Technology Analysis & Strategic Management

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ctas20

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Published online: 28 Apr 2010.

To cite this article: Nienchu Wu , Hsin-Hann Tsai , Yu-Shing Chang & Hsiao-Cheng Yu (2010) The radio frequency identification industry development strategies of Asian countries, Technology Analysis & Strategic Management, 22:4, 417-431, DOI: 10.1080/09537321003714329

To link to this article: http://dx.doi.org/10.1080/09537321003714329

Technology Analysis & Strategic Management
Vol. 22, No. 4, May 2010, 417–431

The radio frequency identification industry development strategies of Asian countries

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The radio frequency identification (RFID) system uses radio waves to remotely capture and process information stored in a tiny silicon chip. Having the potential to replace bar codes on consumer products, RFID technology can enhance the efficiency in material handling/transportation and provide more intelligence in business transactions. Although there are challenges and obstacles with the adoption of RFID in businesses worldwide, governments of a few Asian countries have established proactive policies and have taken supportive actions to facilitate the development of this emerging industry. This research summarises the approaches, progress and the development strategies of RFID in Japan, China, Taiwan, Korea and Singapore. The visions and strategies in developing RFID industries in these countries could provide references for other countries.

Keywords: RFID; development strategies; Asian countries

1. Background

In the past few years, radio frequency identification (RFID) has attracted popular hope, hype and optimism. It has been hailed in the mainstream press as a revolutionary technology that will enable completely new ways of doing business. For example, CNN included RFID as one of the 'Ten Technologies to Watch' in 2004 (Pescovitz 2003). ZDNet called RFID one of the 10 strategic technologies for 2005 (Farber 2004), while AICPA announced RFID as one of the top 10 major technologies impacting the accounting industry in 2004 (AICPA's Information Technology Center 2004).

Wal-Mart, the world's largest retailer, handled about four billion cartons in 2004 and five billion cartons in 2005 (Nogee 2004). Any small percentage of increase of efficiency in tracking goods in its global supply chain could generate tremendous benefits. Wal-Mart believes an RFID system can reduce its labour and inventory costs. Other benefits of adopting RFID in supply chain management (SCM) include facilitation of source data collection, improvement of data accuracy and more responsiveness to customers' needs. Revenues may be increased by limiting out of stock items throughout its stores around the world. The US Department of Defense (DoD) also appreciates the advantages of RFID systems in managing its logistics. Therefore, both Wal-Mart

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ISSN 0953-7325 print/ISSN 1465-3990 online

DOI: 10.1080/09537321003714329
http://www.informaworld.com

and the DoD mandated that their largest suppliers begin tagging all pallets of goods delivered to their warehouses with RFID starting 1 January 2005, while the remaining suppliers were expected to follow in 2006, but that date came and went, and the expectation of rapid industry adoption of RFID did not take place.

Challenges and obstacles to the quick adoption of the RFID system (Wu et al. 2006) include issues of technology, cost, standards, patent, spectrum allocation and return on investment, etc. The global RFID industry still lacks a unified and globally interoperable standard and consistent ultra-high frequency (UHF) spectrum allocation that has caused many companies to hesitate in adopting RFID systems. The issue has also delayed RFID market growth and cost reduction speed. Also patent-infringement lawsuits have been spreading in RFID markets. Some RFID key players had spelled out its licensing plan to vendors of electronic product code (EPC) Gen 2 products. Potential vendors are concerned about paying high royalty costs. From the application point of view, no comprehensive RFID infrastructure exists yet. It is difficult to calculate the true returns based on limited benefit information from pilot projects in segmented RFID system installations (Ornauer, Michielsen, and Rerisi 2004).

However, several Asian countries have high confidence in the future of RFID technology and have developed distinctive strategies to support the growth of the RFID industry in their countries. Each government needs to consider the comparative advantage of adopting an RFID system and the availability of resources before forming its national strategy on RFID.

