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RFID: The Real and Integrated Story

RFID: The Real and Integrated Story

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ABSTRACT

There is considerable hype and misinformation regarding the use and benefits of Radio Frequency Identity (RFID) technology in supply-chain operations. The reason for this is that while many people talk about RFID technology, very few companies have successfully used it, and fewer have been able to define the actual benefits of using it. Intel's supply network organization formed a unique collaboration with one of our major Original Equipment Manufacturing (OEM) customers to run a proof-of-concept experiment utilizing RFID tags in the combined supply chain of Intel's Malaysian assembly/test facility and our customer's Malaysian laptop assembly plant. They set out to determine the feasibility and operational benefits of this emerging capability.

One of the key goals of this project was to learn about RFID and what implications it will have on how we interact with the supply chain in the future. Another key goal was to partner with Stanford University to identify the necessary elements, as well as construct an industry-first Return On Investment (ROI) model. The project included working with a key OEM customer, Stanford University, MIT, and numerous suppliers of RFID equipment and readers to build a working system in which we could move and track microprocessors through the supply chains of both companies from the back end of the Intel PG8 Test facility onto our customer's consumption point in their manufacturing facility. One of the major benefits was that we were able to forge a new kind of relationship with one of our key customers.

We discuss the following key points in this paper:

- The ecosystem as it exists today.
- Our strategy and approach to understand the technology.
- What we really did with our OEM customer.
- What the value proposition looks like.
- What we learned.

We chronicle the early path-finding project from inception to completion of the shipping of over 70,000 CPUs to our customer in a four-week period. We further attempt to dispel the myths and articulate the realities of what this technology can really offer as it applies to supply network design and optimization in the future.

In the future, we hope to include a proof-of-concept project with a key transportation provider and outline our efforts to align the various entities within Intel that are engaged in RFID experiments. We will also be working on an inventory visibility project with a key boxed product distributor.

INTRODUCTION

As a global, world-class, semiconductor manufacturer, our approach to finding value from Radio Frequency Identity (RFID) technology was quite different at the beginning of 2004 than most other early adopters. While others were being forced to implement RFID as a result of major retailer and government mandates to meet "slap and ship" solutions, we determined that we wanted to explore the idea of how (or if) this technology could help our company and our supply network travelers transform our business practices, and potentially realize improvements across the entire spectrum of our supply networks.

We wanted to test our belief that smart object technology (of which RFID is a part) would offer both operational benefits and the opportunity to make major changes in the supply network ecosystem as a result of additional information. We therefore established a strategy of looking end-to-end across our supply network to determine potential areas of benefit. We then developed short proof-of-concept studies to test potentially high-value areas for the technology, one at a time, using a building-block approach. Over time we will connect the various building blocks into a larger, integrated project that will test the technology throughout the supply chain.

For this specific proof of concept, we chose the segment of our supply chain that included only our final point of manufacturing through distribution out to our customer. We desired to understand several items in this experimental segment. The mundane functions of tag readability, reader and printer reliability, tag, box, and box on pallet placement were the basics, of course; we wanted to know if the technology worked. However, beyond those fundamentals, we were interested in determining if the establishment of a new level of relationship with our customer and the actual integration of information between two companies would provide opportunities for improvements in our planning and operational systems. We did not know specifically where these might be but hoped that they would exist. Of specific interest was the topic of increased visibility across the company boundaries and the potential for benefits as a result.

This "learn as you go" approach was especially valuable with the specific problems encountered in RFID technology itself. In this paper, we chronicle not only our approach but our findings in the areas of technology, operations, value, and business improvement.

THE ECOSYSTEM: WHAT RFID IS

An RFID capability is made up of several technology components that can be embedded into a business environment to improve and transform key supply-chain processes. In this section we describe the fundamental RFID technologies as well as provide insight into the implications and value of integrated RFID system design.

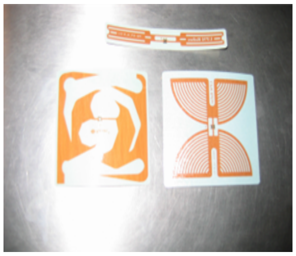

Figure 1: RFID tags

The most basic components of RFID are wireless radio frequency "tags" (Figure 1); these are small devices with a transponder and an antenna that emit data signals when queried/powered by an RFID reader tuned to the tag frequencies.

