2005 (updated December 16, 2005). The RFID SCI article distribution status was used for trend analysis. As detailed below, all 316 papers found in the search were analyzed.

3.1.1. Distribution by country/territory and institution name

Table 1 shows the distribution of publications by country and territory. The US, Japan, Germany, Switzerland, South Korea, Canada, the UK and Finland were the top eight countries publishing RFID articles. Listing publications by institution name, Table 1 shows that the Massachusetts Institute of Technology, University of Washington, and Agriculture & Agriculture Food, Canada, are the top three RFID research institutions.

3.1.2. Distribution by publication year, document type and language

Table 2 displays RFID-related publications by year, document type, and language. Fig. 1 shows the number and percentage of annual publications output. There have been an increasing number of RFID publications since 2003. In the SCI, and SSCI, articles comprised the majority of published RFID document types (Table 2 and Fig. 2). As for distribution by language, we see from Table 2 and Fig. 2 that the majority language of RFID research is done in English. One interesting finding is that there has been an increase in RFID research since 2002; it is clear that RFID technology is becoming ever more important.

3.1.3. Distribution by source title

Table 3 shows that "Microwaves & Radio Frequency," "Microwave Journal," and "Communications of the

Table 1
Distribution of country/territory and institution name

Country	NP	%	Institution name	NP	%
USA	84	26.6	Massachusetts Institute of Technology	7	2.2
Japan	21	6.6	Univ. of Washington	7	2.2
Germany	17	5.4	Agriculture & Agricultural Food Canada	6	1.9
Switzerland	15	4.7	Tampere Univ. of Technology	5	1.6
South Korea	14	4.4	ETH	4	1.3
Canada	11	3.5	Intel Res. Seattle	4	1.3
UK	9	2.8	Nanyang Technol Univ.	4	1.3
Finland	8	2.5	Univ. California Berkeley	4	1.3
France	7	2.2	DLO	3	0.9
Netherlands	7	2.2	Kyoto Univ.	3	0.9
Taiwan	5	1.6	Michigan State Univ.	3	0.9
Singapore	4	1.3	RSA Labs	3	0.9
Slovenia	4	1.3	Swiss Fed Institute of Technology	3	0.9
India	3	0.9	Univ. Ljubljana	3	0.9
Italy	3	0.9	Univ. St Gallen	3	0.9
Australia	2	0.6	Univ. of Wisconsin	3	0.9
Belgium	2	0.6			
New Zealand	2	0.6			
China	2	0.6			
Austria	1	0.3			
Chile	1	0.3			
Czech Republic	1	0.3			
Israel	1	0.3			
Poland	1	0.3			
Portugal	1	0.3			
Spain	1	0.3			
Sweden	1	0.3			

NP: number of publications.

Table 2
Distribution by publication year, document type and language

Pub. Year	NP	%	Document type	NP	%	Language	NP	%
1991	1	0.3	Articles	223	70.6	English	311	98.4
1992	0	0.0	News Items	54	17.1	German	4	1.3
1993	2	0.6	Editorial Materials	31	9.8	Slovak	1	0.3
1994	2	0.6	Letters	4	1.3			
1995	3	0.9	Reviews	3	0.9			
1996	4	1.3	Meeting Abstracts	1	0.3			
1997	10	3.2						
1998	5	1.6						
1999	18	5.7						
2000	9	2.8						
2001	13	4.1						
2002	14	4.4						
2003	40	12.7						
2004	78	24.7						
2005	117	37.0						

NP: number of publications.

ACM'' are the journals with the most publications on RFID.

3.1.4. Distribution by subject category

Table 4 shows that ''engineering'' (electrical and electronic), ''telecommunications,'' and ''computer science'' (software engineering) were the three most frequently used key words appearing in RFID publications.

