RFID applications in manufacturing

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Abstract

There is more to RFID than just tags that exchange data with readers wirelessly in response to electromagnetic stimuli. There is also middleware to filter out repetitive and irrelevant data, and to translate raw feeds between tags and data structures that software applications can use. It is a fast moving technology, with evolving and competing standards from ISO, from the US-based EPCglobal consortium, and from individual companies who follow neither but whose products, if successful, may become a de facto standard.

Most current applications in manufacturing are driven by external mandates, from Wal-Mart or DoD, to which the dominant response has been "slap-and-ship," where suppliers attach tags to finished goods just before shipment, and some even outsource that operation to 3rd parties. For in-house applications, a few companies have begun to realize the value of a technology that can make any object on the shop floor self-identifying to the information system and have begun to use it to track tools, fixtures, or pallets, to trigger the picking of kits, or to trace products.

These applications, however, have barely scratched the surface. RFID, for example, can be used to mistake-proof mixed-flow assembly of such products as PCs, with no dimensional differences between products to serve as the basis for classical poka-yokes. In different forms, the combination of RFID with kanbans also offers opportunities for smoother integration with the overall information system. Finally, RFID can be the basis for effective and efficient access control in factories handling dangerous or sensitive materials.

The main obstacle to the spread of RFID in manufacturing is the success of barcodes, the previous generation of auto-ID technology. In most applications, reading barcodes requires human intervention, a clean, high-contrast environment, and often more than one attempt. In addition, not only is the amount of data that can be stored in a bar code is much smaller than in an RFID tag but it cannot be updated. In many applications the functional potential of RFID may not yet beat the low cost of barcodes, but it is only a matter of time before it does.

1 From tags to middleware and applications

1.1 Focus on EPCglobal

The RFID industry is in flux, with competing standards and proprietary technology available from various manufacturers around the world, keeping costs high. EPCglobal is a consortium of industry leaders like Wal-Mart, Cisco, Procter & Gamble, Lockheed-Martin, and Hewlett-Packard among others, started at MIT in 2000 as the "Auto-ID center." EPC stands for "Electronic Product Code," and, as the name "EPCglobal" suggests, this organization is a leading contender for setting RFID standards in supply chain applications. Our discussion is focused on the EPCglobal approach, not because it is the only option, but because it is the one we know best and because a broader coverage would exceed the bounds of this paper.

EPCglobal classifies tags into the following six classes:

- *Class 0:* Read Only – Programmed by the factory that manufactures the tag
- *Class 1:* Write Once, Read Many (WORM) – Programmed by the factory or the user
- *Class 2:* Read Write – Can be programmed over and over based on requirements

- *Class 3:* Read Write with on-board sensors – to record such parameters as Temperature, etc.
- *Class 4:* Read/Write with integrated transmitters – can communicate independent of readers
- *Class 5:* Read/Write with integrated transmitters – all Class-4 capabilities along with the ability to communicate with and passive devices

EPCglobal's key strategy to make tags cheap is to restrict the amount of data they carry to identification, with detailed data about tagged objects stored elsewhere. EPC data on currently defined Class-0 and Class-1 EPCglobal tags is made up of 96 bits and can be classified into the 4 sections, for example, in the form "01.0000A89.00016F.000169DC0," where:

1. "01" is a header section determining the structure of the content.
2. "0000A89" is a Manufacturer / Domain Manager section identifying the company or entity that is responsible for maintaining the subsequent numbers
3. "00016F" identifies a product or group of products.
4. "000169DC0" is the serial number of a product unit. It can be a bottle of shampoo or a battle tank.

Reading a tag is only the first step. The tag data need to be filtered, translated into access keys, and used to retrieve the information available about the object. Preparing this data so that it can be an input to an application performing a service for manufacturing is the job of the middleware described in the following section.

1.2 Middleware

RFID readers collect large amounts of data, most of which are redundant or irrelevant. The middleware filters out this data and let through in a usable form the input needed to track production activity, trace the history of parts as needed, trigger shipping, receive materials, operate the kanban system and other applications. In the opposite direction, the middleware also formats the data for updating tags in Classes 2 and above. In the EPCglobal approach, the following components are needed for software applications to link information with physical objects, as shown in Figure 1:

1. *EPC.* The Electronic Product Code (EPC) is the data in the RFID tag. A reader polling all the tags in its environment every 2 ms sends data as through a fire hose, most of which needs to be filtered out. Other data sources, such as barcode systems or sensors, do not necessarily have this problem.
2. *EPC Middleware*. These services enable data exchange between an EPC reader or a network of readers, and an EPC/RFID based business application The middleware server accumulates and filters raw tag reads and only keeps that which is due to objects entering or leaving the reader's range.
3. *ALE*. Application Level Events (ALE) is an Interface definition that defines how an EPC/RFID application interacts with the EPC reader or a network of readers.
4. *ONS.* The Object Naming Service (ONS) translates the bytes in the EPC into the web address (URL) of the object data. This is needed because EPC tags only contain identification data. ONS is an automated networking service similar to the Domain Naming Service (DNS) that maps internet addresses like "123.45.365.12" to names like "www.mydomain.com."
5. *PML.* The Physical Markup Language (PML), based on XML, provides a format for storing and retrieving data about objects that can be parsed by multiple applications. It surrounds the data items with tags like <pmlcore:productID> and </pmlcore:productID>, and these pairs of tags are nested as needed to allow applications to load the content into their own data structures.
6. *EPCIS*. EPC Information Services (EPCIS) is an inter-application data exchange standard that defines a secure, Web Services based data exchange mechanism that can be used by trading partners and, in general, all EPC-based applications to exchange EPC data and event information.

