RFID Testing on Returnable Containers June 2009

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Executive Summary

Adoption of Radio Frequency Identification (RFID) technologies continues to increase each year as the costs of the technology rapidly decline and more businesses realize its benefits. Employing a RFID system gives business owners new visibility throughout the supply chain, enabling this collected information to be converted into decision making business intelligence. Using RFID to manage inventory and clearly knowing where and who last touched a product in the supply chain offers companies significant and competitive advantages in the marketplace. RFID can result in improved food safety processes and food security procedures by quickly and accurately identifying issues which can critically reduce time and expense in food recalls. From a retailer's perspective, RFID is a key tool in managing inventories, reducing out of stock situations and monitoring key performance indicators. One of the most vocal advocates for RFID adoption is Wal-Mart which is reaping these supply chain benefits.

One of the reasons that RFID has been so widely deployed is global standards. In the last five years, global RFID standards have been adopted by more than 130 countries. As this global deployment has increased, more companies are seeking better answers to the practical questions. For example, can RFID technology withstand harsh environmental conditions and still operate effectively? The produce supply chain is one of the most difficult and environmentally extreme material handling processes. For example, temperatures can range at harvest from 100 degrees Fahrenheit (F) to cold storage at 33 degrees F to 70 degrees F ambient store temperature to over 170 degrees F during the sanitation process. Another question and key barrier to adoption is whether RFID tags can withstand repeated use.

The members of the Reusable Packaging Association (RPA) undertook a rigorous study –including a year-long field trial - to answer these two crucial questions: *can a single use RFID tag be used multiple times? And can it withstand the harsh extremes of the produce supply chain?* To answer these questions, we wanted to conduct a full scale, real world test of the existing technology to determine if RFID tags could be used for multiple trips, withstand harsh production and transportation environments and still be readable once the reusable asset had been recovered for reuse *and used again.* Throughout the trial, there was considerable interest within the industry to see if RFID could be successfully utilized to track both products and reusable assets through the entire supply chain.

For the test, we selected a produce industry application because of the many challenges within this unique supply chain. During the trial, produce was packed in reusable plastic containers (RPCs) directly in the field under many different field conditions. The produce was then sent to cooling facilities where product temperatures are dropped to an optimum level to ensure freshness and transportability. Following the cooling operation, the product was loaded on trucks and other containers for shipment to end user customers.

This scenario required that the tags utilized on the assets must withstand considerable temperature swings, wet and cold environments, shipping vibration and other transportation challenges and be successfully read when entering into an end users distribution system. Also, once received by the end user, the reusable asset must be reclaimed, shipped back for reprocessing, washed, stacked and transported back to the user. The ability of the tag and other technology to handle this multiple use was a critical factor in the test.

At the conclusion of the study, we determined that the answer to both questions - can a single use RFID tag be used multiple times? And can it withstand the harsh extremes of the produce supply chain? – was yes. We believe the results of the study clearly demonstrate the capability of RFID tags to track successfully reusable assets through a very challenging produce application. The results and data derived from the test give the reusable packaging systems industry a more accurate picture of where the technology is today, and will assist to identify the potential for RFID for both growers and retailers. By building on these results and the growing body of knowledge about the use of RFID technology in the supply chain, we believe RPA members and other interested parties can begin to find new ways to utilize this promising technology to improve the utilization and management of their reusable assets and to reduce inventory at all levels and overall costs throughout the system.

This RFID study is part of the RPA's continuing commitment and efforts to develop knowledge specific to reusable packaging solutions. We want to acknowledge and thank the following for their assistance in this study

Retail
Wal-Mart Stores Inc., Bentonville AR

Growers
Frontera Produce, Edinburg, TX
Stemilt, Wenatchee, WA
Tanimura and Antle, Salinas, CA

Reusable Containers
Georgia-Pacific, Atlanta, GA
IFCO SYSTEMS N.A., Houston, Texas
ORBIS Container Corporation, Fresno, CA

RFID Technology Providers
Alien Technology, Morgan Hill, CA
Avery Dennison, Pasadena, CA
Impinj, Seattle, WA
UPM Raflatac, Hebron, KY

Packaging Expertise and Testing
Michigan State University School of Packaging
The Kennedy Group, Willoughby, Ohio

ASTM Testing Performed By
Michigan State School of Packaging
Dr. Paul Singh

RFID Readability Testing Performed By
California State Polytechnic University
Dr. Jay Singh

Final Field Testing
Project Management By
QLM Consulting
G. Michael McCartney, Principal

Introduction

The Reusable Packaging Association (RPA) is collaborative effort between manufacturers, poolers, distributors, retailers and educators to promote the environmental, safety, and economic benefits of reusable packaging. The RPA serves as the collective voice of industry and uses its knowledge of the members' products and services to advance the adoption of reusable packaging and systems throughout the supply chain. The RPA is focused on promoting the expansion of reusables as the preferred packaging solution across supply chains in all industries.

The RPA considers advances in technology, including RFID, as a potential means to increase the efficiency of supply chain economics by giving asset owners visibility of the location of these assets, including the exact number of reusable assets at any point and time in the supply chain.