3.2. Technology trends and forecasts

The analysis of technological innovation, trends, adopting organizations and industry diffusion reveals the

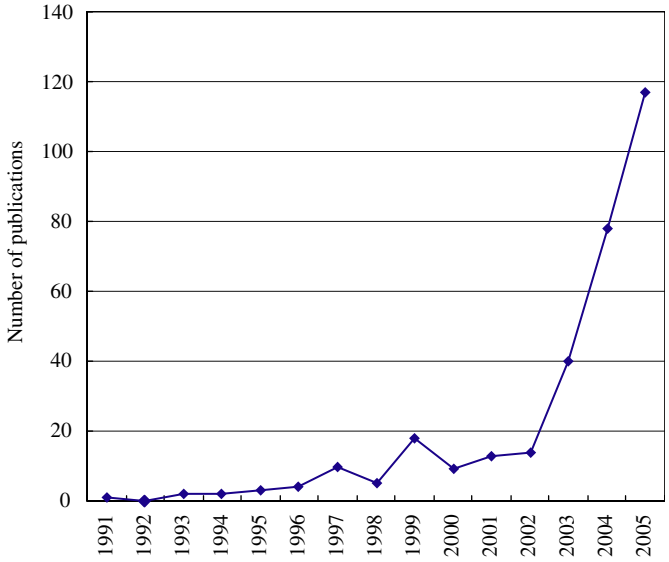

Fig. 1. Annual publication output (Total publications: 316).

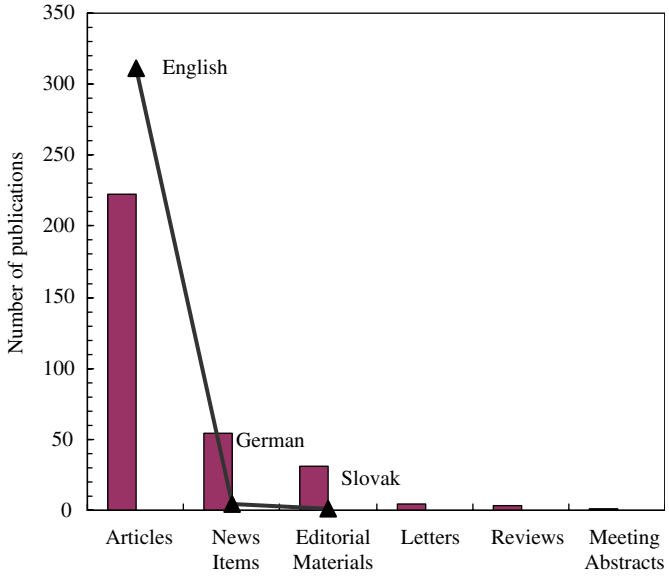

Fig. 2. Distribution by document type and language (total publications: 316).

existence of two eras: from 1991 to 2000, and from 2001 to 2005.

3.2.1. Technology innovation of RFID (1991–2000)

From a retrospective view of RFID technological innovation, we found that RFID technology was improved before its diffusion. This included improving the system itself, the tags, the transmission quality, and the data communication distance and also reducing the physical size of the RFID unit (Schwind, 1985). The significant events during RFID development were the improvement in data transmission distances (Anonymous, 1985), the reduction of the RFID unit's size (Tuttle, 1996), the application of wireless technology for better communication (Browne, 1997), the improvement in the RFID equipment (Anonymous, 1997b) and tag flexibility (Legg, 1997), the increase

Table 3
Distribution by source title

Source title	NA	%
Microwaves & Radio Frequency	27	8.5
Microwave Journal	21	6.6
Communications of the ACM	10	3.2
Control Engineering	9	2.8
Electronics Letters	8	2.5
EDN	6	1.9
Computers And Electronics In Agriculture	5	1.6
IEEE Micro	5	1.6
Informacije Midem-Journal of Microelectronics Electronic Components and Materials	5	1.6
Assembly Automation	4	1.3
Dr Dobbs Journal	4	1.3
IEEE Pervasive Computing	4	1.3
IEEE Transactions on Microwave Theory and Techniques	4	1.3
IEICE Transactions on Electronics	4	1.3
Microwave and Optical Technology Letters	4	1.3
Canadian Journal of Animal Science	3	0.9
Electronic Design	3	0.9
IEE Review	3	0.9
IEEE Journal of Solid-State Circuits	3	0.9
Industrial Management & Data Systems	3	0.9
Intech	3	0.9
Journal of Construction Engineering and Management-ASCE	3	0.9
Pervasive Computing, Proceedings	3	0.9
Proceedings of the IEEE	3	0.9
R&D Magazine	3	0.9
Technology Review	3	0.9
Ubiquitous Computing Systems	3	0.9
Ambient Intelligence, Proceedings	2	0.6
Applied Engineering in Agriculture	2	0.6
Computer	2	0.6
Cryptographic Hardware and Embedded Systems—ches2004, proceedings	2	0.6
Electronics World	2	0.6
Fleischwirtschaft	2	0.6
Food Australia	2	0.6
Holonic and Multi-Agent Systems for Manufacturing, Proceedings	2	0.6
IEEE Microwave and Wireless Components Letters	2	0.6
IEEE Security & Privacy	2	0.6
IEEE Transactions on Electron Devices	2	0.6
IEICEce Transactions on Communications	2	0.6
Industrial Engineer	2	0.6
Journal of Animal Science	2	0.6
Livestock Production Science	2	0.6
Microelectronics International	2	0.6
Microelectronics Reliability	2	0.6
Packaging Technology and Science	2	0.6
Pharmazeutische Industrie	2	0.6
Pulp & Paper-Canada	2	0.6
Sadhana-Academy Proceedings in Engineering Sciences	2	0.6
Scientific American	2	0.6
Ubicomp2004: Ubiquitous Computing, Proceedings	2	0.6
Wireless Networks	2	0.6
Wirtschaftsinformatik	2	0.6