In a *supply chain* application, the data needs to be available to multiple participating organizations, and it makes sense to store it in an XML-based format that can be read consistently by all parties, regardless of their information systems. Inside one company and inside one plant in particular, the situation may be different. More types of data need to circulate more rapidly within a company than between companies, and it is all within the control of one single organization. Multiple applications may be in use Product Data Management (PDM), for production planning (ERP), production scheduling (eKanban or APS), tracking (MES), maintenance management (CMMS), supervisory control (SCADA), analytics (OLAP), and others, but a well thought out integration effort may already have developed a *local* middleware layer, with common metadata, a publish-and-subscribe model of live data exchange, a shared real-time database for status data, and a data warehouse for history. Within such an environment, the ONS/PML structure of Figure 1 appears to be unnecessary overhead. Tag content can be translated directly into database keys rather than URLs, for all applications to retrieve detailed data through SQL queries based on the company's private repository of metadata. The data can then be replicated as needed in PML for communication with outsiders.

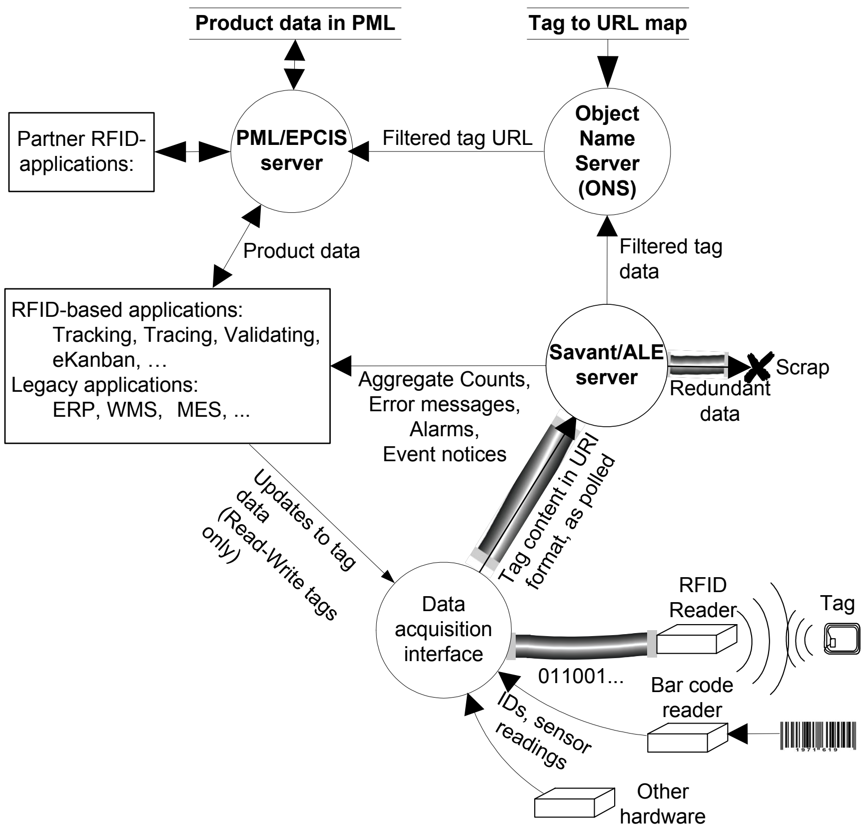

Figure 1. The EPCglobal middleware architecture

1.3 Application software

The application software that reads and possibly updates tags should share data as needed with the applications already in use in the plant. As shown in Figure 2, the suppliers of such applications may have different strategies on RFID. While ORACLE stays aloof from middleware, SAP provides its own. SAP describes its Auto-ID infrastructure in terms of applications, saying, for example that it helps support pick, pack and ship operations. This is not the same as saying that it provides ONS and PML services as described above, and suggests that it may be both more efficient and less flexible than the architecture shown in Figure 1.

While Figure 2 only references Oracle and SAP, many applications built for pilot projects have used the available software infrastructure in the company, such as Java, Microsoft .NET, as well, extensions provided by ERP and WMS vendors such as SAP, Oracle, and Provia.

2 Applications driven by external mandates

2.1 Wal-Mart

Wal-Mart buys $178 billion dollars worth of packaged goods annually, and is looking to RFID to improve visibility into inventories from distribution centers through to retail shelves. The main stated goal is to improve availability of products to consumers while increasing their own revenue and the revenue of their suppliers. Additional benefits will also be enjoyed throughout the Wal-Mart distribution network in terms of visibility, automation of shipping/routing/receiving, better tracking and routing decisions, etc.