The implementation of RFID involves applying a RFID tag to a reusable asset in a manner in which that asset can be read or identified by an RFID reader within a reasonable proximity. Since each asset will have a unique identification number, the location of the asset can be known precisely. Today, there is a great deal of experience and information that has already been gathered using single use RFID tags on corrugated boxes. However, very little information is known about RFID tags used multiple times in conjunction with reusable packaging. This study will assist the industry in understanding the benefits, implementation and application of RFID for reusable containers and pallets in the sometimes environmentally harsh perishable supply chain.

The RPA engaged with QLM Consulting as project manager of the study. Part of the scope of the work undertaken by QLM Consulting was to determine:

- Can RFID tags withstand the stresses of the perishable supply chain from field to retail shelf, multiple times?
- Which RFID tags can be used for what containers?
- What RFID tag form factors are acceptable?
- Where is the optimal placement of the RFID tag to ensure repeated readability?
- Can RFID tags be read accurately when placed on reusable packaging in the knocked-down orientation?

As a means of fulfilling this scope of work, QLM designed a multi-phase trial of the RFID technology for multi-use tags and asset tracking to validate business benefits, document use cases and generate requirements for technology vendors for the benefit and use of RPA, its members and the public at large.

In addition, QLM arranged to test RFID tag readability with various Gen 2 tags on containers from three reusable container manufacturers using different container sizes, primarily models 6411 and 6428. QLM also identified, within the parameters of the test, the best placement of tags, tests for impact and durability, including vibration and cooling conditions, and suggested possible packaging changes to maximize readability.

<u>Summary of RFID Trials</u>

A summary of the testing:

After more than two years of testing, the multi-phase trials of the RFID technology for use with RPCs (models 6428 and 6411) in fresh produce distribution applications has concluded. The testing was conducted in three phases:

- Phase I: Distribution related physical testing of loaded and tagged RPCs in a packaging dynamics lab
- Phase II: RFID tag readability testing for RPCs from Phase I in an RFID testing center

Phases I and II were used to determine the optimum RFID tags and RPCs for use in Phase III.

- Phase III: Tagged RPCs monitored in real life shipments from farm through distribution and back to the farm

1. These RFID tags were subjected to the harshest and most vigorous testing in packaging labs under ASTM guidelines before they were field tested.
2. During field testing, the RFID tags underwent extreme changes in temperature from over a 100 degrees F in the field to 32 degrees F in cold storage and over 170 degrees F in the sanitation cycle.
3. Additionally, the RFID tags were exposed to dry field conditions, wet and cold storage environments, warehousing, store racking and hand deliveries to the store shelves.
4. Further, each of the RFID tags used during field testing were subjected to an average of over a 1,000 mile transportation distance, before being unloaded at a distribution center, then reloaded onto local trucks for delivery to the stores, redelivered back for sanitation, and finally redeployed to the produce company for reuse.
5. The project team performed over 160 hours of testing and over 14,000 individual tests. This involved subjecting four pallets, 230 RPCs (erected and flattened) to *Sinusoidal Vibration Tests* and *Drop Tests on all edges (or over 7,300 tests).*
    a. Each tagged container was tested at four different attenuation levels, inbound and outbound through a RFID portal, in two configurations: erected and filled with produce as well as flattened and stacked at 70 high (Model 6411) and 35 high (Model 6428).

Summary of Test Results

The key findings of this study are:

1. RFID tags that are designed for single use can be used for multiple trips without any deterioration in performance if positioned correctly on reusable containers.
2. RFID tags were subjected to ASTM recommended vibration and drop testing protocols and not all RFID tags performed at a 100% read level.
    a. The three highest performing and off-the-shelf Class 1 Gen2 RFID tags selected for field testing were manufactured by Alien Technology, UPM and Avery Dennison.
    b. The commercially available EPC Gen2 RFID readers used for the study were manufactured by Alien Technology and Impinj.
3. After more than 5,000 tests, QLM found that there is a wide range of placement options on the reusable containers that result in superior performance.
4. From the RFID tag readability perspective, although each of the three reusable containers tested were different in design, this factor did not affect RFID performance when the tags were correctly positioned.
5. After testing thousands of containers, QLM found that 109 of 110 collapsible containers on a pallet could be repeatedly read with 100% accuracy within three seconds.
    a. This three-second time represents the time taken by the fork lift driver to move the containers at a safe speed through the RFID dock portal.
6. The RFID tags that were field tested were encapsulated in two grades of plastic film and both configurations performed at a 100% level and met their suppliers' specifications.

RFID Testing Protocols, Process and Procedures

The RFID testing was divided into three phases.

The first phase was vibration and drop testing. These test procedures were dictated by ASTM test protocols, designed to determine whether the internal structure of the RFID tag can withstand the stresses of the test. Four RFID tags were placed on each container (two tags on each short side). Four pallets were also tested with one of the four RFID tags placed on each of the four corners. The containers were numbered and locations noted by layer throughout the test and filled with carrots in model 6411 RPCs and with apples in the model 6428 RPCs.

After the ASTM testing was performed at Michigan State's School of Packaging, all containers with original tags still intact were stretch wrapped and shipped to the RFID Testing Facility in Ohio.

The second phase of the test was to determine if the RFID tags could be read after the stress test. Each tag on each container and pallet was read using a Symbol Handheld RFID reader.

Acceptance Criteria

The RFID tag passed the test if during two attempted readings using a Symbol Handheld RFID reader, the tag could be read. If the tag could not be read, the tag failed the test. There was some concern that reading the large RFID tag on the smaller container would not be possible. In fact, the RFID tag was read with the same effectiveness whether the container was small or large.