NA: number of articles.

Table 4
Distribution by subject category

Subject category	Record Count	%
Telecommunications	67	21.2
Computer science, software engineering	25	7.9
Computer science, hardware & architecture	19	6.0
Computer science, information systems	17	5.4
Automation & control systems	16	5.1
Engineering, industrial	15	4.7
Instruments & instrumentation	14	4.4
Computer science, theory & methods	11	3.5
Engineering, manufacturing	11	3.5
Computer science, interdisciplinary applications	10	3.2
Food science & technology	10	3.2
Materials science, multidisciplinary	10	3.2
Multidisciplinary sciences	9	2.8
Agriculture, dairy & animal science	8	2.5
Engineering, multidisciplinary	8	2.5
Physics, applied	6	1.9
Agriculture, multidisciplinary	5	1.6
Construction & building technology	4	1.3
Engineering, biomedical	4	1.3
Engineering, civil	4	1.3
Optics	4	1.3
Pharmacology & pharmacy	4	1.3
Agricultural engineering	3	0.9
Engineering, chemical	3	0.9
Fisheries	3	0.9

in tag communication distance and the complexity of its functions (Schweber, 1998, 1997), the avoidance of data transmission collisions (Schweber, 1999), the improvement of millimeter-wave bands and point-to-point communication links (Browne, 1999), and the improvement in energy savings (Chlamtac et al., 1999). Also significant were the increase in tag reception signal sensitivity (Lee, 1999), the adoption of the technology by various enterprises (Artmann, 1999), the improvement in tracking and the production of more efficient technology (Jansen and Krabs, 1999), and the improvement in communication afforded by patch antennas (Kossel et al., 1999). After this series of innovations overcame RFID weaknesses, a milestone was reached in 2000 when international RFID standards were established, setting the stage for widespread adoption of the technology (Anonymous, 2000b). This event enticed diverse international enterprises to adopt the technology to enhance operational monitoring and efficiency.

3.2.2. Organization adoption of RFID (1991–2000)

A variety of RFID applications were used by different enterprises, and their contribution to RFID development enhanced automated data capture by manufactures (Udoka, 1991). RFID tags were used to connect smart cars to smart highways for safer transportation (Legg, 1994), they were employed by various enterprises for product distribution (Schneiderman, 1995), and for tracking construction vehicles (Naresh and Jahren, 1997). The tags were used by the military for supplies management (Anonymous, 1997a), by manufacturers for monitoring production (Labs, 1998), by the post office to "put zip in the mail" (Heftman, 1998), by airlines to speed up airline baggage handling (Goldberg, 1999), by farmers to track sugar cane (Anonymous, 1999), by book retailer for the book trade (Hicks, 1999), by the European Union for identification and registration of animals (Wismans, 1999), and for electronic commerce (Anonymous, 2000a). While many enterprises have already applied RFID technology, the technology and its applications must continue to be improved. RFID faces new challenges as various enterprises prepare for the rapid and large-scale adoption and diffusion of this technology.

3.2.3. New challenges and organization diffusion (2001–2005)

This study discusses the new challenges faced by RFID as well as its diffusion based on the data from 2001 to 2005, the details of which are presented below.