This paper summarises and compares the current RFID industry development strategies of five Asian countries, including China, Taiwan, Japan, Korea and Singapore. Section 2 of this paper uses Porter's industry value chain concept to examine the value chain and business models of the RFID industry. This examination will set the stage for describing the different emphases in the RFID development strategies of each of the five Asian countries. Section 3 describes the current RFID industry development status and strategies of the five Asian countries. Section 4 describes the necessities and advantages of government-led RFID strategies. Section 5 provides our conclusion and suggestions for other countries to develop their own RFID strategy. Finally a glossary of terms used in this paper appears in the Appendix (Table A1).

2. RFID industry value chain

An industry chain includes upstream material suppliers and manufacturers as well as downstream logistic service providers and system solution providers. Each entity contributes value to the competitiveness of the industry (Porter 1980). A government's industrial policy seeks to provide an advantageous environment and infrastructure to facilitate successful enterprises (Xiao 1984).

An RFID system consists of three basic components (Finkenzeller 2003): the tag, the reader and the data processing application system. A tag contains unique identity information about the item to which it is affixed or in which it is embedded. A reader communicates with a tag to collect information stored in it. Data processing equipment, which can be as simple as a personal computer or as complex as a networked enterprise management information system, processes the collected data.

RFID is a wireless data retrieval technology which can be a critical part of an information management system. It is difficult for any one company to provide a total RFID solution from chip to system that can satisfy customers' diverse needs. As a result, an RFID industry is composed of firms that specialise in RFID components, tags, readers, software and application systems (Wu 2003). From a value chain perspective, the RFID industry can be categorised into several value providers with their respective business models.

2.1. *Component providers*

RFID components include chip, antenna, tag inlay materials, reader integrated circuits (ICs), a variety of reader antennas, and related glue and label materials. For example, IC designers design RFID chips according to international standards with the feature requirements of their customers. Antenna designers provide an antenna design that can function under a certain radio spectrum range in a specific environment. The components will then be sold to downstream tag providers. Some large firms subcontract IC design houses to design RFID chips to sell under their brand name.

Competency in RFID chip and tag development requires the following four areas of expertise: digital design, analog design, memory design and antenna design. Different kinds of tags are used in different application environments, making domain knowledge an extremely important aspect of competitive advantage. Additionally, tag antennas, functioning in UHF and microwave frequency bands, must be specifically designed for the different substances to which they will be affixed.

2.2. *Tag providers*

Three types of RFID tag providers sell tags to system integrators: (1) RFID chip designers that integrate antennas with chips to make complete RFID tags. (2) Companies that buy RFID chips and antennas to assemble them into tags. (3) Companies that buy completed tags from original equipment manufacturers (OEM) and resell them under their brand name.

2.3. *Reader providers*

The reader providers integrate reader antennas, firmware and application software, according to both the system integrator's (SI) and the customer's needs. Sometimes tag providers also provide readers since readers and tags must be compatible. However, the reader business is very different from the tag business because the number of readers sold in a year may be in the thousands while that of tags may be in the millions.

2.4. *Middleware and software providers*

Middleware both transfers tagidentifications to the host system and acts like a filter between the readers and the host computer that runs the application software. The core competency of middleware and software development includes OS (operating system) design, database management and security.The information technology (IT) infrastructure of RFID applications needs to be integrated with an enterprise's software system, e.g. in SCM, enterprise resource planning (ERP), customer relationship management (CRM), or the warehouse management system (WMS).

2.5. *System integrators*

A system integrator makes sure that an RFID system provides a solution to a client's needs. All tag data collected by readers is linked to the enterprise IT system for manipulation. This linkage requires an overall plan that specifies what data to capture and retain, and how it will be used within the organisation. It involves system application knowledge, scenario analysis, RFID hardware and software integration, and IT infrastructure setup. System integrators must possess strong application domain knowledge with system-engineering capability to integrate RFID hardware with software.

3. RFID industry development strategies in the Asian countries

Low frequency spectrums (LF, 125–136 kHz) and high frequency spectrums (HF, 13.56 MHz) were allocated for commercial RFID applications several years ago. However, these spectrums are not suitable for most applications requiring a longer reading distance and higher processing speed. As a result, the RFID international standards bodies are suggesting an allotment of a ultra high frequency band (UHF, 868–960 MHz) and microwave band (2.45 GHz) for RFID applications(Nogee 2004; Pine, Michielsen, and Reresi 2003). RFID operating in the UHF band can reach 1–2 meters read-distance, has a higher data transfer rate, has a lower tag price and is more suitable for global SCM applications.