Multiple frequencies have been identified for RFID that have different purposes, distance capabilities, and costs. Figure 2 provides usage information about Low Frequency (LF), High Frequency (HF), Ultra-High Frequency (UHF), and microwave technologies. HF (13.56 MHz) has been used for some time in various applications. UHF (915 MHz in the US) has been focused on for the recent retail supply-chain mandates and investment due to its distance and cost attributes.

	Frequency	Distance & Cost	Example Application
LF	125 kHz	Few cm, ¢	Auto-Immobilizer
HF	13.56 MHz	1m, 50¢	Building Access
UHF	915 MHz	7m, 50¢	Supply Chain / retail / CPG
µwave	2.4 GHz	10m, $'s	Traffic Toll

Figure 2: RFID frequency and use spectrum

RFID tags have superior capabilities and benefits over barcode technology in the following ways:

- A power source is not required for passive RFID tags, which is a key defining benefit.
- Non "Line of Sight," high-speed, and multiple reads are possible, changing the nature of how this technology can be applied.
- The RFID Electronic Product Code (EPC) standard extends the UPC standard, by providing for an individual unit to have a specific and unique identity (ID).
- RFID tags can have read *and* write capability for both ID and other data.
- An RFID tag and a battery create an active RFID capability with the attributes of a wireless sensing and communication device (e.g., sensor/mote).

RFID Readers/Printers

RFID readers are placed at designated points along the supply chain (such as when arriving at or leaving a distribution center). Readers send an RF signal to power and activate the tags, process the signals, and receive data. Reader-collected data can then be filtered and proliferated to product information databases and business services. RFID readers can also write to a read/write-capable tag, changing the data on the tag during their lifetime. RFID printers are also available to print information on tag-embedded paper labels as well as write to the RFID tag silicon.

It needs to be pointed out that while RFID reader/printer capabilities are evolving rapidly, the UHF RFID industry and technologies are still immature. The onus rests with the RFID user community to define well-architected, cost-effective RFID integrated systems, and to drive more robust and capable technology components.

RFID Standards

A cross-industry-standards consortium, EPCGlobal, created out of the research work done at the MIT Auto-ID lab, is defining standards for data exchange and architecture. EPC-formatted data on an RFID tag provide an industry-standard way to identify and exchange information about an item. The EPC standard includes a product serial number and can provide links to information such as country of origin or use-by dates.

Integrated RFID Design

RFID is not simply putting readers and printers into a distribution center and tagging boxes and pallets. There are many other ecosystem implications that determine the design (capabilities and constraints) of an integrated RFID system that are more than the sum of their parts.

Ecosystem Implications

The ecosystem implications are as follows:

- **Environment:** RFID readers use radio waves to power nearby tags. Radio waves are subject to interference and can be impacted by devices tuned to a similar frequency (e.g., barcode readers, WLANs, etc.) by the material content of the tagged objects (metal, liquid) and by the form factor of the tagged parts, boxes, and pallets**.**
- **RFID and IT infrastructure integration:** To create a working RFID system, an integrated design is necessary of the specific reader, tag, and printer as well as a reader form-factor design (portal, etc.). The combined interactions of the RFID components in a "setting-based" design will dictate how well the RFID system will perform. In addition, the RFID reader infrastructure requires self-manageability characteristics (e.g., RF profile characterization and debugging, etc.), cross-reader interaction capabilities, and a well-architected alignment to existing computing infrastructure.
- **Application architecture:** There are two aspects of application architecture that must be considered with RFID:
  - The real-time interaction architecture between users, reader, tags, and tagged objects in the specific business environment (e.g., a distribution center) to capture the physical workflow activities.
  - The "middleware" architecture that creates the bridge between the physical workflow and the higher-level enterprise applications, such as the following:
    - Managing the real-time RFID-generated data flow.
    - Filtering and directing information back into the RFID infrastructure.
    - Performing aggregation and communication to/from the enterprise systems.

  Critical components of RFID application architecture are the two-way filters that maximize real-time local decision making as well as enable global strategy and business rule setting.
- **Information management:** RFID necessitates a new approach to information architecture and management due to the creation of a unique identity associated with a specific physical object. Identity and other information about an object can be embedded in the RFID tag and can persist throughout the lifecycle of the object. Perfect visibility into the physical movement of objects through existing business processes enables new associations between the physical workflow and the logical systems. A few of the implications of this include the following:
  - Persistent object-contained information and identity.
  - Highly distributed information structure and physical data storage.
  - Object nesting (e.g., units to boxes to pallets, etc.) and resulting information hierarchies.
  - New information, associations, and aggregation created by physical object proximity.

