Encoding, Application and Association of Radio Frequency Identification Tags on High Speed Manufacturing Lines

Executive Summary

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Abstract

One of the entry points of radio frequency identification technology in supply chain applications is at the manufacturing line, after production, as packaged goods leave for the next link of the network of suppliers, carriers, distributors and retailers. To RFID-enable packaged products, an RFID device needs to be attached to the packaging and an identification number needs to be generated and stored accordingly. Today, a few early adopters of the technology already started to apply RFID tags to some of their cases and pallets and to collect and store the information. These processes however, are still to a large extent done at a slow pace, manually or in an experimental mode, and that may not be suited for large scale applications. To address this issue, this research document focuses on the implementation of an RFID enabled process under strict time and performance constraints, for case packaged goods and pallets. This document reviews the currently published information on the topic and the Auto-ID technology standards. It analyses system integration challenges, proposes a process for case and pallet level encoding, application and association and discusses some of information systems requirements for the implementation. It proposes a framework of options with the requirements and considerations the author believes to be most relevant.
Contents

1. Introduction................................................................................................................................. 3
   1.1. Motivation............................................................................................................................... 4
   1.2. Methodology.......................................................................................................................... 5
2. System Integration ......................................................................................................................... 6
3. Case Level ................................................................................................................................... 8
4. Pallet Level .................................................................................................................................. 9
5. Information systems ................................................................................................................... 11
6. Observations ............................................................................................................................... 12
   6.1. Next Steps .............................................................................................................................. 13
7. References .................................................................................................................................... 13
1. Introduction

This document analyzes the implementation of Radio Frequency Identification tags on pallets and case packaged products operating on high speed manufacturing lines. It follows the standards developed originally by the Auto-ID Center at the Massachusetts Institute of Technology and the definition that a high speed line is the one that is capable of producing one case per second.

It comprehends an analysis of the following processes:
- Encoding, or the formation of the EPC – electronic product code
- Programming of the EPC chip
- Automatic application of tags to cases and pallets
- Validation of tags applied
- Association of product code with individual unit
- Data management and storage

It also includes reflections on:
- System integration
- Response time, performance and reliability for different components of the system

It assesses the challenges involved on doing it in high speed production lines, where the issues tend to scale up and a higher degree of automation is usually required, comparing to the current test pilots and experimental setups. The goal is not to exhaust all different alternatives but to propose a framework of options with the requirements and considerations the author believes to be most relevant.

The components of Auto-ID standard RFID implementations include:

- Hardware
  - Tags – to store the electronic product identification code - EPC
  - Readers – to read and write tags
  - Data servers – to filter, store and share data
  - Network infrastructure – physical means where the information flows; including antennas, copper and optical fiber cable, hubs and switches.

- Software applications
  - Savants – to manage readers and filter data
  - EPC IS – to store EPCs as items move to different locations in the supply chain
  - ONS – to translate an EPC into an internet address where the information is stored
  - EPC Discovery Service – to allow the finding of the information addressed by the ONS and stored at the EPC IS.
  - Enterprise applications - to manage and store business information
  - EPC Access Registry – repository for EPC IS interface descriptions

Figure 1 below illustrates the interconnections between these components.
1.1. Motivation

For over 25 years companies have used bar codes to identify products across their supply chains. They are used at the pallet, case and item level and applications range from identifying products at the manufacturing site to checking out at a retail store. Radio Frequency Identification is a technology that has been used for some time as well, but the costs involved usually limited the use to a few applications, like for example tracking of high value assets. RF identification technology advantages over the barcodes are primarily the elimination of the line-of-sight or contact requirement and the capacity of storing specific information about the item in its chip memory. That allows a great number of new applications like for instance automatic inventory control.

Over the past three to four years, these companies have started test piloting RFID technologies in their warehouses, distribution centers and manufacturing facilities. Their primary goal with this implementation strategy was to be able to learn and understand the capacities and limitations of the technology and evaluate how it interfaced with their products and processes. Over the past six months, the technology gained a new level of attractiveness when large US and European retail chains, and also a central US military organization required their top suppliers to adopt RFID on products shipped to their warehouses and distribution centers.
Today, several large corporations that have high-speed manufacturing capabilities are facing the challenge of implementing RFID into their manufacturing sites, either to take advantage of the potential of this technology or to comply with customer’s mandates.

The motivation for this research is to address some of these challenges, focusing on the first steps of the RFID implementation process – the point where the information is generated. Code formation, tag application and information association are elementary parts of the process to manufacturers and can influence the results of the entire system.