The following five sections summarise the RFID industry development histories and status, RFID industry development strategies and early RFID applications in China, Taiwan, Korea, Japan and Singapore.

3.1. *China*

Well over 70% of the more than US$200 billion worth of goods imported into the USA from the Pacific Rim each year comes from China (*RFID Journal* 2005b). Manufacturers in China will eventually be required by global buyers to put RFID tags on pallets and cases. Chinese policymakers realise the market for RFID is going to be big and that its benefit is not only to improve the global supply chain efficiency for international buyers, but also improve the efficiency of its domestic logistic infrastructure and manufacturing operations.

China's Fudan University has developed a UHF RFID chip and cooperated with SAP (the leading German software company) to develop an RFID application system. The technology of low-cost antenna manufacturing and RFID tag assembly, however, is still lacking. Hopefully, the cost of RFID tags will decrease when manufacturers in China have a huge demand for RFID tags (Harrop and Das 2006).

In February 2004, the Chinese government established China's RFID standards study group for purposes of establishing guidelines for UHF spectrum regulations and the development of Chinese RFID standards (CRFID). Suggesting China's intention to develop its RFID industry, the Minister of Industry Information, Madam Zhang Qi said, 'China should be big enough to develop and deploy its own standards' (Guillory 2006). The interoperability of RFID tags with global RFID readers is essential because products manufactured in China are expected to be shipped to global markets and tags must be readable by RFID readers deployed anywhere in the world.

As RFID technology proposals will be voted upon by member states in the international standards body, the Chinese government wishes to receive as much support from the member states as possible. When the CRFID Technology Association was established in 2001, there were five RFID technology proposals competing for CRFID's endorsement, including EPC, International Standards Organization (ISO), Ubiquitous ID (identifier) center (UID), Association for Automatic Identification and Mobility (AIM) and IPico proposed IP-X air interface protocol (IPicoX). These RFID technology providers are willing to transfer their technologies to Chinese partners in exchange for China's support in the voting for the global RFID standard in the international standards body and the license to enter the potentially large RFID market in China.

The Chinese government wishes to reach the following objectives by setting a unique Chinese national RFID standard (*RFID Journal* 2005a): (1) Upgrading technology: China's RFID technologies lag behind those of other countries. By leveraging CRFID standards, Chinese companies may have a chance to catch up with RFID technologies; (2) Increasing competitiveness: Through

alliance with companies with advanced RFID technologies, Chinese companies could incur fewer licensing expenses and become competitive in the global RFID market.

In October 2006, China released 863 RFID programs to sponsor more than RMB 100 million for 20 RFID technologies and application development projects (AMTO 2007), which covered chip, antenna, reader, middleware, application and standard development. They hope to upgrade the Chinese RFID industry capability before they release their CRFID standard.

By keeping the cost of RFID tags low in China, Chinese companies can increase their competitiveness in securing their position as contract manufacturers for global markets. In the USA or the European Union (EU), for example, industry standards are contributed and negotiated in standards organisation by companies, industry groups, university scholars, technology innovators, or even consumer groups. Being centrally controlled, the Chinese government will definitely have a strong influence on the CRFID standard.

In June 2006, China published the 'White Paper on China's RFID Technology and Policy' (USITO 2006), and defined a guideline for developing RFID technologies in China. That is 'to establish an independent development pattern with enterprises as main players, featuring close combination of administration, production, learning, research and application, on the basis of national conditions of China'. Under the guidance of actual application requirements, China hopes to make breakthroughs in key RFID technologies to facilitate formation of RFID technology innovation system and industrial chain; and to draft China's own RFID standard series.