  This opportunity creates potential havoc with existing information systems. We found that our current systems and processes were not structured to take advantage of this persistent level of information, nor were the data structures even in place to receive this level of information about our products. Although in some cases we desire unit- and box-level traceability, we are not structured in our systems to accommodate this level of data or the quantity of data provided.

  Furthermore, we found that our ability to communicate with our supply-chain travelers, in this case our customers, was lacking in process and in common language.
- **Regulation and compliance**: RFID requires more than procuring the appropriate hardware and software and installing it into a warehouse. Issues not normally

considered during an enterprise-based technology implementation must be taken into account.

As RFID UHF takes hold in the United States due to mandates by the DOD and key retailers (Wal-Mart, etc.), additional regulation and compliance work must be done by companies operating global supply chains to ensure seamless RFID-based interaction. The 915 MHz-925 MHz UHF spectrum has been allocated for use in the United States and is driving alignment across the US-based RFID technology industry (reader and tag vendors, etc.).

However, the European Union is aligning around the 868 MHz spectrum and is facing more stringent constraints on the use of the RFID communication protocol (e.g., "Listen, Then Talk"). Many of the key Far East countries (e.g., China, Taiwan, Malaysia, etc.) have not yet aligned to a standard UHF frequency, and in many cases have already dedicated that frequency for other uses. To operate in these countries requires special permits/licenses issued on a site-by-site basis by the local government.

STRATEGY AND APPROACH

Our overall research vision defines ubiquitous computing technologies in the context of our business, and it identifies the types of technology that would make that vision real and valued in our manufacturing and supply-chain processes. RFID (providing easily accessible and unique identity) was a key and early foundational capability necessary to realize our vision. With this in mind, we began the first of a series of proof of concepts that would provide that foundation for the future.

End-to-End

While the value of an end-to-end vision shaped our RFID approach and philosophy, we realized we had to be innovative to make these ideas a reality.

First, we set strategies to shape our first year of investigation.

Second, we created a loose network of RFID investigators across the company and defined a criteria framework for their projects/trials and for aligning them with our end-to-end vision. We hired ethnographers (corporate anthropologists) to spend time in our factories and warehouses documenting the world from the product perspective.

Research seed funding was used to create a shared RFID lab in an Intel distribution center. This was a place that any project team could experiment with a broad suite of technology components and RFID artifacts in a real-world environment. However, we knew a few RFID tags in a lab wouldn't provide us with the insight into improvements, opportunities, and challenges that scale experiments would.

We needed organic experimentation in a high-volume manufacturing environment, grounded in real business problems, with quantifiable ROI and a good fit for RFID capabilities. This would provide a base of trials for us to learn from collectively. We focused on areas with the highest potential business value and began our "building-block approach" with the Intel Malaysia Assembly/Test to OEM manufacturing proof of concept.

Our approach in designing the proof of concept included a number of elements to ensure that the information captured would be reliable and usable within our existing manufacturing operations. These elements are as follows:

Deploy the proof of concept in a high-volume real-world production environment. We wanted to discover RFID's impact on our actual operations. The proof of concept was designed for, and deployed within, the production facilities at Intel Malaysia, the company's largest semiconductor assembly and test facility. In this high-volume manufacturing setting, we could extensively test the effects on manufacturing processes, material flows, information flows, business processes, regulatory environments, and resource utilization. Of particular interest was how it would interact with the wireless environment, material and informational flows, facility layout, and processing steps of producing and shipping large volumes of product.

Collaborate with a major customer. We believed that RFID, as a paradigm-shifting and possibly disruptive technology, could have significant impact on the supply chain beyond Intel's walls. Therefore, we wanted the proof of concept to extend if possible into our customers' operations. After considering a number of potential partners, we decided to work with one customer in order to limit complexity. A major PC OEM with notebook PC manufacturing facilities in Malaysia became that partner.

Focus on interactions. We knew that data would be collected in new ways and expected that the data collected would be richer and more complete than those collected by current methods. Since we anticipated that both the new methods and the enhanced data would present new challenges to existing processes and capabilities, one of our objectives was to explore how RFID changed the interactions between people, product, infrastructure, data, and supply-chain partners.

Measure and document key knowledge. We knew that success in this proof of concept was only a beginning, and that documenting and sharing the lessons learned would be the real benefit as we moved into other areas and other proofs of concept. There were two categories of learning we wanted to document: the mundane functional aspects of readability, writeability, distance of reads etc. and questions regarding frequencies, reliability, and function. We also wanted to understand the integration effects on our systems and processes that additional data would drive and offer, including the opportunity to drive inventory savings as a result of visibility. Finally, we were interested in the less quantitative opportunities offered by the technology regarding our relationship with our customers.