The third phase of the RFID testing was to determine:

- The optimum RFID tag, one that read consistently better than the others, and to determine the best tag placement location on the container for consistent reads.

The final phase of the RFID test was in the field to determine if the selected higher performing RFID tags could continue to perform after the containers were put through a complete material handling cycle from harvest to purchase. The major steps and processes were:

1. Fit-for-service container delivered to produce grower/shipper's farm or distribution center.
2. Containers sent out to field for harvesting of products.
3. Containers filled with harvested products trucked back to the distribution center or food processing center.
4. Containers stored temporarily awaiting customer assignment.
5. Containers palletized and loaded on a refrigerated truck.
6. Products transported to a large regional distribution/processing center.
7. Containers de-palletized into small lots and delivered to stores.
8. Containers placed in stores for products to sell.
9. Containers returned to the back of the store and stacked for pick up.
10. Containers picked up and delivered by truck to the sorting center.
11. Containers sorted by size and type of container.
12. Palletized containers shipped to a sanitation center/warehouse.
13. Pallets unloaded and containers sent through the sanitation process.
14. Sanitized containers dried and palletized.

15. Fit for service containers delivered to the grower/shipper.

During this final phase the containers were filled with produce provided by three volunteering companies:

- Stemilt Growers, Wenatchee, WA, provided fresh apples from Washington.
- Tanimura and Antle, Salinas, CA, provided fresh Romaine lettuce from Salinas, California.
- Frontera Produce, Edinburg, TX, provided fresh Texas grown Chili peppers

In addition, Wal-Mart Stores Inc. volunteered to assist the team in all phases of the supply chain until the products were received at its Cleburne, TX distribution center. RFID tags were supplied by Alien Technology, Avery Dennison and UPM- Raflatac. RFID readers and antennas and technical assistance were provided by Alien Technology and Impinj. A Symbol Motorola RFID handheld reader was used exclusively through the testing for tag verification.

The Kennedy Group provided the use of their state of the art RFID testing center in Ohio as well as technical assistance. ORBIS volunteered its sanitation facility in Garland, TX. Containers were provided by Georgia-Pacific Corporation, IFCO SYSTEMS N.A, and ORBIS. All RFID tags, readers, antennas and hardware were commercially available products.

The RFID team included Dr. Paul Singh, Michigan State University, School of Packaging; Dr. Jay Singh, California State Polytechnic University; and G. Michael McCartney, project leader, QLM Consulting Principal.

RFID Testing Protocols

This protocol has been adopted from ASTM D 4169-04a (*Standard Practice for Performance Testing of Shipping Containers and Systems*) to address the ability of tagged (RFID) reusable plastic containers (RPCs) used for fresh produce to withstand their intended distribution environment. The goal was to evaluate readability issues of the RFID tags after the containers have been subjected to a test protocol consisting of a sequence of anticipated hazard elements encountered in their distribution cycle.

Two sets of tests were conducted based on the impact of tag locations on the erected and knock-down configurations of the RPCs. The two sets of tests identified are as below:

Test Set I: Erected and loaded RPCs and
Test Set II: Empty and knocked-down RPCs.

Test Specimen:

Reusable Plastic Containers:

Two sizes of RPCs, 6411 and 6428, were tested through distribution environment simulation as discussed below. Following is the list of the RPC suppliers that participated in this study:

Model 6411: IFCO, Georgia-Pacific, ORBIS
Model 6428: IFCO, Georgia-Pacific, ORBIS

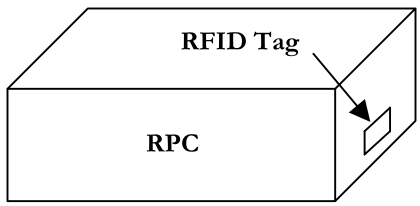
In addition, a standard CHEP Pallet with one RFID tag placed at each of the four corners was also included in the tests.

RFID Tags and Hardware:

The RFID vendors were allowed to send their hardware and software meeting the EPC Global Gen2 Specifications for the lab testing phase of the study. Passive UHF tags and all equipment were required to be on the EPC Global Approved Product listing.

Tag Placement:

Tags were placed on containers of both sizes at the bottom-center on one of the smaller faces in the existing label holders with no more than two tags being applied on one smaller face.



Procedure

Reusable plastic container description: As stated in manufacturer's brochures.

Acceptance Criteria:

Testing was continued uninterrupted till such time that one of the following occurred:

a. The reusable plastic containers were not fully functional.
b. The RFID tags exhibited visible damage.

Assurance Level:

Due to the imperative need for the RFID tags to be fully functional until the RPCs are replaced or retired, Assurance Level I was used for all tests. This level provides the most severe intensity levels.

Conditioning:

Tagged containers were conditioned at a temperature from 33 - 45 degrees F for 24-72 hours at the following conditions as specified by ASTM D4332 (*Standard Practice for Conditioning Containers, Packages, or Packaging Components for Testing*) prior to any testing:

Environment (ISO 2233 condition)	Temperature, °C (°F)	Relative Humidity, %
Refrigerated storage	5 ± 2 (41 ± 4)	85 ± 5

The tagged containers were loaded with an expected amount of simulated load.