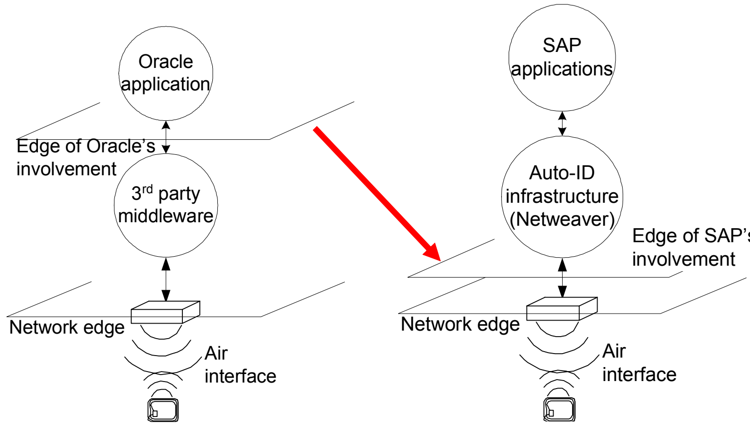

Figure 2. Strategies of application providers

Many manufacturers, particularly in China, have Wal-Mart as a major customer, and are compelled to develop some form of RFID application by Wal-Mart's mandate that shipped goods should bear RFID tags. According to press reports, Wal-Mart's implementation is not proceeding according to plan. Wal-Mart called for 100 suppliers to be doing the following by January 2005:

1. Attaching EPC Version 1 read-only UHF (915MHz) tags on all pallets and cases shipped to three Texas distribution centers. Allowable tags included Class 0, for which the data is entered by the tag manufacturer, and Class 1, which can be written by the tag user.
2. Have the tags perform to EPC specifications:
    - Pallets to be read at dock doors with 100% success at 10 feet.
    - Cases to be read on conveyors with 100% success at 600 ft/min

This aggressive plan, however, is behind schedule for several reasons, having to do with both the technology and its slow acceptance by suppliers and consumers.

- As of 12/2004, 100% success in reading tags had not been achieved. In its stores, Wal-Mart reports 60%.
- Only 40 of the 100 targeted suppliers were tagging all their shipments. To suppliers, complying with the Wal-Mart mandate is a cost of doing business, rather than an opportunity to improve information systems, and they find the costs too high.
- Wal-Mart has pulled back from its goal of tagging individual items, due to opposition from consumers who felt it to be an invasion of privacy.

There is presently no change to the existing requirement to have both a bar code label and human readable information provided on each shipment. This redundancy protects Wal-Mart from risks from the new technology, and ensures that all existing processes at the company do not need to change, but it does put an additional burden on the suppliers that are looking to deploy RFID. Overall, 1 billion cases will need to be tagged each year, and, at a cost of $0.50 per tagging, it works out to $500M/year. Wal-Mart has asked suppliers to provide details of how they will benefit internally from RFID, but many are turning to the Slap-and-Ship approach discussed later, which precludes any internal benefits.

2.2 US Department of Defense

The US Department of Defense (DoD) buys $24 billion dollars worth of packaged products annually, from more than 40,000 suppliers. The US DoD has been using RFID in logistics since Gulf War I. The huge volumes of materials that need to be transferred in a short period of time, with a high degree of precision in location, are a challenge for any technology. RFID tracking of shipping containers held up well in the early 90s, and the decision was made recently to further expand the use of RFID. While the Wal-Mart mandate is unfunded, the DoD's comes with supplier support. For manufacturers, it remains an external mandate, not directly related to internal, and its main short term result may be more slap-and-ship.

2.3 Slap-and-ship

The Slap-and-Ship approach to meeting customer mandates often involves the outsourcing of RFID compliance. In this model, the manufacturer pays a third party to ensure that shipments meet the RFID customer mandates. The third party may be a distributor or logistics provider that is already in the supply chain, or it may be a company that is contracted just for the compliance activities. The processing of the manufacturers products happens as follows:

1. The manufacturer ships finished goods, to the slap-and-ship service provider.
2. The service provider does the following:
    a. Break the shipment down to have access to each individual carton.
    b. Tag cartons per the customer's specifications.
    c. Rebuild pallets.
    d. Tag pallets per the customer's specifications.
    e. Ship tagged cartons and pallets to the customer
    f. Issue Advanced Shipment Notification (ASN) or other transactional information as required

Slap-and-ship requires minimal internal training and investment for hardware or software. It is a fast, pay-as-you-go way to satisfy inconsistent and evolving mandates from multiple customers. Beyond the short term, however, this approach has the following disadvantages:

1. It affords no opportunity for internal use of the information.
2. It involves no learning of the technology in the supplier organization.
3. It involves an additional link in the supply chain, which translates to more transportation and handling.

3 Applications driven by internal needs

Most RFID applications in *manufacturing* are centered on the fully automatic identification of objects that may not be in the line of sight of the readers. They improve shopfloor inventory tracking and automate warehouse operations, including shipping / receiving. Over the past few years, documented examples include the following:

- *Toyota (South Africa).* Carrier tagged to streamline manufacturing and vehicle tracking. The tags are intended to remain with the vehicle throughout its life and hold its maintenance history.
- *Harley Davidson.* Process automation by tagging bins carrying parts to provide instructions to employees at each stage of the process.
- *Johnson Controls*. Tracking of car and truck seat through the assembly process.
- *TrenStar.* Beer keg tracking to improve demand forecasts and improving efficiency.
- *International Paper*. Paper roll tracking at for reduction of lost or misdirected rolls.
- *The Gap.* Denim apparel tracking to improve customer service through better inventory management.
- *Raxel.* Tagging reusable plastic biohazard containers to avoid contamination.
- *Michelin*. Tire tagging to comply with the TREAD act and recall management.

While we could cite many more examples, the fact is that they remain pilot projects and that RFID technology is still not a common sight in factories. To clarify what it can do for manufacturing, the following sections examine a few specific cases in some detail, in warehouse management, manufacturing engineering, and production control.