We utilized our engagement with Stanford and MIT professors and students to ensure that we were measuring and documenting our results and knowledge. This has allowed us to share this knowledge with our key partners and has provided the baseline for more advanced analytics to evaluate applications of the technology for the greatest business value in the future.

THE RFID LOGISTICS PROOF OF CONCEPT

The Existing Manufacturing Environment

The proof of concept took place in the facilities of Intel Manufacturing in Penang, Malaysia ("the factory"); in Intel's adjacent Malaysian Integrated Warehouse ("the warehouse"); and in the PC OEM's manufacturing facility ("the customer") nearby. The proof of concept tracked the movement of Intel® Centrino™ mobile technology-based microprocessors from the end of the manufacturing line (where individual processors are inserted into carrier trays), through Intel's warehouse, and finally to the point in the customer's manufacturing line where individual processors are delivered for insertion into notebook subassemblies.

Data

At a basic, functional level, the goal of the project was to provide real-time, location-level data via RFID. Further goals related to the potential value of that data stream were as follows:

- Gain understanding of possible data architectures and data management techniques.
- Identify how RFID can structurally affect existing data flows and existing applications.
- Determine the type of data visibility our customers will desire.
- Determine the type of data Intel would like from its customers.
- Determine the best methods of data retention for later data mining.

Process

One of the key decisions was the selection of the appropriate frequency for the system to operate in. Since the selection of frequency defines the tags and the equipment to be used, and enables the level of readability distances that are possible, the appropriate selection drives the subsequent capabilities. After several experiments with proximity and distance of read capability, we settled on the 910-920 MHz range as the appropriate frequency to meet our distance and read requirements. The specific frequency depends upon the country and the firmware used. The Tyco equipment that we used has two primary ranges. One is an EU version that is best suited for usage in the 865-868 MHz range and the other is equipment for US and Asia with a range of 910-920 MHz. We used the latter.

After we selected the generic frequency, we then worked with the Malaysian government to obtain a special use permit to operate UHF readers in their country. The government identified that we would need to operate in a narrow range of 917.5-922.5 MHz due to the GSM cell phone usage that was just below and above this limited frequency range. After getting the basic equipment, we worked with the vendor to create a firmware (software upgrade for the reader) that ensured the reader was only operating in the frequency range that we were permitted to use.

After agreeing to and enabling ourselves to operate in this frequency range, we went to the various sites in Asia and conducted a spectral analysis of the various facilities where we were going to install the equipment. This was done to ensure that we could safely operate the readers without impacting any of the other wireless devices that were operating around the 915 MHz range. We did find that we needed shielding and antenna tuning to eliminate significant interference with our hand-held barcode systems that used RF to transmit signals in our warehouses.

We had two primary hardware configurations. The first was designed to write/create the tags and the other was designed to read the tags. For the write application we would use one reader, antenna, and PC. We used additional Mylar shielding to help pinpoint and limit the range of the antenna so that we would only write to a tag that was very close to the antenna. These reading stations (portals) were designed to read tagged boxes that were either inside of a metal cage or sitting on a pallet.

Tag selection was guided by the UHF frequency decision and by available space on the intermediate box. The tag had to fit in a 3.5" x 4" space on the end of the box. After

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testing numerous 64-bit and 96-bit tags, we selected a Class 1 "butterfly antenna" tag from UPM Rafsec with a 96-bit memory capacity.

The RFID equipment (antennas, readers, and PC) at each processing station was tied into our factory network and sent data to a server for consolidation. The linkage into the server was an Intel-created middleware. The middleware managed the large amount of data generated by the RFID readers: it collected them, and parsed them, deciding which data were relevant, and it delivered appropriate data to the database. The relevancy of the data was determined by several criteria. Actual movement or change of state was key. Many-time multiple reads are accomplished but there is no movement or state change. We desired to filter that information and only capture and transmit when something of note actually happened. This becomes a laborious process of designing what is desired, testing it, looking at the results, and then redesigning the filters based on actuals.

The middleware also managed the RFID readers and antennas by telling them when to turn on and how long to run. We wanted to push as much intelligence and data management to the edge of the network and use the readers and the middleware to decipher the data that was important and needed to be sent onto the database. This was very critical in that it allowed us to not overload the database with irrelevant or redundant data.