In April 2007, China's State Radio Regulation Committee (SRRC) had approved bandwidths in the 840.25–844.75 MHz and 920.25–924.75 MHz ranges for use by UHF RFID tags and interrogators in China. Each band is divided into 20 channels, each consisting of 250 kHz of spectrum. China's approval of the two UHF bands can be viewed as good news for US and European companies. China's 920–925 MHz band overlaps the 902–928 MHz band used in the USA, so US RFID tags will be readable by interrogators approved for use in China. Although China's 840.25–844.75 MHz band is lower than Europe's UHF RFID band, European RFID tags should still be readable in China. China has not finalised the Chinese standard yet. ISO-18000-6B and 6C type can be adopted in China, but the regulation of UHF band release policy shows that the Chinese government wants to play a central role in global manufacture. Their regulation allows the tag attached at Chinese manufacturers to be read in the USA and Europe within the supplier chain and global logistic market.

China has explored RFID applications in the following areas (USITO 2006):

- Public security
- Production management and control
- Modern logistics and supply chain management
- Supervision and management of exported and imported goods at ports
- Traffic management
- Military application
- Major projects and activities (gaming, ticketing, vehicles and facilities).

China has over 1.3 billion people and a high annual economic growth rate. If the government wants to employ certain RFID applications on a large-scale, fixed investments could be shared by a large number of users and RFID tag costs could be reduced because of the economic-scale effect. Additionally, China could deploy RFID systems in its logistics infrastructure directly without wasting resources on a barcode system.

3.2. *Taiwan*

IC fabrication and packaging industries are already in place to provide a basis for low-cost manufacturing of RFID tags in Taiwan. In the past several years, Taiwan has successfully developed low frequency (125–133 kHz) and high frequency (13.56 MHz) RFID chips. Currently, there are companies researching RFID chips, tags, tag assembly and reader systems that operate in the UHF and 2.45 GHz bands. Taiwan has developed a frequency-independent chip that has a 1k bits R/W (read/write) memory with write-protection functionality, capable of transmitting over broad frequency ranges (HF, UHF and microwave). Low-cost assembly and packaging for RFID tags at UHF and 2.45 GHz bands are still technical challenges. To save costs and time, one giant paper company in Taiwan has been developing advanced printing technology to attach RFID IC and antennae directly to product labels to avoid the extra step in attaching RFID tags to product labels.

The Taiwanese government's RFID strategy focuses on RFID applications in supply chain management (the S programme) and in developing a platform for RFID applications (the R programme). Taiwan's mission is to develop high-value service industries with RFID as an enabling technology. The Taiwanese government has funding for pilot projects for RFID applications, including SCM, cargo management, container tracking and logistic management. RFID also finds application opportunities in the ubiquitous wireless coverage infrastructure in Taiwan. Implementation of RFID technologies in Taiwan includes usage in Taipei's Mass Rapid Transit (MRT), access control, parking, libraries, and hospital staff and patient management. Some of Taiwan's RFID vendors have focused on niche markets such as intelligent toys. The major RFID field trial projects include:

- Container tracking and global logistic applications
- Pallet level tracking applications
- Medical/ pharmaceutical applications
- LPG management applications
- Automation applications
- Baggage handling applications.

The Industrial Technology Research Institute (ITRI) has established an EPC standard testing laboratory to provide testing and certifying services for RFID products and systems of Taiwanese vendors. As of 2006, over 200 companies have joined the RFID Technology and Application Alliance organised by ITRI. The Institute for Information Industry (III) has been focusing on RFID middleware and applications systems development.

Acer has also received government R&D funding to establish an RFID EPC network platform with local Object Naming Service (ONS) and EPC Information Service (IS) functions which can be an RFID information distribution node of EPC networking systems in Taiwan. The purpose of this platform is to service all Taiwanese suppliers in transferring their EPC information to worldwide customers, such as Wal-Mart.