Distribution Cycle:

Based on the anticipated distribution cycle, the following tests were performed on the tagged RPCs without interruption (unless the acceptance criterion was violated):

1. *Sinusoidal Vibration Test*:

This test was performed in accordance with ASTM D999 (*Standard Methods for Vibration Testing of Shipping Containers*). The resonance frequency (maximum displacement of stacked containers) was isolated by the sweep and dwell process for RPCs stacked to represent a 110 inch trailer clearance accounting for pallet height and top clearance on an electro-hydraulic vibration test system. The test was performed at the following test level:

Assurance Level	Frequency Range, Hz	Amplitude (0-peak), g	Dwell Time, min
I	3 to 100	0.5	15

The vibration sequence was performed for five cycles or failure, whichever occurred first.

2. *Manual Handling (Drop) Test*:

Drop Tests (ASTM D5276, *Standard Test Methods for Drop Testing of Packages*): The filled containers were subjected to six drops representing one cycle. The sequence consisted of the following:

- Drop on the bottom face
- Drop on shortest edge
- Drop on adjacent longer edge
- Drop on one base corner
- Drop on opposite base corner
- Drop on bottom face

The RPCs were filled with simulated loads representing the rated maximum capacity of the container. The containers were subjected to examination after each cycle. A total of five cycles of drops were conducted unless the RPC failed during the test.

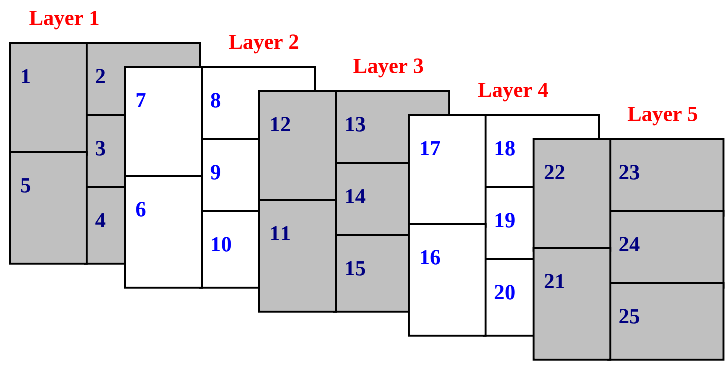
The RPCs were drop tested from drop heights based on the total container weight as described in ASTM D4169 at assurance Level I.

REUSABLE PLASTIC CONTAINERS
ORBIS, GEORGIA-PACIFIC, IFCO

RPC Specification

Manufacturer	Code Name	Model No.	Size	Weight (lbs)
ORBIS		6428	23 ½ x 15 ¾ x 11 3/8	5.2
ORBIS		6411	23 5/8 x 15 ¾ x 4 ½	3.1
IFCO		6428	23 ½ x 15 ¾ x 11 3/8	5.7
Georgia Pacific		6411	23 5/8 x 15 ¾ x 4 ½	3.2

RPC Position on Pallet



Drop Test Results

Manufacturer	Code Name	Model No.	Number of RPC Tested	Comments
COMPANY A		6428	25	25 RPCs hinge failure within 1st cycle 4th or 5th drop (corner drops)
COMPANY A		6411	60	1 RPC hinge failed after 5 cycles of drops
COMPANY C	I	6428	25	•13 RPCs hinge failure within 1st cycle 4th or 5th drop •6 RPCs hinge failure within 2nd cycle 4th or 5th drop • 1 RPCs hinge failure within 3rd cycle 4th drop •3 RPCs hinge failure within 4th cycle 4th drop • 2 RPC No failure after 5 cycles of drops
Company B		6411	60	No RPC failed after 5 cycles of drops