Our customer had a similar network running at their facility. We shared data files via e-mail that were then uploaded to the receiving sites network. In future POCs we expect to share these data directly with our customers as well as integrate them into our ERP tools. Also of note here is that since we were not feeding data directly into our ERP tools, we were simultaneously running two processes throughout the proof of concept. The first process was our standard process used to build and ship our material. The second process enabled all of our RFID-based transactions. With greater integration in the future, we would be able to operate with one process that would update both RFID and other information at the same time.

The products we were tagging were Intel Centrino mobile technology-based processors boxed at 250 units per intermediate box. We had an RFID tag on the intermediate box, as well as on the overpack box. In addition to the boxes, we also tagged the transportation media (metal trolley and shipping pallet) to establish parent-child relationships.

At the physical level, data tags were loaded with a unique identifier. This unique ID was linked in the middleware and database to the specific data characteristics that we tracked for each intermediate box. This data included the following:

Manufacturing information:

- Product code (SKU) number and quantity in a group pack.
- Lot numbers, country of origin, overpack ID, and intermediate box tags.
- Transaction times and locations.

Supply-chain and order information:

- Cart name and/or pallet ID.
- Delivery Note (DN) number/House Airway Bill (HAWB) number.
- Customer Part number/Customer PO number.

The data that were in our database mimicked those which are tracked in our order management processing system. We ran the proof of concept, gathered data, summarized our findings, and began the analysis stage. In this stage we collected and summarized our key lessons learned.

RETURN ON INVESTMENT

As a part of this study, we endeavored to determine if there was a value to increased visibility due to the existence of more real-time data. Dr. Hau Lee of Stanford University had a special interest in the value proposition regarding RFID. He participated in our proof of concept, with special attention to ROI.

There are three areas that Dr. Lee investigated for possible issues regarding ROI. They are illustrated in Figure 3.

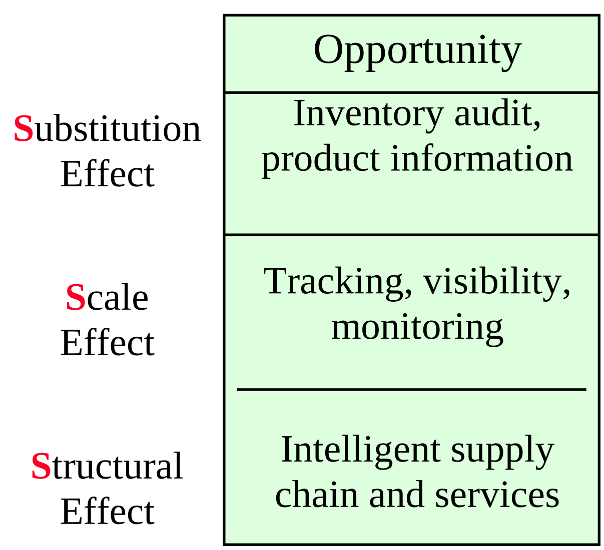

Figure 3: Areas investigated by Dr. Lee

Substitution would imply simply replacing current barcode or other data-management practices with RFID and due to the ease of data capture, this would provide payback. The work done on this POC and work that Intel Solutions Services did with Tyson foods and other clients clearly indicates with data, that substitution alone does not provide a good ROI for RFID. There is about 12 to 15 cents per read that can be saved and regardless of tag cost or level of infrastructure, this alone is insufficient to pay for any level of RFID implementation.

Scale is a much more likely opportunity for savings. This implies that one would install RFID across a wide range of products or processes. However, it is still not apparent in our research that scale will provide adequate payback to offset the investment. This is really substitution across a larger base.

It is believed that structure is the most likely area for a good ROI. Structure would imply that fundamental changes in the manner and process of the business can be enacted via the existence and use of more timely and abundant data. An end-to-end expansion should be able to create a much greater value and benefit as follows:

BY NETWORK:

> when RFID technologies are deployed throughout the supply network, so that smart objects can be traced throughout the network.

BY TIME:

> when RFID technologies deployed on a product can manage that product throughout its product lifecycle, from product generation all the way to product return and disposal.

One specific example of this premise was evaluated in detail. The opportunity to reduce safety stock inventory as a result of more frequent views of the actual consumption was tested and modeled. Dr. Lee has established a relationship between an increase in visibility and the decrease in safety stock required in a company. The formulas are illustrated in Figure 4.

Downstream visibility	*Safety stock at Mfg DC*
No	$k\sigma$
Yes	$\sqrt{1-f}\,k\sigma$

***f* = fraction of revealed demand over replenishment cycle**

Figure 4: Value of visibility

Using this relationship, Dr. Lee was able to develop a potential savings due to visibility for a retail sample illustrated in Figure 5.