3.1 Warehouse Management

Figure 1 shows the opportunities available through "internal integration" – that is, using RFID not only to satisfy a customer mandate but to help run operations as well. *Configuration 1* is slap-and-ship. *Configuration 2* requires 1 portal reader per dock, a network, and an interface to the EDI system to generate advance shipping notices (ASN), or an initial investment on the order of $40K, to which we must add about $1K/year for reusable pallet tags and about $300K/year for 5,000 disposable case tags per day, including the labor needed to attach them. In Configuration 2, we see two new elements:

- A portal reader at the gate between production and the warehouse.
- The Warehouse Management System (WMS), with a flow of updates about pallets coming in and going out from the RFID network.

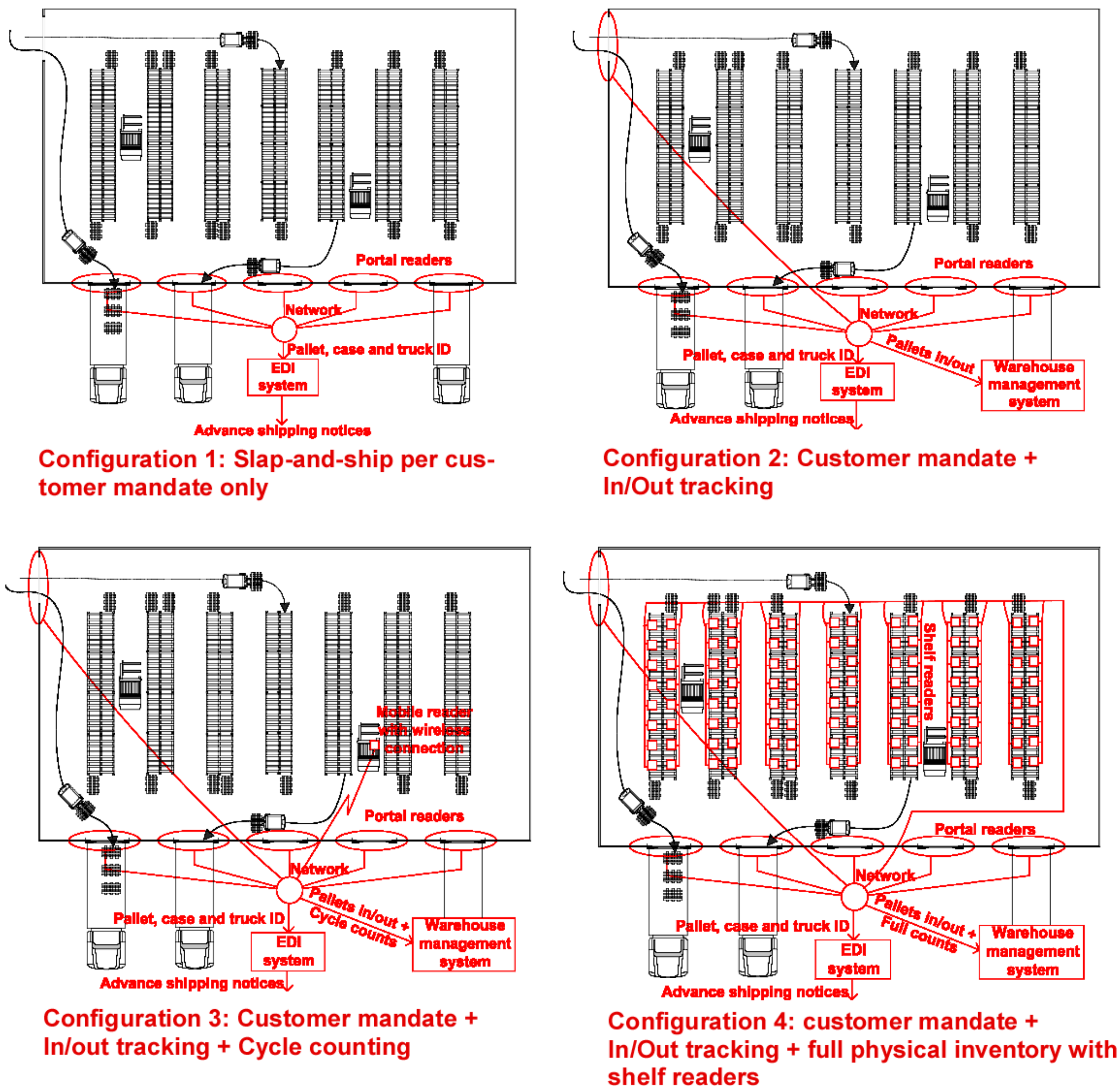

Figure 3. Four configurations of RFID application to warehouse management

The warehouse manager needs to keep track of in- and outflows anyway, and can be done with the RFID system for an incremental cost on the order of $50K to cover the additional portal and the WMS adapter for in/out transactions. For this application, the promise of RFID is a reduction in theft and shrinkage, transaction input labor, and input errors. Configuration 2 actually is the level Wal-Mart is currently pursuing in 104 of its stores.

Configuration 3 adds one mobile reader mounted on a forklift and able to interrogate shelves as it drives by, without human intervention, and an additional "WMS adapter" for cycle counting. The WMS's cycle counting module tells the RFID system which shelves to count, and the RFID system returns the results found. The necessity of cycle counts in a lean environment is a matter of debate, but not in this paper. If the plant's policy is to perform cycle counts, then the RFID system can be used for this purpose for an additional investment on the order of $25K, with the benefits of faster, easier and more accurate cycle counts.