1.2. Methodology

The analysis process involved a comprehensive review of articles and books published by research centers, vendors, system integrators as well as the specialized press on the topic of RFID technology and project implementation. Data collection also included several interviews with experts in the field of radio frequency identification, manufacturing processes, logistics engineering and quality assurance from one major multinational CPG company in the US. Interviews were also conducted with system integrators, RFID hardware manufacturers and researchers from the Auto-ID laboratory at MIT. It included people that were involved in the development of the technology and/or on the deployment effort.

With this collection of information, the analysis process that followed explored the identification of the current state of the technology, capacities and limitations as well the system integration challenges involved. With the observations drawn from this assessment, it was possible to define the research scope and to outline a process and a set of considerations that were identified as most relevant.

The selected focus of research is on processes involving radio-frequency “friendly” products and packaging. That stands for products and packaging that do not interfere with the propagation of UHF radio frequency waves. It includes products and packaging with high percentage of air space, low presence of metallic particles and low water content. The reason for restricting the analysis to these classes of products and technologies is strategic and it is meant to remove from this analysis some of the complexity already identified on field trials developed by CPG companies. It serves the purpose of establishing the grounds to enable early adopters to learn as much as possible from the introduction of this evolving technology.

The suggested process for case and pallet level applications constitutes a sequence of steps that addresses the questions on how and where to execute tag encoding application and association. The relevant considerations were defined to be the time constraint, the influence of the materials (excluding the interference effect), equipment characteristics and the operating procedures involved. To address the Information Systems considerations, an estimation exercise was done in order to analyze some of the network and data management requirements.

Here the author assumes that in the case and pallet level application, what we are identifying is the container and the product/items it holds. This relationship is unique and is valid only as long as the package continues to be at the condition it was at the time the association occurred. In order to maintain identification uniqueness, the principle that needs to be followed is that at any time, there will be only one valid EPC association.
2. System Integration

It is possible to reapply learning’s from the implementation of other new technologies to the implementation of RFID in manufacturing lines. In the work of Greenwood [8] on the implementation of flexible manufacturing systems, it is possible to find a few similarities to the introduction of RFID, especially regarding the justification for investment on a promising but yet evolving technology. By the time flexible manufacturing was introduced, there were no standard approach to the problem and it was not simple to find suppliers and developers that had extensive experience in integrating the systems. It was also difficult to find support for the ongoing operation. Similarly to what it was then, careful attention to design and the use of sound project management practices will be essential to overcome the challenges and take full advantage of the potential RFID technology has to offer.

The implementation of RFID in manufacturing lines will involve more than the introduction of the Auto-ID standard elements described above. The implementation of RFID as a project can be viewed as the introduction of a new manufacturing or operation technology, in combination with the introduction of a new information system technology. Therefore, putting RFID to work can be viewed as the integration of two complementary systems. The first involves placing the tags on the product appropriately and getting data out of the system reliably. The second involves managing and integrating the data that is being generated, transforming it into information that is useful. It will require a great deal of integration between the different areas, inside and outside the companies, redefinition of business rules and processes, personal capability development and significant capital investment.

Placing the tags and getting good data reliably, include mainly the following challenges:

- Maximize system performance
  - Design alternatives that improve technical and operational overall results
- Minimizing capital investment costs
  - Reduce the risks of obsolesce with fast developing technology
- Technology Transfer and Training
  - Personal trained and qualified
  - Include RFID technologies into people’s skill requirements
  - Update current operating procedures
- Reduce external interferences
  - Prevent existing RF emitting systems to interfere with RFID systems
- Data consistency and security
  - Data has to be verified and protected from interference
- Reliability of the process must not interfere with overall performance
  - Line performance must not be affected by RFID system

These challenges require the involvement from several areas within the organization including: product packaging development, industrial engineering, process engineering, supply chain, logistics and material management, procurement, quality assurance and finance.

Companies that have already started addressing these issues decided to proceed by selecting a sample product and location, where an in-depth analysis of the issues can be followed
by a group of experts. Results from field trials have shown that the technology is capable of providing the desired functionality. However, overall performance of system still needs to be improved in order not to interfere with overall performance.

Managing and integrating the data into current information systems, include mainly the following challenges:

- Data storage, retrieval and standardization
  - Dealing with current and historical data
  - Inter systems compatibility
- Telecommunication and computational infrastructure
  - Adequate to the new volume and flow of information
- Electronic Business processes design and adaptation
  - Adequate to new information format and content
- Data and system integrity, security and reliability
  - Data has to be correct and readily available to the appropriate user

These challenges will require involvement of information technology professionals as well as process and logistics engineering groups.

As it can be found currently in the specialized press, the current stage of the implementation does not include full integration between all these systems and there is no end to end solution that could be found in the market. Field trial and experimental systems have also shown that technology is capable of providing the desired functionality. However, legacy systems, facilities management and resource planning systems are only starting to be adapted to receive the new form of information and business processes are starting to be designed.