Sample Preparation

RPC Model 6428

RPC Model 6411

Loaded ORBIS 6428 RPCs before Vibration Testing

Loaded ORBIS 6428 RPCs on Vibration Table

Loaded ORBIS 6411 RPCs before Vibration Testing

Loaded ORBIS 6411 RPCs on Vibration Table

Loaded IFCO 6428 RPCs before Vibration Testing

Loaded IFCO 6428 RPCs on Vibration Table

Loaded Georgia-Pacific 6411 RPCs before Vibration Testing

Loaded Georgia-Pacific 6411RPCs on Vibration Table

ORBIS 6428

ORBIS 6411

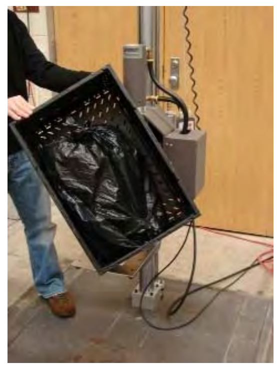
IFCO 6428

Georgia-Pacific 6411
Drop Test Orientation
RPC 6428; Drop ht. 18"; Load 45 lb

Bottom Face

Shortest Edge

Adjacent Longer Edge



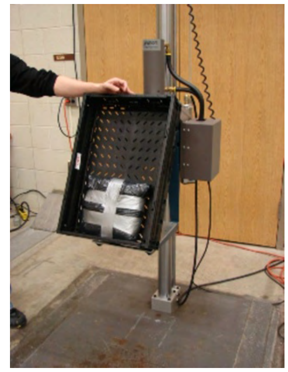
Base Corner

Opposite Base Corner

Bottom Face

RPC 6411; Drop Ht. 24"; Load 8lb

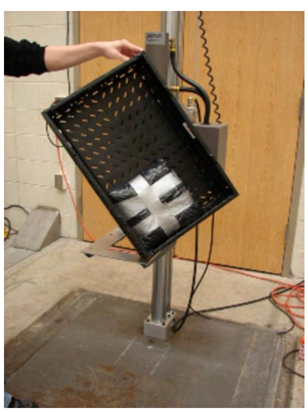
Bottom Face



Shortest Edge

Adjacent Longer Edge

Base Corner



Opposite Base Corner

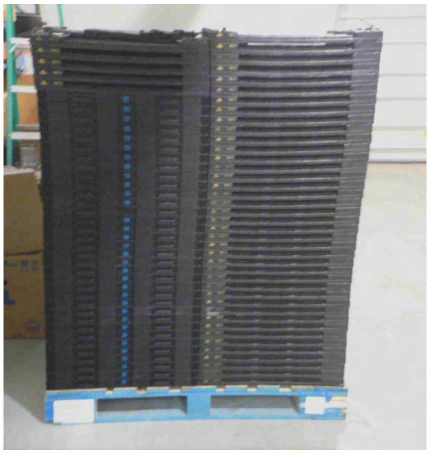
Bottom Face

After physical testing was concluded, the tested erected and loaded RPCs (ORBIS, Georgia-Pacific, IFCO) were stretch wrapped and shipped to Kennedy Group's RFID testing center in Ohio.

RFID Testing Center

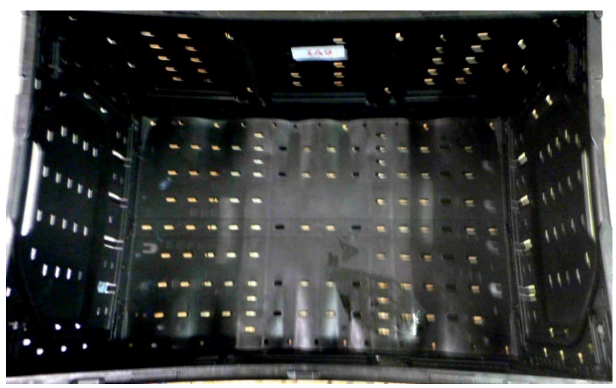
After testing each tag on the RPCs, the following observations were made:

- 4 tags were tested on 170 containers.
- 680 tests were conducted.
- 3 of the 4 RFID tags were 100% passable.
- 1 of the 4 RFID tags did not meet the acceptance criteria.



RFID Containers Received at RFID Test Center

RFID Portal and RFID Tagged Containers



RFID Container Internal Non-RFID Label

RFID Containers on Pallet Being Processed

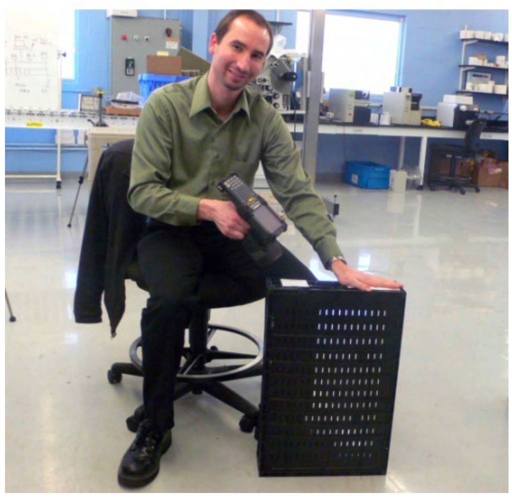
IFCO Containers

RFID Tags on Containers - Average Condition after Physical Testing

RFID Testing Center and Equipment

RFID Testing Equipment

RFID Portal Side View



RFID Tag Mortality Testing

Final Phase: Field Testing of Containers

Following the selection of the top performing RFID tags, these tags were affixed by hand to the label area on each of the reusable containers. The RFID tags were encoded by each of the participating companies prior to their being shipped out to the farms for harvesting.

Until this field trial was conducted the effect, if any, of the contents of the produce was not known. Would the contents of the container make any measurable differences in reading accuracy? Specifically, could the water content of the product shipped have any influence on RFID tag readability? The field phase products were Washington apples, Californian grown lettuce and Texas chili peppers. The lettuce, which has high water content, was field harvested and wrapped with a commercial food grade plastic. Given the known ability of water to detune radio frequencies, this test would indicate any degradation in radio signal strength or create any off axis multi-path issues. The apples and peppers were selected to determine whether seeds, pits, or shape might affect the radio frequencies.

The tags were encapsulated in two proprietary ways. The Kennedy Group given their long history of creating labels fashioned an orange label that was flexible and appeared quite robust. UPM provided a clear film material that could be used in a standard RFID printer and that appeared to be much more pliable and considerably less robust than the orange labels.

Example of an Orange Label Next to a Standard Bar Code Label on a Georgia Pacific Container

Distance was also a factor to consider. The ASTM testing had already indicated that not all RFID tags could withstand vibration and drop tests. The field test sought to determine whether these RFID tags' performance would be changed when subjected to the harsh realities of long distance refrigerated trucking. The roundtrip distances traveled were estimated to be:

1. Wenatchee, WA to Cleburne, TX to Wal-Mart stores to Garland to Washington = 4,363 miles
2. Salinas, CA to Cleburne, TX to Wal-Mart stores to Garland to Salinas, CA = 3,346 miles
3. Edinburg, TX to Cleburne, TX to Wal-Mart stores to Garland to Edinburg, TX = 1,059 miles
4. To each trip an additional 100 miles was added to cover the distances from the Wal-Mart Distribution Center in Cleburne out and back to the Wal-Mart Supercenter store.