The next step, shown in *Configuration 4*, would be to place a reader on every shelf to maintain a full physical inventory in real time. In most plants, it would be overkill. There are, however, other circumstances where it would not be because of the high value of the stored items. The semiconductor industry, for example, holds wafers in process in RFID-equipped carriers that communicate with readers on stockers so that the manufacturing execution system has real-time visibility into WIP status. The economics work out because the chips on the wafers in a single carrier are potentially worth tens of thousands of dollars. In other industries, this logic may also apply to stores of dies used in diecasting or injection molding.

3.2 Manufacturing Engineering

In 2002, Yoshikazu Suzuki, at Omron's Ayabe plant near Kyoto, developed what he called a "digital yatai" for non-repetitive production of application-specific systems for displacement measurement, photoelectric sensing, film thickness measurement, digital fine scopes, or board solder inspection. In everyday Japanese, a "yatai" is a cook-to-order food stall on the street;. Suzuki's digital yatai, a workstation that slides back and forth between shelves holding tooling and parts, as shown in Figure 4, with a computer screen prompting the operator for the next step.

Figure 4. Yatai in everyday life and on the Omron shop floor

Given that every assembly job in the digital yatai is custom, the operator cannot memorize sequences of tasks and relies on the visual instructions at every step. The transition between screens of instructions is triggered by sensors detecting the completion of each step, and the selection of parts and tools for each step is validated through auto-ID technology, using barcodes on parts and RFID tags on tools and fixtures. The system uses PowerPoint to display instructions, a PLC and a DeviceNet network to communicate with sensors, barcode scanners, RFID readers and validation switches, with wireless interfaces between the work station and the shelves.

In its initial implementation, the digital yatai was able to reduce assembly times by about 50% by eliminating the hesitation and information lookup activities that were previously required. The step by step guidance with validation also reduced errors in station setups, part and tool picking, and processing. Unlike most reported RFID applications in manufacturing, this one is not in production control or logistics but in the heart of the production process itself.

3.3 Mistake-proofing of mixed-flow assembly

The classical Poka-Yokes developed since the 1960's often rely on dimensional differences between products. As car engines large and run down an assembly line, whisker or limit switches can be strategically placed to be triggered by some and not others. But, in PC assembly today, many different configurations may be built inside the same cases, with no differences in outer dimensions. With hundreds or thousands of variations, some form of auto-ID is necessary.

Barcodes have been used for this purpose, but, in computer assembly, barcode reading still involves either an operator moving the part under a reader or taking a mobile reader to the part. Because it involves extra labor, pick validation through barcodes does not fully qualify as mistake-proofing: in a crunch, it will be disabled to increase output. True mistake-proofing is only achieved with devices that are deeply embedded within the production process and require no additional labor. As a result, there is no short-term benefit to be gained from bypassing these devices. Satisfying this condition makes RFID a qualitatively superior solution to this problem. Figure 5 shows one assembly station within a mixed-flow assembly line. At a supermarket just off the line, a "water spider" picks kits of parts for and sequences these kits on a gravity flow rack a few minutes before they are used. The challenge here is to make sure that the water spider accurately picks the parts for each kit, and delivers the kits to the flow rack in sequence.

In *Configuration 1*, Figure 6 shows how simple tags, carrying only Product IDs, can be used both to let the pick-to-light controller know which items to pick and to validate the sequence of kit pallets presented to the assembler. The product sequence information is fed to the pick-to-light controller just early enough for the water spider to pick the kits in time for assembly. Product sequences are determined earlier, but subject to last minute changes, not only at the start of the assembly line but part of the way through as well. In particular, a unit that is found defective in process might be pulled out and replaced by another unit that had been previously pulled out and repaired. If our station here is the 40th of a 50-station line, this is likely to occur. On the other hand, we can make sure it does not happen within the 8 stations preceding it by restricting pullouts and swaps to a few designated stations. Then we can be sure that products passing in front of the reader will make it to the assembly station in the same sequence.