3.3. *Japan*

Japan's MITI (Ministry of International Trade and Industry) is chartered with the mission to promote the RFID technology in Japan. MITI has two major initiatives for the development of the Japanese RFID industry (Yumoto 2005). One strategy is to develop and promote a Japanese RFID standard. The Ubiquitous ID Center (UID Center) is Japan's RFID standard organisation. Its

mission is to identify core technologies and to establish standards for the automatic identification of physical objects and locations, as well as to work toward the ultimate objective of realising a ubiquitous computing environment. The UID Center includes members such as the ubiquitous network infrastructure committee, the Ucode tag technology work group, and the U-TAD work group. The UID Center has joint research agreements on ubiquitous networking technologies with the Institute of Computing Technology, the Academy of Sciences of China, the RFID Association of Korea, and the T-Engine Application Development Center (TEADEC) of Singapore (Ubquitous ID Center 2004). Because most members of the UID Center are Japanese companies and little support from international companies exists, its protocols and standards are not expected to be internationally accepted. METI also recognises EPC as an international RFID standard observed by Japan's industries (Yumoto 2005).

The other strategy, the HIBIKI project, is to develop low-cost RFID tags (Yumoto 2005). Its target is to develop relevant technologies in materials, designs and manufacturing processes for the realisation of a 5 yen (5–6 US cents) RFID tag that conforms to the EPC Gen2 (ISO-18000 type C) specification, with the assumption of a demand volume of 100 million per month. Hitachi Ltd., has been the project leader and has collaborated with NEC, DNP and Toppan. High throughput and precision assembly systems for reducing RFID assembly and attachment costs are being researched.

Many RFID applications are being considered and tested, including RFID tags on sushi plates for check-out billing purposes by sushi restaurants and RFID tags embedded in ground bricks that can respond as guidance signals to blind people. Since 2002, METI has initiated a 3-R project (reuse, reduce and recycle) using RFID technology for the management and tracking of electrical appliances and their life cycle from manufacturing to logistics to recycling. The Japanese government has selected the seven most promising RFID application areas and has sponsored funding for field trial projects. They are as follows:

- Electric home appliances and electronic equipment/devices
- Construction machinery, industrial vehicles and agricultural machinery
- Publishing, book stores and libraries
- Medical and pharmaceutical products
- Department stores and apparel
- International marine and land container transportation
- CD/DVD media and retail rental stores.

Japan has allocated 125–134 kHz, 13.56 MHz, 2.4–2.5 GHz, and 5.8 GHz for RFID use. Recently the 950 MHz band has been re-allocated for unlicensed, low-power, passive RFID use.

3.4. *Korea*

The Korean Ministry of Information and Communication (MIC) has an IT 839 program, which depicts a telecom strategic goal for the future. RFID technology is recognised by the Korean government as one of the nine essential driving forces critical for developing future services. To insure development of these services, the Korean government has allocated a five-year budget of US$800 million for R&D of RFID/USN (Ubiquitous Sensor Network) technologies and applications development (Ilett 2005).

Major associations involved with RFID/USN issues include: the USN Center, the Telecommunication Technology Association-RFID/USN project group and the Mobile RFID Forum. The major technology research institute is the Electronics and Telecommunications Research

Institute (ETRI), a non-profit organisation in Korea. It started developing read-only passive RFID technologies (900 MHz) in 2004, read/write technologies (433 MHz) in 2005, and moved on to sensory RFID technologies in 2006, and communication RFID in 2008.

Targeting over 36 million cell phone users in Korea, the electronic giants, Samsung and LG Electronics along with Korean mobile phone operators are eager to capitalise on the potential opportunities of new services and significant revenues generated by RFID-enabled mobile phones and advanced cellular infrastructure. RFID sensor tags along with Korea's RFID/USN programme will enhance RFID capability with a variety of memory types and sensor functions. Through wireless, mobile networks (GSM, GPRS and 3G) and the Internet, digital content and application systems (SCM, ERP and CRM) will be integrated and diversified, an achievement that can expedite the realisation of a truly ubiquitous digital world.

RFID technology will also play a key role in Korea's U-City (Ubiquitous City) project, which will include automated payment of parking fees, vehicle identification, house keys, in-store services like product information, fashion news, etc., automated checkout in retail stores, RFID tags for sewer pipes, and for tracking locations of vehicles, children and pets. Other promising RFID applications include asset management, warehousing, transportation ticketing, airline baggage, pallet and case level supply chain management systems, etc.