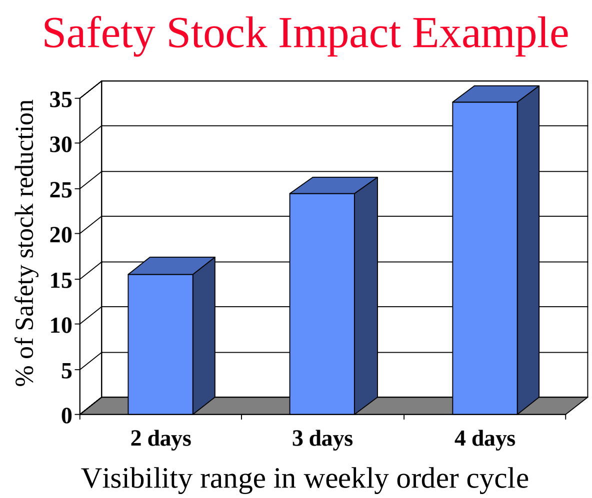

Figure 5: Safety stock impact of visibility

At this time, we are continuing the work with Dr. Lee to better quantify the opportunities for savings. There is much more work to be done, but this approach appears to provide a good opportunity for long-term savings and benefit. This does not yet address the more systemic changes in supply-chain organization that may be possible. This will be a key topic of interest in our next series of tests.

WHAT WE LEARNED

Throughout our first year of discovery, and especially with this particular RFID project, we identified several key lessons. We learned a great deal about the actual discrete functioning of the technology regarding tags, readers, frequencies, country regulations, and placement of readers, tags, and support equipment. We also discovered much about current and future possible business impacts in our supply network. Many of these lessons will help us to shape our future experiments to gain even deeper knowledge. We are confident that the technology will provide us with more timely and granular detail about our products and processes. We have yet to discover exactly how to take full advantage of this detail in our supply-chain operations. Our end-to-end thinking is helping us to formulate the next steps and experiments and take fuller advantage of the lessons we have learned so far.

Following is a discussion of some of the key lessons we learned.

Lesson 1: This New Technology Must Be Learned in the Real World

This technology must be learned by working with the actual readers, tags, and products in high-volume production environments and by working on real problems that are unsolvable by current methods. By finding real problems we could engage the key players in the supply chain and begin to understand the true value and limitations of RFID. We found significant differences in read rates, ease of use, and consistency of data in the actual production environment than we had in our lab. One issue of note was that in our lab, we made sure to gather quantifiable read rate data. In the production environment, our operators continued to jiggle the pallets around until they got full reads and the data captured did not illustrate how much time this took.

It became clear to us as we both designed our experiments and ran them, that our approach needed to be more holistic to fully understand the following: 1) the business context including problem definition, boundaries, and impact; 2) the physical environment including workflow, people, process, product, data, and layout; 3) the "logical" system and infrastructure environment including existing system interactions; and 4) the RFID component technologies *and* the specific integrated RFID solution.

Every aspect of the physical environment had to be taken into account to maximize the accuracy and reliability of the RFID technology as follows.

- On the object: placement, orientation, form factor and materials, and spacing, plus our tags on the boxes.
- Around the object: casings, carriers, transport materials, structure, and hierarchy.
- With the object: physical proximity and relationship associations.

We did learn a great deal about physical placement of tags, difficulty in reading, consistency of read, and capabilities of the equipment. Our takeaway was that each environment, box type, product, and tag type needs specific testing in the environment to refine the particulars of the circumstance, and that lab testing or carryover from previous other products is not applicable or sufficient.

Lesson 2: New Types Of Expertise Are Needed

From the beginning of the RFID effort at Intel, we had to create and apply new methods and techniques for the projects, ranging from how we capture our business requirements, to designing the data structures and applications, to building and testing robust RFID systems. In addition, we had to address new requirements and include unexpected tasks, much different from a normal enterprise application project.

Ethnography

From the outset, we were sure that simple substitution of RFID for barcode would not be a profitable endeavor. We were looking for more fundamental opportunities. We decided to attempt to understand how unique identity at the object level could or would affect our fundamental business processes. We therefore set out to capture the requirements in a new way, from the product point of view.