3.2.3.1. New challenges of technological innovations (2001–2005). From the retrospective analysis, we found that RFID technological innovation passed through three eras. The first era focused on tag innovation such as data communication, accessing control, enhancing better communication, developing an integrated active antenna, and consuming less electrical power. The second era applied tags to automation, integration services, and ubiquitous computing applications. The third era brought manufacturing automation, logistical control, e-commerce applications, mass production of very small and cheap tags, interaction via mobile communication, applying RFID to track consumer's goods, and diffusion of tags to the world. The significant second era events were that tag chips and smart cards became pervasive (Sakamura and Koshizuka, 2001), better data communication was achieved (Rogin, 2001), access control by magnetic storage media was implemented, fingerprint and voice identification became possible (Svecko and Ratej, 2001), communication between objects was allowed (Ferguson, 2002); during this era, RFID and PC technologies paved the way for increasing profits in aggregate industry (Callahan, 2002).

Also, person-to-person communication markets became saturated, prompting the communication market to adopt object-to-object communication via RFID (Shimizu et al., 2002) so that it could to easily handle several items simultaneously (Deville et al., 2002), integrated active antennas (Biebl, 2003) and plastic-compatible low-resistance printable gold Nan particle conductors for flexible electronics (Huang et al., 2003) were developed, automation of manufacturing and logistical control was implemented (Keskilammi et al., 2003), three-dimensional electromagnetic (EM) simulation tools simplified the design of RFID tags (Rautio, 2003), and RFID was employed in automation (Want, 2004). Moreover, chips on

paper technology utilizing anisortropically conductive adhesives for smart label applications produced a new generation of paper-thin smart labels (Rasul, 2004), additional new technologies were stimulated and services integrated (Sarma, 2004), the RFID technology was applied to ubiquitous computing needs (Floerkemeier and Lampe, 2004), and the technology was recommended for e-commerce applications (Murakami and Terano, 2003). Other developments include the improved ease of access and control of digital media contents (Oh and Woo, 2004), the use of RFID to locate objects inside buildings (Ni et al., 2004), the mass production of very small, cheap RFID tags (Bohn and Mattern, 2004), the development of the technology to allow mobile systems to communicate with RFID (de Medeiros et al., 2004), production of an architecture for implementing technology (Kohn et al., 2005), the application of printed electronics to item-level tracking of consumer goods (Subramanian et al., 2005), and the production of ultra-small chips to be applied to paper and paper-like media (Usami and Ohki, 2003). After these technological innovations to RFID, the diffusion of tags to the world has become a reality, and a foundation has been set for the further rapid diffusion of RFID into various enterprises internationally (Borriello, 2005).

3.2.3.2. Organizational diffusion, supply chain management (SCM), health, privacy and others (2001–2005). As it underwent its technical evolution, RFID diffused to SCM, the health industry, privacy and security, and others industries. Enterprises adopting RFID are described as follows. Table 5 shows the overview of RFID technology diffusion.

Table 5
The overview of RFID technology diffusion

Year	Type	Organization adoption	Contribution	Author
2001	Transportation	Active transponders for a fare collection	RFID tags monitored passenger access to public transportation	Gyger and Desjeux (2001)
2002	Automobile SCM	RFID tags improved tracking, quality on a Ford line in Mexico	Improved quality control	Johnson (2002)
2003	SCM	RFID picked up steam with high-tech tracking for supply chain management	Improved SCM	Anonymous (2003b)
2003	SCM	RFID emerged in the supply chain	Applied to SCM processing	Anonymous (2003c)
2003	Automobile SCM	Automotive industry drove the RFID market	RFID applied to SCM of automotive industry	Anonymous (2003a)
2004	Retailers	RFID speeded up concession purchases at Seahawks stadium	Improved waiting times at the cashier	Anonymous (2004b)
2004	Software	Oracle Corp. launched RFID program to meet initiatives	Database software developed RFID software	Anonymous (2004a)
2004	SCM	Ultra-low-cost UHF RFID tags were designed for supply chain applications	Decreased tag cost for SCM.	Glidden.et al. (2004)
2004	SCM	RFID become a major niche as a livestock tracker	Used for Inventory check	Anonymous (2004d)
2004	SCM	RFID systems were integrated into the manufacturing supply chain	Used for SCM management	Anonymous (2004c)
2004	SCM	Used in supply chain	Used for SCM management	Luckett (2004)
2004	Library security and media circulation	RFID was used for security and media circulation in libraries	Used for library Management	Kern (2004)
2004	SCM	Radio frequency identification systems used in supply chain management.	Used for SCM management	Penttila et al. (2004)
2005	SCM	Used for supply-chain applications and implementation issues	Used for SCM management	Angeles (2005)
2005	Food industry SCM	RFID used in Foods & Vegetables supply chain and prevented from product recalls	Used for SCM management	Anonymous (2005c) Kumar and Budin (2006)
2005	SCM	The potential impact of RFID on supply-chain management	Used for SCM management	Strassner and Fleisch (2005)
2005	Construction	RFID applied to the construction industry	Used to many construct parts management	Yagi et al. (2005)
2005	Airlines	RFID helped airlines track assets	Used to tracking passenger luggage	Anonymous (2005a)
2005	e-supply chains in grocery	Future impacts of RFID on e-supply chains in grocery retailing evaluated	Improved SCM in grocery management	Prater and Frazier (2005)
2005	SCM	Successful RFID supply chain was a lunched	Diffused of SCM	Anonymous (2005d)