Korea has selected six RFID pilot projects related to government services:

- Government procurement management
- Ammunition management
- Import/export logistics infrastructure
- Import beef tracing service
- Airport baggage tracking system
- RFID-based harbour logistics.

For access control, Korea has allocated the 135 kHz spectrums, for smart card and inventory, the 13.56 MHz spectrum, for container and tyre pressure sensors, the 433.67–434.17 MHz spectrum, and for logistics and distribution, the 908.5∼914 MHz spectrum.

3.5. *Singapore*

Singapore was the earliest adopter of RFID in port management and air cargo management systems in Asia. Is has become the first pilot port in Asia under the US Container Security Initiative which uses RFID e-seals for all containers bound for US ports. RFID embedded e-seals can enhance container-tracking efficiency, improve security and reduce labour costs. Singapore's public transportation fare system was based on contactless RFID solutions, operating in 13.56 MHz band. Also developed was its RFID-based national library system in 1998 (Yeoh 2005) and an RFID patient tracking system during the SARS outbreak period in 2003.

Based on its successful RFID adoption experience and its understanding of the potential benefits of RFID in supply chain management, the Singaporean government set a goal to develop Singapore into an RFID Hub in Asia. Infocom Development Authority (IDA), a statutory board of the Singapore government with promotion, development and regulatory functions for the information and communications industries, announced an investment of US$10 million in RFID technologies in July 2004. Also it committed to invest US$20 million for the establishment of five RFID supply chain management systems in Singapore by 2006.

A*STAR (Agency for Science, Technology & Research) is the leading RFID technology research and development centre in Singapore (Yeoh 2005). Within A*STAR, three research

Table 1. Summary of Asian RFID industry status and development strategies.

	China	Taiwan	Japan	Korea	Singapore
Main strategic goals	• Developing China's standards to upgrade its technical level • A worldwide factory	• Using RFID to establish innovative service industry	• Leading in RFID application industry	• Using RFID for promoting IT service industry	• Using RFID as global logistic hub in Asia
Major strategic approaches	• Promotion of international standardisation • Development of RFID technologies • Cost leadership • Field trial application projects	• Development of RFID technologies • Cost leadership • Field trial application projects	• Promotion of international standardisation • Development of RFID technologies • Field trial application projects	• Development of RFID technologies • Field trial application projects	• Development of RFID technologies • Field trial application projects
Major promoting standards	• ISO18000 • EPC • UID • China Standard	• EPC • ISO18000	• EPC • UID • ISO18000	• ISO18000 • UID	• ISO18000 • EPC • UID
Available spectrum band in UHF (MHz)	• 840–845/Max 2 W ERP in centre 16 channels • 920–925/2W ERP Max 2 W ERP in centre 16 channels	• 922–928/Indoor 4W EIRP /outdoor 2WEIRP	• 950–956/Max 4 W EIRP 952–954MHz	• 433 • 908.5–914/4W EIRP	• 866–869/0.5W ERP • 923–925/0.5W ERP and 2W ERP w license
Responsible government organisations	• CAS • MII	• MOEA	• MITI	• MIC	• IDA

(*Continued*)

Table 1. Continued.

	China	Taiwan	Japan	Korea	Singapore
Major RFID R&D organisations	• SAC • Auto-ID Fudan University	• ITRI • III	• UID Centre • Auto-ID Keio University	• ETRI	• IME • I^2R • SIMTech
Major applications	• Public security • Production management and control • Logistics and SCM • Traffic management • Military applications • Others (gaming, ticketing etc.)	• Publication and Books • Medical/Pharmaceutical • Container Transportation • SCM • Automation • Automobiles	• Electric Appliances • Machineries • Publication and Books • Medical/Pharmaceutical • Department Stores • Container Transportation • CD/DVD	• Government Procurement • Ammunition • Import/Export Logistics • Import Beef Tracing • Airport Baggage • RFID-based Harbor Logistics	• Electronic Road Pricing • National Library • Containers (under US CSI) • Fare System • People Tracking in Hospital (for SARS)

institutes have been working on RFID-related research projects:

(1) The Institute of Microelectronics (IME) (Institute of Microelectronics 2006) was dedicated to developing low-cost R/W RFID chip, reader IC, antenna and self-assemble technologies in the 2.45 GHz band.
(2) The Institute for Infocom Research (I2R) was interested in dual band RFID Systems (868 and 915 MHz), readers, tags (2.45 GHz passive and 433 MHz active), antenna and logistic tracking applications.
(3) The Singapore Institute of Manufacturing Technology (SIMTech) has developed RFID middleware and a cargo handling control system.