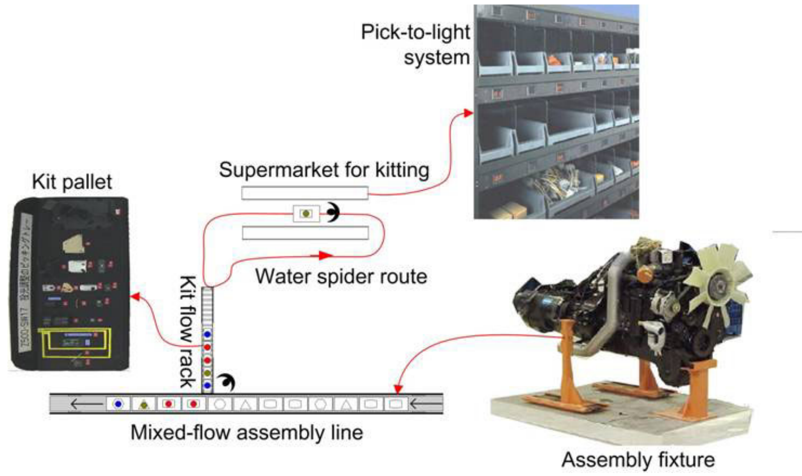

Figure 5. An assembly station on a mixed-flow assembly line

In Configuration 1, the operation of the assembly station hinges on the availability of the central Manufacturing Execution System (MES) to provide bill of materials information to the pick-to-light controller. If this system goes down for any reason, so does assembly. In *Configuration 2*, dependence on the plantwide MES is reduced by using more powerful tags. Given that the tags on fixtures and pallets are not throwaways, a possible strategy is to use tags that can hold enough information to enable the station to operate temporarily without communicating with the central system. Configurations 1 and 2 use proximity readers, with a range of a few inches, so that there can be no collision between tags from different fixtures. One might be tempted to reduce cost by using only one central reader at the assembly station that would be able to poll all the tags in the vicinity, with anti-collision technology. While such a reader would be able to find out which tags are present within its range, it would not know where within this range they are located and therefore miss the *physical sequence* information that is vital in this case. Configuration 3 is therefore not feasible.

3.4 eKanban

Toyota's eKanban system with suppliers has cards with barcodes travel with parts. Unlike traditional kanbans, the cards are used only once, and the pull signal is issued electronically by scanning the barcode before destroying the card. On the other end, this triggers the release of a new card. But while barcodes are cheap enough to be on one-time use cards, the same cannot be said of RFID tags. Since the kanban system is used with returnable containers, another option is to attach the RFID tags to the containers rather than the cards. Unlike supplier eKanbans, kanbans used in-house between two production lines still circulate many times, and, in this case, RFID tags can be attached to the cards. In both cases, the value of using the technology needs to be thought through.

3.4.1 Electronic pull signals

At a work station, where a bin of parts is consumed, the rule is that the kanban must be pulled by the operator as he or she takes out the first part. Instilling in the work force the discipline of following this rule on every bin, every shift of every day is not a small endeavor, and this raises the question of whether it could be automated using RFID.

If the bins are coming down a gravity flow rack towards the work station, the pull signal needs to be issued as soon as the following two conditions are met:

1. The bin has reached the picking end of the rack. A proximity reader mounted at the end of the rack can detect the arrival of the bin's RFID tag within its range.
2. The operator has pulled the first part. The bin can be covered with a "light curtain," broken when the operator reaches into the bin and restored when the operator's hand is completely out.