Table 6
The overview of RFID technology being adopted by health organization

Year	Type	Organization adoption	Contribution	Author
2004	Laboratory information management	RFID technology leveraged to improve laboratory information management	Applied RFID to laboratory information management	Venkatesan and Grauer (2004)
2005	Pharmaceutical industry	The pharmaceutical industry turned to RFID as a cure for many problems	Applied to drug management	Anonymous (2005e)
2005	Biopharmaceutical supply chain	RFID used in the biopharmaceutical supply chain	Applied SCM to the biopharmaceutical industry	Ahlund (2005)
2005	Pharmaceuticals	Pharmaceutical companies sought benefits of RFID	drug management	Anonymous (2005b)
2005	Health Industry	Information technologies used to prevent of medication errors	To prevent human errors	Bonnabry (2005)

Table 7
The overview of RFID technology related privacy and security

Year	Type	Organization application	Contribution	Author
2002	Security and privacy implications	RFID systems and security and privacy implications evaluated	Used for Information security	Weis et al. (2004)
2003	Surveillance device	Various safety guidelines for electronic article surveillance devices with pulsed magnetic compared fields	Used for ensure compliance security system for electronic article surveillance	Kang and Gandhi (2003)
2004	Authentication	Public key authentication provided	Used for authentication identification	Girault and Lefranc (2004)
2004	Privacy	Enhanced privacy of universal re-encryption schemes for RFID tags	Used for privacy protection by utilization universal re-encryption	Saito et al. (2004)
2005	Authentication	Provided efficient authentication of low-cost RFID systems	Used for protect privacy	Lee et al. (2005)

As for the health organization adoption, health facilities adopted RFID later than other enterprises. The majority of current RFID health care applications are used in the pharmaceutical industry for fighting drug counterfeiting, and for process management. Table 6 illustrates the adoption circumstances.

The privacy and security industry is also very important to future RFID growth. To increase privacy and security, authentication systems are being developed, and individual information protection employing RFID technology has begun. Table 7 provides the detailed information.

4. Discussion

RFID technology is automatically shifting from people-to-people communication to object-to-object communication. Automatic identification and process control are valuable to improved business efficiency. The RFID market has grown very rapidly, with the global market expected to top US$7 billion by 2008 (Lee et al., 2005). The historical review found an increasing variety of enterprises employing RFID to improve their efficiency of operations and to gain a competitive advantage. The industries that have employed RFID are shown in Table 8.

Enterprises employing RFID technologies include retailer Wall Mart, cell phone company Nokia, and a number of large pharmaceuticals companies. As Table 9 shows, hospitals are also employing RFID to improve operational shortcomings and drawbacks for better quality control, to raise competitive ability, and to clarify managerial responsibilities.

5. Discussion and research findings

5.1. New challenges and forecasts of RFID promotion and adoption by enterprises

The trend of RFID development has been to be adopted first and then to diffuse into various enterprises rapidly. The goals of enterprises have been to establish RFID infrastructures and then become global leaders in innovation, applications, tag supply, and new technology development. Moreover, new business models provide financial incentives that encourage RFID adoption by new industries such as automobiles, electronics, and shipping. The major goals are to connect material objects with network information to pursue real-time visibility and accuracy with sensors, WLAN, and remote monitoring. Development of applications has focused on health care, transportation,