Intel factories are very capital intensive, and as a result the factory processes and applications are designed with equipment optimization as a priority. If we were going to use RFID technology to tag our products, we needed to understand how these objects physically moved through the supply chain, and what interactions occurred between products, people, equipment, and data (both paper and electronic). This new view of an object's workflow was captured through the use of *ethnography* (e.g., corporate anthropology), where anthropologists studied the factory or warehouse and captured information from the product's point of view. We took our corporate anthropologist into the factories in Penang to study the process in this manner. This gave us new insight into the way the factories operate and also helped us identify the best insertion points for the technology. From this study we decided that the process flow from the end of our testing operations through the boxing, warehousing, and out to the customer would offer the best opportunity to provide us and our customer with real-time availability information that we hoped would be the most useful to changing our management and delivery processes.

Collaborative Supply-Chain Conversations

When RFID project work began with the PC OEM, the level and type of conversation between us changed in very interesting ways. RFID eliminated some of the barriers in typical supplier-customer interaction, by providing a new way for us to examine and improve both the logical processes and physical movement of our objects. A view into the relationship between product planning, manufacturing, logistics, transportation, and consumption at the object level, brought us new insight into our product's lifecycle. There were several areas in which simply doing the proof of concept allowed the planners and logisticians to talk directly without the purchasing and sales organizations filtering information in both directions. Focusing on the product movement versus the commercial terms allowed both companies to derive the truly best processes for both. Several misconceptions regarding needs for labels, codes, selection criteria, etc. were cleared up and modified independent of the actual RFID technology, simply as a result of this increased and different communication.

A fairly mundane but important example of this type of conversation was illustrated by the tracking of an urgent order during the proof of concept. With data, we were able to track an urgent order pulled in from 3 p.m. to 10 a.m. at the manufacturing facility. This order was a rush to the customer. The actual tracking indicated that although it left Intel at 10 a.m., it did not arrive at the customer 30 minutes away until 2 p.m.. (The truck stopped for a two-hour lunch and prayer.) It was then placed on the shelf and not used until later the next day. The ability to track this transaction with data created a dialogue about rush orders and the need and criteria for them when our facilities are a half hour apart. This process will change even prior to use of RFID.

3D RF Characterization and Integrated Testing

As we designed our integrated RFID system, it became evident that new levels of characterization and integration would be necessary for a successful implementation. The first step was to create an RFID testing lab inside of a working distribution center. This gave us a testing environment where we could analyze a variety of RFID tag and reader technologies and frequencies to understand individual components capabilities but also determine the best pairings of tags and readers.

In-situ RF characterization was required next to tune the RFID tag-reader system by evaluating the specific environment's impact (e.g., interference, absorption, etc.) on the RF signals and the resulting system performance. The RF signal could be affected by the object materials, its containers (metal cages, desiccant bags, etc.), current infrastructure (e.g., barcode readers), and the physical layout of the factory or warehouse.

Then the physical objects could be characterized and tuned with the RFID system by generating 3D mappings of the interactions of the reader radio waves with a tagged pallet or transport container. At the same time, we had to comply with international government regulation and RF licensing restrictions. This required on-site RF assessment to verify our RFID system complied with Malaysian spectrum specifications.

Lesson 3: Expect A Long-Term Disruptive Impact On Enterprise Systems and Architectural Landscapes

In the course of our work, it became obvious that we were collecting large amounts of data on the product reads, about each transaction, not only at each leg of the supply chain but multiple times. It further became obvious that if we desired to design an end-to-end, object-centric, RFID-integrated database to cooperate with the tag information, we would need a very different architecture from our current SAP centralized environment.

With data resident with and owned by the individual unique objects, highly distributed information architectures become possible. The idea that all data must be centrally located so decisions can be made does not appear scaleable to us in an extended RFID/Smart Object environment.

In the near term, the use of stopgap middleware and appliance software to handle data filtering tasks appears to work well. We developed such a solution for our project and are evaluating various commercial products for our next efforts. Over time, we expect that the number and diversity of nodes will multiply exponentially, and the need to make localized real-time decisions will increase.

Lesson 4: Structural Change Opportunities

We approached each RFID project with the mindset of making structural changes to our processes instead of just substituting a new technology for an existing one. This made each project much larger than just replacing our existing barcode steps with RFID. Through detailed ROI analysis, we also determined that using RFID to capture *only* the same data that barcodes do today, will *not* bring significant value to a company. Improving productivity, extending visibility, improving underlying operational parameters, and making real-time decisions through the use of RFID and other Smart Object technology offer the best opportunity for payback. The work of Dr. Lee on this project leads us towards the types of benefits that may be possible but are as of yet not fully quantified. More work needs to be done in this area but we are confident that changes in the area of structural business processes will yield the most benefits.