As the adoption of RFID technology for handling electronic business processes increases, the criticality, defined as the importance of having the systems up and running, is also going to increase to very high levels, and operations will increasingly depend on the performance of the system.

Additional challenges related to the implementation include a narrow range of vendors that are experienced with the process and technology. According to experts in the field of system design and integration, it is estimated that after sales costs and efforts comprehend up to 30% of the total amount invested on such systems. Therefore, to increase in-house capabilities will be “key” to the success. Also according to such professionals, getting in house personal trained will increase implementation and costs considerably, from 2 times up to 4 times.

Details like managing products coming from overseas vendors or subsidiaries will also have to be addressed. The decision of whether to tag the item at origin or destination will represent additional logistic challenges such as the increased processing and handling time if tag application is performed off-line and also technical challenges like for example codes and data management, concerned with how and where the ID is going to be generated.

Total system reliability will be crucial to allow the introduction of new and improved business processes. First it is necessary to define the user’s requirements (needs, issues, concerns
and expectations). Then set test performance targets accordingly [5]. As more and more the information gets integrated into operating processes, the higher the required reliability will be. System will need to be fault tolerant and 24X7 redundant. Reliability is expected to be required in the neighborhood of 99.9%, or 500 minutes of downtime per year, up to carrier-grade standards of 99.999%, or 5 minutes of downtime per year [18].

The technology will have to be operational across the supply chain, meaning that systems will be required to be flexible and follow standards. An adoption path that allows the evolution of the technology is important to preserve the functionality over time, as well as to make sure the migration from old to new systems is as smooth as possible. From the work of Lo [11], Rommel [14] and Sarma at all [15] there is evidence that the use of evolutionary implementation strategies is highly beneficial in this case. It addresses issues like building knowledge, increasing performance, reducing obsolescence and improving interoperability across different systems.

3. Case Level

Case level encoding, application and association of EPC tags is a process that can be divided into the 6 different steps shown below.

According to equipment vendors and experts in RFID implementation, the time required to perform each task is considered to be the main constraint of the process. The materials used during the operation, the equipment performance requirements and the procedures involved are additional considerations.

![Figure 2 - Case Level Application](image)

One suggested sequence for the execution of these steps can be found below. This sequence is the one that addresses the major portion of the issues and considerations identified as critical under the constraints of the problem. In this case we assume it is possible to have good control over the quality of the tags and that the tag application doesn’t deteriorate the tag’s operability, therefore, it is best to place the tag on the case first (step 3) and write the EPC to it afterwards (step 4). If that is not the case and either one of the previous assumptions is valid, steps 3 and 4 may need to be inverted and verification may need to be repeated in different times.
A list of these considerations includes:

- **Time**
  - Product identification
  - Code generation and data transfer
  - Tag application
  - EPC writing
  - Verification
- **Material**
  - Case physical characteristics
  - Tag position on the case and pallet formation
  - Tag quality
  - Reprocessing
- **Equipment**
  - Tag application device
  - Printing
  - Tag reading and writing devices
- **Processes and procedures**
  - Material control
  - Process control
  - Change control and validation
  - Training, maintenance and safety procedures
  - Product release
  - Data management and maintenance

4. **Pallet Level**

Pallet level encoding, application and association of EPC tags is a process that can be divided into the 3 different steps described below. The time required to perform each task is no longer considered to be the main constraint of the process, therefore, the main focus of the analysis is shifted to the capacity of reading multiple tags simultaneously with high performance and to making sure the pallet EPC identifies correctly its contents. It includes the materials used during the operation, the equipment performance requirements and the procedures involved in the process.
The process can be divided in 3 main steps: 1) pallet building and encoding, 2) Pallet verification, EPC tag application and writing and 3) Pallet association, aggregation and final verification.

A list of these considerations includes:

- **Material**
  - Pallet formation
  - Tag position on the pallet
  - Use of pre-tagged pallets

- **Equipment**
  - Reader / antenna configuration for multiple simultaneous readings
  - Reading station design to prevent interference

- **Processes and procedures**
  - Material control
  - Process control
  - Change control and validation
  - Training, maintenance and safety procedures
5. Information systems

The information systems infrastructure is treated on a separated chapter here due to the importance and influence it will have on the entire system. To access the design requirements of these systems, the methodology adopted here consisted of building one example elaborated for the case and pallet level applications. This exercise allows a rough estimate and evaluation of the network bandwidth and data volume and storage requirements for the implementation of an RFID – IT network on a manufacturing site with high speed lines and automatic material handling equipment.