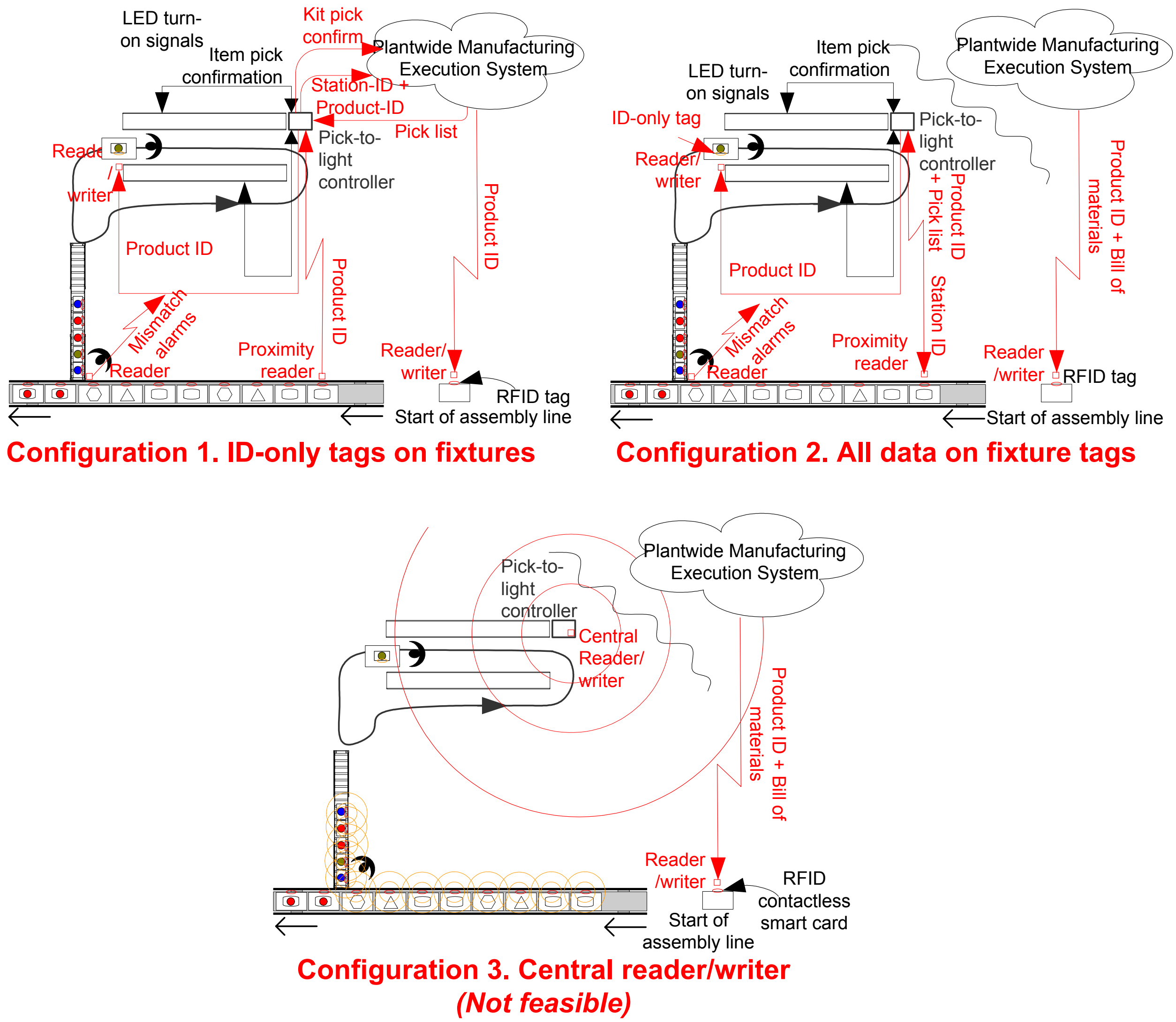

Figure 6. Mistake-proofing configurations with RFID

The concept is illustrated in Figure 7. With the proper logic implemented in software, it can trigger electronic pull signals at the right time without the operator having to take any action specifically for it to happen.

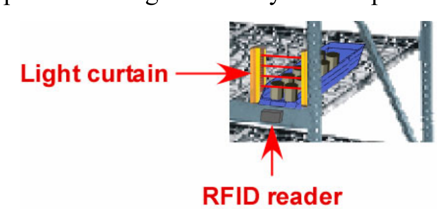

Figure 7. Detecting first part pick from a bin

3.4.2 Kanban loop sizing

The signal generation mechanism of Figure 7 is a non-intrusive means of tracking material movements, and the application can use this data not just to trigger replenishment, but to assist in the sizing of kanban loops and the calculation of replenishment lead times. This information is used to evaluate several key performance indicators of the plant overall as well as every item.

4 Barriers to implementation

4.1 Success of legacy technology: barcodes

Over the past two decades, barcodes have made themselves useful everywhere from factory floors to neighborhood supermarkets. In manufacturing, few applications of IT are as popular as barcodes. They are universally appreciated for having improved data input productivity as well as data quality over manual keyboarding, and, in manufacturing, this past success may be the greatest barrier to RFID.

The best opportunities for RFID are where barcoding is so pervasive that production operators spend a perceptible fraction of their time scanning barcodes. Such a situation is found in computer assembly, for pick validation and component serialization, and a switch to RFID in this context can be the vehicle to help the technology cross the chasm from a sprinkling of pilot systems to mass adoption.

The mandates from Wal-Mart and the DoD so far have not had this effect, as is evidenced by manufacturers resorting to slap-and-ship. While the result may be of value to Wal-Mart and the DoD, it is only a cost of doing business for the manufacturers. The current growth in the RFID industry is fueled by mandates from retailers and supermarkets that see cost-savings largely through labor reduction at the Shipping and Receiving docks. The cost justification, while obvious to retailers, is not for their manufacturing suppliers, and even large contract manufacturers perceive RFID technology as only cutting into margins.

4.2 Cost of RFID tags

Over the past two years, since EPCglobal was formed, costs have come down from >$1 tag to ~$0.2 per passive tag bought in bulk. And while this price is coming down with increasing demand and acceptance, a cheap RFID tag is still 10 times more expensive than a barcode label. This is an issue particularly with Class 0 and Class 1 EPC tags that can be used only once. Tags in Classes 2 and above can be rewritten and therefore their cost per use is only a fraction of their price.

Unless the manufacturing sector comes to view the technology as a viable alternative to barcodes for reducing operating costs, and, there cannot be significant increase in demand for passive tags and additional hardware that goes with it. Therefore, tags / converted labels manufactured with current technology will bottom out at around $0.08 over the next 5 years - nowhere near the <$0.05 promised in the early days of EPC tags. With demand growing at the current pace, tag manufacturers will need technology breakthroughs to lower prices.

4.3 Privacy and Security Concerns

Protection of privacy is not an issue in *manufacturing* applications, but it is in retail, where consumer action groups like the Electronic Frontier Foundation, Electronic Privacy Information Center, or CASPIAN have successfully prevented the introduction of item-level tracking at Wal-Mart and other store chains. In addition, these groups have persuaded governments to pass legislation restricting the use of RFID and related information about consumers. While these restrictions have not direct bearing on manufacturing, they indirectly slow down RFID deployment in manufacturing by keeping costs higher than they would be with unfettered implementation.

4.4 Lack of consensus on standards

ISO, EPCglobal and IEEE are different sources of RFID standards, as are suppliers of RFID hardware -- like Hitachi with its µ-chips -- who go their own way, ignoring published standards. ISO standards cover the whole range of RFID applications, from electronic theft prevention devices in retail stores to contactless smart cards. EPCglobal, formed by the Uniform Code Council and EAN International (soon to be renamed GS1) is focused on a narrower range of tags with limited data content for supply chain management applications and is submitting its standards for approval by ISO. There are also application-specific development, such as Real-Time Location Systems (RTLS), most of which are based on proprietary technology and use neither the EPCglobal nor the ISO RFID standards IEEE's 802.15.4 standard for RTLS aims to reduce the cost of hardware for real-time location tracking by creating a low-power network through devices that work as emitters as well as readers. Solutions based on high-power EPCglobal hardware and triangulation software for location tracking may not catch on if this new platform becomes prevalent.