Through this RFID project we also identified key areas where RFID technology could be used to address current business process- and system-related issues across our product's lifecycle. These areas include the following.

Manufacturing
RFID encourages/enables unit-level routing instead of our current lot-level processes. This finer level of routing visibility provides benefits that range from tighter control of material on the manufacturing floor to decreased throughput time, as individual units can be routed instead of having to wait for a full batch to be made. It also provides a simpler method of creating and tracking product routes.

Logistics
In addition to revamping and eliminating several steps in our processing flows, we believe that RFID can also decrease our workload and improve our productivity. We also identified potential benefits related to cycle counts and an ability to get material through our processing steps quicker than is currently possible.

Customers
With RFID we see several improvements in our customer interactions. The technology enables clean unit-level visibility to the material being received, and eventually consumed by our customers. This greater level of detail can be fed into our demand systems to better support our customers.

Productivity
Currently, operators spend a lot of time printing new labels, verifying data, and barcode scanning the same information numerous times into the various application interfaces. These steps could be simplified or eliminated with RFID, increasing productivity and reducing costs.

Our future work will address putting hard numbers against these areas of learning and opportunity.

Lesson 5: Getting to SCALE–Readiness Across the Supply Chain and the RFID Technology

There is a large difference between technology trials and world-wide, end-to-end deployment and support. The technology standards and RFID system infrastructure are still in their infancy so this can amplify integration and characterization issues. We are beginning to address the many tasks needed to ready the ecosystem and eliminate obstacles to widespread adoption and the value that comes from scale and critical mass.

So, with those things in mind, what does it take to “get ready”? In order to demonstrate the complexity, let us look at one facet of readiness: **standards**. What standards need to be in place to get ready for implementation?

When an RFID project is in the initial planning stages, several selections need to be made:

- Tags that operate in a particular frequency.
- Portals, readers, writers–all the devices that define the integrated RFID system design.
- Information that will be written to and acquired from the tags.
- Application architecture and interfaces (to the RFID systems and legacy enterprise applications).
- The deployment countries and associated frequency standards permissible in those countries.

A broad set of RFID standards are needed, driven from an integrated usage perspective. It is desired that the tags be standard, and thin and flexible as possible. EPCGlobal has made excellent progress in framing the standards questions and driving cross-industry solutions, and companies are aligning to these. But there is still much work to be done to finalize and publish these standards.

However, once industry standards are set, a company still has several more readiness steps to complete.

Once a company has identified its suppliers and customers that will participate in an RFID initiative, the following conditions need to be met:

- Suppliers and customers are ready *and* have implemented the use of key RFID standards in their processes and systems.
- RFID standards must include definitions for content, structure, mechanism, interaction, and interface protocol, and all these must be in place and agreed upon by both sides.
- Once external standards are defined, a company then needs to determine the set and level of standard definitions it will apply and enforce internally for equipment (including readers, tags, systems, databases, etc.), approved vendors, application and data architecture, and strategies for interaction and engagement with customers and suppliers.

This is just a small sample of definitions required for RFID standards readiness.

There are still many things to do to realize the full promise of this technology. However, that does not prohibit us from learning and getting ready across our end-to-end supply networks.

CONCLUSION

We are seeing great promise and signs that the RFID and future upcoming sensor network technologies will help to change the way we think about our manufacturing processes and the interactions with our people and our customers. With only a small experiment, working with one customer, we learned a lot and improved our processes. We know there is much yet to be learned, but now we can build on the knowledge we have gained. We will continue to conduct our proof of concepts on the factory and supply-chain "floor" with real products, real systems, and real people interacting. We will prepare ourselves to contend with and manage the expected volumes of real-time data and attempt to determine how to best use these data to realize the promise of enhancing our supply-chain visibility. We have also learned a great deal about the need for and the characteristics of those standards required to rapidly deploy this technology in a scale (world-wide) approach. We will be working to influence Intel and others to drive for internationally accepted use, data, and frequency standards in the near future.

And finally, while RFID may seem to be a fairly simple and innocuous technology on the surface, a wide range of issues and choices need to be explored and resolved for its successful, wide-scale deployment. Concerns over threats to security and privacy (both real and perceived) are driving legislative action that could raise even greater hurdles to global RFID deployment.

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You can read additional details about this project in the *RFID Journal* and the *Supply Chain Management Review*.

REFERENCES

"Supply Chain Management with RFID," Dr. Hau Lee, Stanford University.

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