Containers Arriving at the Cleburne Wal-Mart Center for Distribution

Another major variable was the entire professional grade sanitation process for ensuring that the containers were free of any foreign materials and fully sanitized. Sanitation is a time-consuming process that involves:

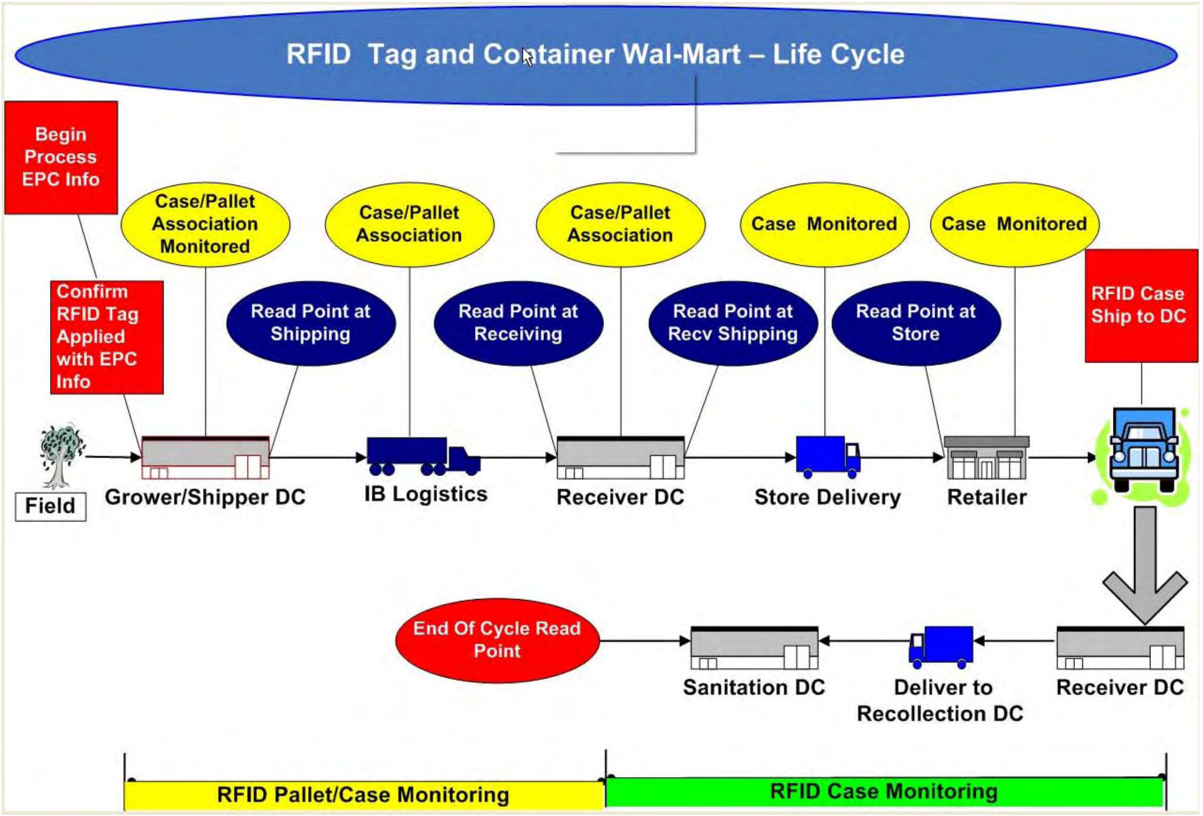
1. Inspecting the containers to remove any foreign matter.
2. Erecting the containers.
3. Conveying the containers through the washing cycle which includes air jets commercially approved soaps.
4. A sanitation cycle where the container is subjected to a water temperature of greater than 170 degrees F for an extended period.
5. A rinse and cool down cycle.
6. An air or fan dry cycle.
7. Hand sorting, shrink wrapping and palletizing the containers.
8. Putting into temporary storage until assigned for duty.

Inside the Garland Sanitation and Processing Facility

The blue machine in the background is the washing and sanitation machine which runs nearly the length of the building. Clearly these RFID tags ability to withstand the temperature changes, distances, changes from one truck to another and the sanitation cycle would determine whether these RFID tags were built to last or were only one-trip quality tags.

The chart below represents many different steps in the food distribution supply chain which include:

1. Fit for Service container delivered to produce grower/shipper's farm or distribution center.
2. Containers sent out to field for harvesting of products.
3. Containers filled with harvested products are trucked back to the distribution center or food processing center.
4. Containers are stored temporarily awaiting customer assignment.
5. Containers are palletized and loaded on a refrigerated truck.
6. Products are transported to a large regional distribution/processing center.
7. Containers are de-palletized into small lots and delivered to stores.
8. Containers are placed in stores for products to sell .
9. Containers are returned to the back of the store and stacked for pickup.
10. Containers are picked up and delivered by truck to the sorting center.
11. Containers are sorted by size and type of container.
12. Palletized Containers are shipped to a sanitation center/warehouse.
13. Pallets are unloaded and sent through the sanitation process.
14. Sanitized containers are dried and palletized.
15. Fit for Service Containers are delivered to the grower/shipper.