Table 8
The overview of RFID technology applied in various industries

Industry	Company	Application	Advantage
Military	US Army	During the Persian gulf war, the US military utilized RFID for its inventory supply management to track large volumes of inventories	RFID applied for supply chain management
Military	Navy	Tracking combat casualties and identifying the wounded arriving for treatment at a field hospital in southern Iraq	Assisted in solder's personal profile and treatment identification
Retailer	Wal-Mart	Pallets and cases tagged beginning in 2005	Achieved internal efficiencies while meeting requirements from their customers
Cell phone	Nokia	It easily enabled customers to initiate mobile services, payment solutions, verification, authentication, ticketing, and exchanging business cards	Provided RFID functions for enterprises and users to save money and streamline processes
Airlines	Airport	RFID helped airlines improve handling the huge amount of luggage items	More efficiently improved safety and saved expenses
Pharmaceutical	Food and Drug Administration	RFID tags attach to genuine drug boxes. When the drug is used at the point of sale, it will check its registration information to verify its authentication	Used in the fight against counterfeit drugs and to verify a drug's authentication

Table 9
The overview of RFID applied in hospitals

Industry	Company	Application	Advantage
Hospital	John Hopkins Medical Center	Tracking IV bags	RFID applied to monitor injection liquid bag for sufficient liquid to prevent injection of air into patient's body
Hospital	Georgetown University Hospital	Tracking blood products from donor to patient	Tracked blood from donor to patient to ensure blood donation and receiver quality
Hospital	Anderson Cancer Center	Tagging drugs with radio chips	Ensured cancer drug safety
Hospital	Obstetrics	Verifying new-born baby identification	Ensured new-born baby identification with their parents
Hospital	Mental Illnesses Department	Managing mental patients	Ensured mental patient location management
Hospital	Infectious Diseases Dept.	Managing infectious disease isolation	Prevented patients with infectious diseases from spread to other areas
Hospital	Surgery	Preventing surgical errors of wrong patient or wrong, operation side	Enhanced surgical safety and prevented human errors
Hospital	Emergency room	Monitoring severe triage patient progression situation	Ensured emergency room critical patient safety
Hospital	Equipment management	Tracking important equipment location and management	Ensured important equipment location.
Hospital	Pharmacy dept.	Tracking and managing drugs tracking and management	Prevented wrong medicine for patient and traced important drugs
Hospital	Waste management	Tracking and managing waste disposal materials	Tracked waste disposal materials on the proper track
Hospital	Inpatient management	Tracking correct prescriptions and injection for the right patient	Prevented human errors and treatment delay

production, SCM, shipping, warehousing, security and industrial safety, and environmental safety management. To achieve these goals, a retrospective historical review and a strengths, weaknesses, opportunities, threats (SWOT) analysis of our current circumstance is needed in order to propose targets which can be achieved.

A variety of enterprises are adopting RFID technology to solve their current problems. However, there are a number of challenges and obstacles such as technology standards, patents, costs, infrastructure, return on investment (ROI), and barcode to RFID migration that need to be met for successful RFID adoption, diffusion and

Table 10
The various types of challenges caused by adopting RFID

Types of challenges	Challenges issues	Description
Technology challenges	• Material effects on antenna power pattern • Tag antenna orientation affects radio wave reception • Collision caused by simultaneous radio transmission	The antenna plays an important role of communication between tag and reader. The strength of radio wave is reflected or refracted by different materials. Customers' goods are various which will refract of communication wave of its tag and reader
Standard challenges	• Lack of a unified RFID standard • Lack of consistent UHF spectrum allocation for RFID	The lack of a complete and international unified standard is causing many enterprises to hesitate in adopting RFID systems
Patent Challenges	• Manufacturing costs • Customization costs	Vendors are concerning about high patent royalty payment. This situation becomes obstacle holding back to develop RFID system
Cost challenges		1. Cost is one of the factor for enterprise to implement RFID. The manufacturing cost is such as 1 chip; US \$0.25–\$0.35 a pieces of 1–10 M 2. Inlay/Substrate with antenna; \$0.02 to \$0.10 depending materials and material used 3. Assembly; appropriately from \$0.02 to \$0.04 4. Licensing, referencing Intermec's licensing plan, 5–7.5% of the hardware value
		The implementation of RFID customer's design system will incur considerable of system design, customization and configuration costs
Infrastructure challenges		The adoption of UHF RFID system to implement an entire supply chain management will benefit many companies and process flows; however, so many infrastructures of enterprises are required to interaction with each other. Therefore, this is a big infrastructure challenges
ROI challenges		RFID is a pioneer program. There is shortage of comprehensive and limited information to evaluate RFID installation cost and investment of return information for enterprises evaluation of installation
Barcode to RFID migration challenges		The barcode system is implemented by many enterprises. RFID is on developing stage, therefore, enterprises will keep two systems to operate. This will incur a double cost of maintenance two systems for operation

assimilation (Wu et al., 2005). These challenges and obstacles are described in Table 10.