In order to be compatible with spectrum allocations in both the USA and Europe, Singapore has released two blocks of frequency spectrums in the UHF band for RFID applications: the 866–869 MHz spectrum was allocated, without license, for devices operating with an ERP (equivalent radioactive power) less than 0.5 W and the 923–925 MHz spectrum was allocated, without license, for devices operating with ERP less than 0.5W or, and with license, for devices operating with an ERP of more than 2.0 W.

3.6. *Summary*

We examined the RFID industry development strategy of five Asian countries and found different strategic goals required by the different governments. China is using RFID to be a worldwide factory, Taiwan is using RFID to establish an innovative service industry, Japan hopes to be a leader in the RFID application industry, Korea uses RFID/USN for IT service industry promotion, and Singapore wants to use RFID technology as a global logistic hub. Every country would like to use field trial application projects to establish successful templates to help their domestic users to understand the RFID technology and deployment experience. Because of their large markets, China and Japan can promote or influence the RFID international standard, or even develop their own standards. Taiwan and China hope to leverage their existing industry to be a cost leader in the RFID industry. The Asian countries often provide R&D funding to their government-sponsored R&D institutes to develop RFID-related technologies and pilot field application projects. That can help the governments to realise their RFID industry development policies. From the available UHF bandwidth view, we also found the Asian countries still allocate a non-consistent UHF spectrum. That is one of the major challenges and obstacles in the RFID market. The RFID development histories, current status, applications and strategies of the five Asian countries are summarised in Table 1.

4. The benefits of government-led RFID strategies

Unlike the USA and the European countries, the adoption of RFID in Asian countries is not driven by retailers. Instead, most initiatives are often headed by government and/or suppliers. Government-led RFID development strategies may have the following benefits:

- RFID systems are far from simple plug-and-play solutions which enable users to make purchasing decisions and implement on their own. Any RFID tag is expected to be read by RFID readers manufactured by any foreign venders and installed in any foreign countries. Any RFID reader is expected to read RFID tags attached to goods manufactured in any country in the

world. A government is more likely to have capital and spectrum resources to select proper RFID industry policies/regulations and to guide domestic enterprises to head in a concerted direction and plough through the technical issues and bottlenecks at the current stage of the RFID development. Government-sponsored research institutes have more technical expertise and resources, which could be used to develop proper RFID technologies, to establish successful pilot systems and to share experience with domestic companies. With government guidance and support, individual companies can join efforts and complement each other in building an RFID system solution.

- Multiple RFID technology proposals are competing in the international standards organisation. In deciding which RFID technology proposal to endorse, an Asian government may be able to negotiate technology transfer deals for its domestic companies. Asian governments that have already allocated radio spectra for RFID use give their domestic vendors advantages in designing and testing their RFID products/systems.
- While individual enterprises can only install their private RFID systems within their own premises, the government has the resources and authority to build a nationwide RFID infrastructure for the entire country. Based on the network externality effect, the more users and applications on an RFID network, the more usefulness and benefits the RFID network will have. The true benefit and impact of RFID will become realised if segmented domestic RFID installations can be connected into a nationwide RFID infrastructure, and national RFID infrastructures can be connected into a global RFID infrastructure.

5. Conclusions and recommendations

Since the economic strength and technical capability of Asian countries are not as competitive as those in industrialised countries of the West, Asian countries cannot expect that a domestic RFID industry can establish itself through free competition with multinational giants. Initiatives from government technology policies to drive RFID industry development strategies are essential. The Asian countries in this study view RFID as a high-impact technology and an emerging new industry. While the challenges for wide adoption of RFID remain high, they are not insurmountable. As more efforts are put into RFID research and development, more pilots are run and more data is collected, the industry will be better equipped to attack problems that stand in the way of worldwide adoption.