Standards are a complex game played by different rules in different countries and industries, with winners that are difficult to predict. The importance of standards, however, varies with the application. The Hong Kong Airport authority, for example, would like to use RFID luggage tags, but it would be useless unless other airports did too, with compatible tags and readers. A consensus on standards is essential for this application. For applications that are local to a manufacturing shop floor, on the other hand, hardware that follows standards may be cheaper and easier to get, but nonstandard hardware. In manufacturing, the absence of a consensus on standards may be an excuse to postpone the implementation of RFID, but it is not the kind of technical show stopper that it is for airports.

5 Biographical Sketches

5.1 Michel Baudin

Since 1987, Michel Baudin has consulted for such clients as Honda of America, Dell Computer, Canon Virginia, Boeing, Raytheon, Unilever, MetalEurop, the CIADEA automotive group, Hoechst, and others on lean manufacturing implementation, and for high-technology companies like Hewlett Packard, Intel, Motorola. Winbond, and National Semiconductor on production scheduling, process transfer from R&D to production, and computer system architecture for manufacturing applications. He also designed the MS/X OnTime production scheduler marketed by Tyecin Systems and led the EU-funded INRECA research project.

Since 1995, he has taught short courses on the details of lean manufacturing, the management of lean manufacturing implementation, the lean approach to quality, and lean manufacturing for small and medium-size companies, as well as customized in-house seminars for consulting clients. These courses have been offered to the public through UC Berkeley extension, the University of Dayton's Center for Competitive Change, and the Hong Kong Productivity Center, and have been used in house by Honda, Boeing, Canon, Raytheon, Applied Materials, VDO, Siemens, and others.

His prior experience includes being a director of the Menlo Park Technology Center of Teknekron Corporation, leading a group at Schlumberger/Fairchild that designed, tested, and supported maintenance management, production scheduling, and quality control software that is in use in semiconductor factories; giving technical support for CIM installations in Japan on behalf of Consilium corporation; and implementing the OPT scheduling system in two General Motors factories.

Mr. Baudin is author of three books, Lean Logistics (2005), Lean Assembly (2002), both from Productivity Press and Manufacturing Systems Analysis(1990), from Prentice Hall as well as 24 articles and papers in various journals since 1977. His academic background includes a Master's Degree in Engineering from the Ecole des Mines, Paris; work at the Hahn-Meitner Institute of Berlin; and research at the University of Tokyo. He is a senior fellow of the University of Dayton's Center for Competitive Change, and a member of the IMSE External Advisory Board of Ohio University. Michel Baudin is fluent in French, Japanese, and German, and is learning Spanish.

5.2 Arun Rao

Arun Rao has more than 12 years of management and executive experience, including strategic planning, project management, consulting and software design & development. In 2001, Mr. Rao founded Baysquare Technologies, a self-funded Enterprise Software company based in Santa Clara, CA, that provides platforms and solutions for real-time data processing environments, RFID solutions and business consulting.

The company builds packaged solutions for large-scale data processing (EPC/RFID middleware, distributed business applications, GSM/Telecom software), and provides expert consulting services to clients such as Verisign, IBM and various startup companies around the globe. Mr. Rao’s industry experience includes Flextronics International (NASDAQ: FLEX), where he built and managed the global Business Integration Services (BIS) department that is responsible for all B2B implementations.

Prior to Flextronics, Mr. Rao worked at SBK Labs, an Enterprise Software company providing Technology and Business Solutions based on AutoID/RFID standards. While at SBK Labs, he helped make the company a founding member of the EPCglobal standards organization, and represented the company on the EPCIS Working Group. He also worked at developing strategic relationships with various leading RFID vendors and organizations. Over the years, Mr. Rao has worked at several successful startups - most recently, at a venture-backed Supply Chain applications company in the SF Bay Area, where he built and led the technical consulting practice, as well as designed the key Integration Platform and Methodology used in all implementations. Mr. Rao also designed and developed the Enterprise Adapter Framework for Netfish, a leading Middleware and RosettaNet B2B solutions provider (now a part of IONA).

In the 90s, he worked as an EDI and Middleware Solutions Consultant for the Baan company. In this role, he successfully delivered enterprise solutions to customers and partners in East & South East Asian countries, India and the Middle East; as well as to multinational corporations such as HP, Philips Semiconductors and Acer. Mr. Rao holds a Bachelors degree in Electronics & Communications Engineering from Mysore University in India.

6 References

[1] Das Internet der Dinge : Ubiquitous Computing und RFID in der PraxisVisionen, Technologien, Anwendungen, Handlungsanleitungen by Elgar Fleisch (Editor), Friedemann Mattern (Editor), Springer; (April, 2005)

[2] RFID Handbook : Fundamentals and Applications in Contactless Smart Cards and Identification, by Klaus Finkenzeller, John Wiley & Sons (May 9, 2003)

[2] RFID Labeling: Smart Labeling Concepts & Applications for the Consumer Packaged Goods Supply Chain, by Robert Kleist et al., Banta Book Group (August, 2004)

[3] RFID in the Enterprise, by Tom Polizzi, WCCN Publishing, Inc. (2004)

[4] RFID Field Guide : Deploying Radio Frequency Identification Systems, by Manish Bhuptani, Shahram Moradpour, Prentice Hall PTR (February 10, 2005)

[5] The Electronic Product Code (EPC): Naming Scheme for Physical Objects, by David L. Brock, MIT White Paper (2001)

[6] Hardware Certification Paper, by EPCglobal Inc., (August 27, 2003)