In the RFID bibliometric analysis and historical review, we explored the technology trends and forecasts for RFID adoption. Further, we propose clear goal identification and a SWOT analysis for government agencies. Also, international standards need to be established to create tags, software, and communication devices for the global market. Government incentive projects can promote the adoption of RFID technology and stimulate its diffusion into related enterprises. Research, implementation, and fund disbursement can achieve enhanced RFID technological advancement and globalization.

5.2. *RFID contribution from managerial perspective and opportunities for enterprises*

The contribution of various enterprises to the adoption of RFID can be divided into four categories: (1) Identification of objects and persons, (2) tracking process flow, (3) authentication, authorization, and security, and (4) financial record keeping.

5.2.1. *Identification of object, person*

RFID can identify objects or personnel by tag frequency comparison. Therefore, this technology is used by many enterprises to identify their products for managerial accuracy such as by SCM for goods management, by medical laboratories for improving information accuracy, by pharmaceuticals companies for fighting counterfeit drugs, and by hospitals for processing IV, transfusion, and blood bags, for managing toxic drugs, and to prevent human error.

5.2.2. *Tracking of process flow*

Enterprises are also employing RFID in tracking job process flow. The automotive industry uses RFID to track auto parts processing flow, SCM to manage goods replenishment and inventory flow, airlines to track passengers' luggage flow, and hospitals to monitor patient location, track epidemic infections, prevent fatal disease

outbreaks, track valuable equipment location, and monitor the efficiency of Emergency Room treatment processing.

5.2.3. Authentication, authorization and security

Enterprises are using RFID for authentication in information security. Libraries are using it to verify users for access to electronic resources, software companies for data access surveillance, hospitals for monitoring physician access to electronic medical records, and for data security and privacy protection management.

5.2.4. Financial record keeping

Other enterprises are employing RFID to shorten customer waiting time by improving accounting payment functions. Wal-Mart is employing RFID to calculate goods prices before customer arrival at the cashier counter to speed up customer traffic flow, transportation companies use RFID for fare collection, and airlines use it in ticketing. Further, from the managerial perspective, RFID can be employed in mutual identification of provider and user to ensure accuracy of object and personnel identification, for access authorization and tracking, for privacy protection, and in accounting functions such as payment surveillance.

Organizations devote a great deal of their resources to improving their customer relations management, creating new services and products, lowering prices, improving the efficiency of their production and distribution functions, and finding new markets. Strategic employment of IT can impact a firm's performance in all of these areas, and more and more enterprises have found that employing RFID gives them a competitive advantage.

6. Conclusions

To gain a clearer insight into RFID trends, forecasts and contributions, historical review and bibliometric methods were applied in this research. This study reveals that an increasing variety of enterprises are employing RFID to strengthen their managers' ability to enhance organizational change and to manage growth in an increasingly competitive environment.

After its introduction trends and forecasts, RFID technology surged onto the market very rapidly, and the global RFID market is expected to top US $7 billion by 2008 (Jaques, 2005). An increasing number and a widening variety of enterprises are employing RFID to improve the efficiency of their operations and to gain a competitive advantage. Many industries are also launching RFID programs to help them solve their operation problems; they are applying new innovation systems and models in order to meet their information and financial needs. To implement RFID, enterprises will have to resolve issues of technology development, international standards and regulations, and costs (Wu et al., 2005). As these issues are addressed, it is certain that RFID will continue to innovate and diffuse and that it will quickly be assimilated into our daily lives.

7. Implications

RFID is being utilized in various enterprises to improve efficiency of operation. These technologies are being applied to everything from monitoring the manufacturing process to tracking good and services as they are distributed. RFID is also a tool for detecting human error. When errors occur, a mobile short message can be sent, warning employees to pay attention and to correct the error immediately. Many enterprises are also employing RFID in order to achieve operational efficiency. However, recommendations for RFID deployment are that it be used as a stand-alone application in pallet- or carton-level tracking first (Wu et al., 2005). Moreover, employing RFID at healthcare facilities to solve operational problems is a trend that will be diffused and assimilated to many areas in the near future.

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