Having played proactive roles in developing RFID, the distinctive RFID industry development strategies of Asian countries can be highlighted as follows: Taiwan wishes to manufacture RFID ICs and tags given Taiwan's industry strength in IC fabrication and packaging. China leverages its potentially huge RFID market demand to attract collaboration from international RFID vendors in an attempt to upgrade its domestic RFID technologies. Korea invests heavily in R&D of RFID technologies in an attempt to become a leading supplier in the global information and communications technology industry. Japan explores the market potentials of RFID in a ubiquitous sensor network. Singapore adopts RFID applications eagerly in order to position itself as a hub of global logistics in Asia.

RFID technology is still emerging and the industry is still young. There are a variety of issues and decisions in standards, regulations, technologies, products, business models and priorities that a country needs to assess in order to construct a national policy and competitive industry development strategy for RFID. Such policy has to be based on realistic assessment of the competitive advantages; financial, technical and human resources; existing industry characteristics and structures; as well as the government's vision and determination. With the different specifications

of RFID products, e.g. frequency spectrums, communications protocols, power sources, chip memory sizes and packaging technologies, etc., any company interested in entering this market is advised to determine its strategic position and focus on a specific specification of an RFID product, thus creating a segmented niche in the global RFID market.

Acknowledgements

We are grateful for the RFID industry information provided by ITRI. We thank the ClarIDy Solutions for offering the consultation of products.

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Appendix

Table A1. Glossary of RFID

Term	Explanation
RFID	Radio-frequency identification (RFID) is an automatic identification method, relying on storing and remotely retrieving data using devices called RFID tags or transponders
Tag/transponders	A combination of a microchip and antenna that can be programmed with information to identify items and transmit that information to a receiver. Some tags can also receive new information, such as location information during shipment
Active tag	Tags that use batteries as a partial or complete source of power to boost the effective operating range of the tag and to offer additional features over passive tags, such as temperature sensing
UHF	Ultra high frequency (UHF) designates a range (band) of electromagnetic waves whose frequency is between 300 MHz and 3 GHz (3000 MHz). Also known as the decimeter band or decimeter wave as the wavelengths range from ten to one decimeters
EPC	Electronic Product Code (EPC) An identification standard created by the Auto-ID Centre that provides additional information to existing bar codes. The EPC can identify manufacturers, product categories, and individual items. See also Auto-ID Centre and Bar Code
CRFID	China defines its own RFID standard
UID	Ubiquitous ID (identifier). An identification standard created by the UID center in Japan. The Ubiquitous ID technology is for automatically identifying information stored in bar codes, electronic tags, and microcomputers embedded in various physical objects around us in order to provide more advanced information services and environmental control
ERP	Enterprise Resource Planning
EIRP	Given the gain and transmit power of an antenna, we can calculate how much power we would need to put into an isotropic antenna to get the same peak power as we get in the main beam of a directional antenna. This power is called the effective isotropic radiated power (EIRP). EIRP is larger than the actual power by the antenna gain, or in dBm
HIBIKI Project	HIBIKI Project led by Hitachi Inc. Achieve in 2 years period (2004–2005) to develop RFID tags and reader chips in selling cost of 5 Japanese yen (little less than 5 US cents). Needs to be compliant with that of current EPC Gen2 specifications, and preferably to ISO standards (18000-6 type C) to be applied to global standard tag
CAS	China Association for Standardization (CAS).
MII	Ministry of Information Industry of PR China
MOEA	Ministry of Economic Affairs, ROC, Taiwan
MITI	Ministry of International Trade and Industry of Japan
MIC	Ministry of Information Communication of Korea
IDA	Infocomm Development Authority of Singapore
SAC	Standardization Administration of China
ITRI	Industrial Technology Research Institute, Taiwan
MIC	Market Intelligent Center, Taiwan
ETRI	Electronics and Telecommunications Research Institute, Korea
IME	Institution of Microelectronics, Singapore
I^2R	Institute for Inforcomm Research, Singapore
SIMTech	Singapore Institute of Manufacturing Technology