Information systems encompasses the hardware and software infrastructure required to retrieve, process and store the data generated by the RFID network of tags, writers / readers and database servers. Information systems can be divided in three areas: 1) Base systems consisted of logic controllers and operation equipment; 2) Middleware consisted of data management and storage systems and 3) Applications, consisted of decision, planning and business transaction systems.

The main considerations here are related to the data volume to be generated and stored. A simple exercise can be proposed making use of a unit of data to be generated by a tag read. In this case, data size is known and so the total data volume to be generated will be a function of the number of tags in the reader’s field on a given moment and also the number of readers.

Figure 6 - Information Systems Overview
For a system equivalent in size of the one illustrated in Figure 6, the volume of information is expected to be in the order of units of kilobytes per second, or hundreds of megabytes per day. Due to volume, performance and data consistency requirements, storage systems will have to consider capacity to handle I/O operations, storage size and data protection.

For compassion purposes, according to experts in supply chain and data warehouse information systems, this estimate represents a data volume that is 3 to 6 times the current amounts generated today. According to the current available specifications from integrators and developers, it is expected that after the raw data is filtered at the Savant/Middleware level, this volume will be reduced considerably. However, it is not all clear at this point what will be impact of further aggregation of information as it migrates to different points in the supply chain. Nevertheless, this analysis provides an assessment for one individual organization, and that is that it will be dealing with approximately 1 to 10 Tera bytes of data per year, assuming all information generated is retained.

6. Observations

This research document was developed based on the analysis of current implementations of RFID systems, with the inputs from some of the leaders in the industry and taking into consideration a good portion of the published information on the topic available today. Under the definition of the time and performance constraints and motivated by the importance of making these processes a reliable source of information for the broad range of supply chain applications envisioned for the future, the boundaries of the problem were defined. The document was divided into system integration challenges, case and pallet level encoding, application and association and information technology requirements. The focus relied on the design of the processes and on making sure that most critical characteristics of the problem were captured under the different considerations.

Under such conditions, this analysis suggests that the integration of the different components of the system will include challenges related to performance maximization, investment analysis addressing the risk of obsolescence and system interoperability with internal and external systems. It will also have to address requirements for technology transfer and training, data management, product and process design. The analysis also suggests that early adopters will benefit the most of the technology by developing it internally and using the test pilot implementation approach, learning with the process and building capability to develop, operate and maintain this mission critical system.

For the case level application, the observation is that the tag writing step is the most critical one when it comes to time and that the reliability of the tag applicator and the tags themselves are the most critical considerations when it comes to performance. At the pallet level, it suggests that the most critical considerations are related to performance, and the potential major sources of impact are data consistency during pallet formation, the influence the operation procedures, as well as the need to prevent interferences from different readers and pallets on the physical layout of operation.

Related to the data generation and storage requirements, the analysis presented here suggests that the volume of data that the RFID system is going to generate is compatible to
currently available data management systems and that the expected evolution of the capacity of information systems is also in synchronism with the expected growth in volume of data.

Limitations from this analysis rely on the several simplifications that were done. By selecting a narrow range of products and only one type of packaging, the case level application process was limited in scope and pallet level application assumed a sequence of events and a level of automation that is not always possible to have or to achieve at the different manufacturing sites. Also, the analysis for the Information System requirements only included one type of electronic product code and did not include the dynamic characteristics of the information sharing between the different systems, restricting the analysis to one link of the network, between the readers and the first database server.

From a broader perspective, the processes analyzed here illustrate the complexity and multidisciplinary characteristic of implementing this new technology and integrating all these different systems. With the potential to affect disciplines that range from product development and process engineering to information management and logistics, the project design and execution phases will have to adapt to existing and processes in order to guarantee the sustainability of the operation. This analysis also indicates that the design of the system will have to contemplate compatibility and the capacity to expand to new RFID-enabled processes that will evolve with the introduction of the technology.

6.1. Next Steps

Along with the current research under development at the different Auto-ID centers, the Packaging Special Interest Group from US center and the System Integration research from the UK center are the ones that have strongest interface with the issues discussed in this research document.

In line with the Packaging SIG focus, during the course of this research, a number of issues related material RFID compatibility and application guidelines were identified but excluded from the focus of this research. Although some general principles were highlighted on different publications, the interference each material has on the operation of passive tags is one of the areas that I have identified as crucial and deserving of more understanding. Tag application in different packaging alternatives, other than corrugated cases, is another possible expansion to the topic surfaced here.

Related to the work developed by the UK center, the use of the product identity for controlling the manufacturing operation is an topic that was covered by Brusey et all [2], Hodges et all [10] and MacFarlane et all [12] on a robotic manufacturing cell. The suggestion is to expand this application to additional manufacturing processes, in other industries such as pharmaceutical’s packaging, electronics and semi-conductors fabrication.

7. References