View of the Entire Cycle

All field tests were performed at the Garland, TX distribution center, owned and operated by ORBIS Container Corporation.

RFID Testing Protocols

All measurements and all tests were performed in exactly the same way that the tests were performed at the Kennedy RFID Testing Center. The height of the RFID antennas and distances between the lowest antenna and the highest were measured to ensure that all components were replicated.

The Alien Antennas were used for both the Alien Reader and the Impinj Reader. RFID cabling spanned approximately 15 feet. The Alien Reader was mounted above the dock door. The Impinj Reader was mounted in exactly the same way and the reader used the same RFID cables. Standard Alien Reader software and Impinj software were used to record all data on to Excel spreadsheets.

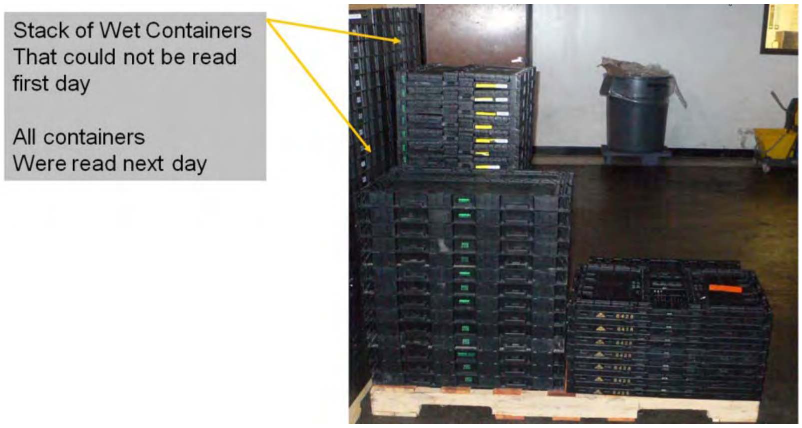
RFID Reader Setup

The interior temperature ranged from 75 to 80 degrees F. Containers would be placed in a collapsed position on a pallet for testing as seen below.

Each container was hand erected and transported through the RFID gateway. At the gateway a light would flash to indicate a positive read. RFID tags that were not able to be read were placed to the side where another tester would try again. If the tag failed twice, the container was set to the side. After many attempts, we deduced that the RFID tags that were not being read were a result of the RFID tags being still wet from the sanitation process. The no-read containers were allowed to dry overnight and retested the following day.

Wet Conditions

Wet Containers and Tags



No RFID Read Containers and Tags

The same testing methods were employed to test RFID tag reading performance of containers stacked in 5 columns and 110 per pallet. A forklift traveling at a speed up to 5 miles per hour traveled through the dock portal at least 3 times with each of the 3 different container types. Each test was performed employing an Alien Reader and an Impinj reader to test the same palletized containers.

First Round Results

- 2,322 tags were read with no change in performance.
- All wet tags that were allowed to dry were read the next day.
- 84 containers were returned with no tags.

The Impinj Reader quite impressively read almost 100% of the RFID tags on containers in less than three seconds. This performance was made more remarkable because it was performed without any optimization using competitor's antennas.

A control pallet from each supplier of RPCs was set up to test the performance of two EPC compliant Gen2 RFID readers; one from Alien Technology and one from Impinj

Summary of Results

Alien System			
Total Tags Being Read		Total Reads	Elapsed Time
Company A	109	89	9.0 seconds
Company B	110	102	9.0 seconds
Company C	110	102	5.0 seconds
Impinj Reader with Alien Antennas		Total Reads	Elapsed Time
Company A	109	108	2.0 Seconds
Company B	110	103	2.0 Seconds
Company C	110	103	2.0 Seconds

Second Round Results

For the second round, the containers were distributed through the full supply chain cycle. The final location was a recollection at the Garland distribution center where the same procedures were followed as in the first round. There was no difference in RFID reader hardware; however, the software was upgraded to the latest version as of January 2009.

The second cycle of the RFID project was completed. As summarized in the chart below:

1. 100% of the tags were read 100% of the time on all 934 RFID tags.
2. 5 RFID tags were not readable.

3. Full pallet reads of collapsed containers were 109/110 consistently independent of Reader Type in under 3 seconds.

4. A total of 23 RFID tags fell off of the containers as a result of material handling processes.

Round 2	Company C	Company B	Total Tags	Read Rate
RFID Reads	221	713	934	100%
Dead tags	0	5	5	0%
No RFID tags	5	18	23	

For all rounds, the results were 109 RFID tags that had fallen off the containers, and there were only 5 RFID tags that were not readable. It became clear that good labeling adhesives and the type of encapsulation methods were important considerations in implementing an RFID enabled reusable container. (Determining the reasons that tags were not readable was not within the scope of this study. However, the 5 non-readable RFID tags appeared to show the effects of the abuses inherent in the material handling full supply chain.)

The RFID tags continued to be read at a 100% rate though the second round. The change from 9 seconds to 2 seconds experienced in round one was completely changed in round two, closing completely the performance gap of between RFID readers reading pallets. In the second round, there were no measurable differences in reader performance. All containers were read in less than 3 seconds. The software changes, although software deployment was not a testing focus, made by the RFID providers produced their intended results with performance being consistent at 109 out of 110 reads or 99.1%.

Conclusion

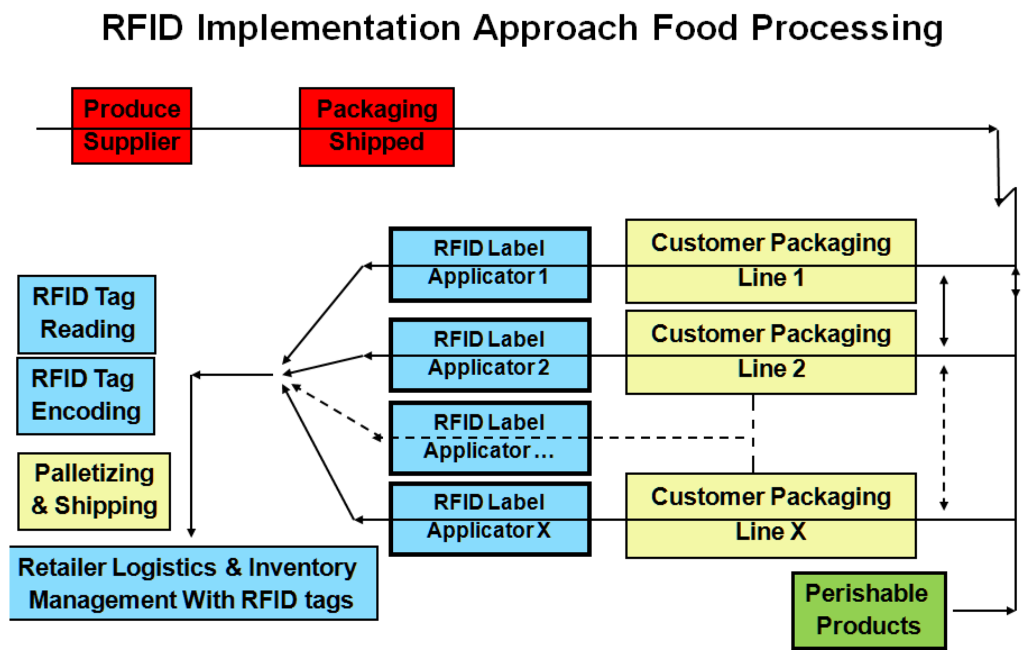
1. RFID tags designed for single use can be used for multiple trips without any deterioration in performance-if positioned correctly on reusable containers
2. These RFID tags were subjected to the harshest and most vigorous testing in packaging labs under ASTM guidelines
3. During field testing, the RFID tags faced extreme changes in temperatures from over a 100 + degrees F in the farmer's field to 32 degrees F in cold storage and over 170 degrees F in the sanitation cycle.
4. Additionally, the RFID tags were exposed to dry field conditions, wet cold storage environments, warehouse, store racking and hand deliveries to the store shelves.
5. Each of the RFID tags was subjected to an average transportation distance of over 1,000 miles before being unloaded at a distribution center. There the product was then reloaded onto local trucks and delivered to stores. After store usage, the RPCs were redelivered back to the sanitation facility, and finally deployed to the produce company for reuse.
6. RFID tags where subjected to ASTM vibration and drop testing. Not all RFID tags performed at a 100% level.
7. The three highest performing RFID tags selected for field testing are produced by Alien Technology, UPM, and Avery Dennison. These were off the shelf manufactured tags.
    a. The RFID readers were standard commercially available EPC Gen2 readers and were manufacturered by Alien Technology and Impinj.
8. The project team performed over 160 hours of testing and over 14,000 tests. The tests involved four pallets; 230 containers erected and flattened were subjected to *Sinusoidal Vibration Tests and Drop Tests on all edges or over 7,300 tests.*
    a. Each container was tested at four different attenuation levels, inbound and outbound, erected and filled with produce, and then collapsed, stacked at 70 high(6411) and 35 high(6428).
9. After more than 5,000 tests, QLM found there is a wide range of placement options on the reusable containers resulting in superior performance
10. The RFID tags tested were encapsulated in two different ways, one with heavy duty plastic film and the other with a lighter duty plastic film. Each performed at a 100% level and met their suppliers' specifications.
11. From a RFID tag readability perspective, although each of the three reusable containers tested were different container design, the design did not affect RFID performance once the tags were correctly positioned.
12. After testing thousands of containers, QLM found that 109 of 110 collapse containers on one pallet could be read repeatedly within 3 seconds.
    a. This three second time represents the elapsed time it takes the fork lift driver to move the containers at a safe speed through the RFID dock portal.

Until the RPA commissioned this RFID test with RPCs, no data existed to prove whether RFID tag performance could withstand the harshness of the material handling supply change and the supply chain's rigorous wide range of temperature variations. As a result of the knowledge gleaned from this study, RFID tags designed for one use can now be reused with greater confidence in multiple trip applications. These findings streamline the material handling costs and reduce the time and energy needed to implement and maintain an RFID system. Moreover, the elimination of many laborious steps involved in one-way tag applications demonstrates another significant economic advantage for reusable systems in comparison to one-way packaging choices (see Appendix). For more information, contact the RPA at http://www.choosereusables.org or call +1 (703) 224-8284.

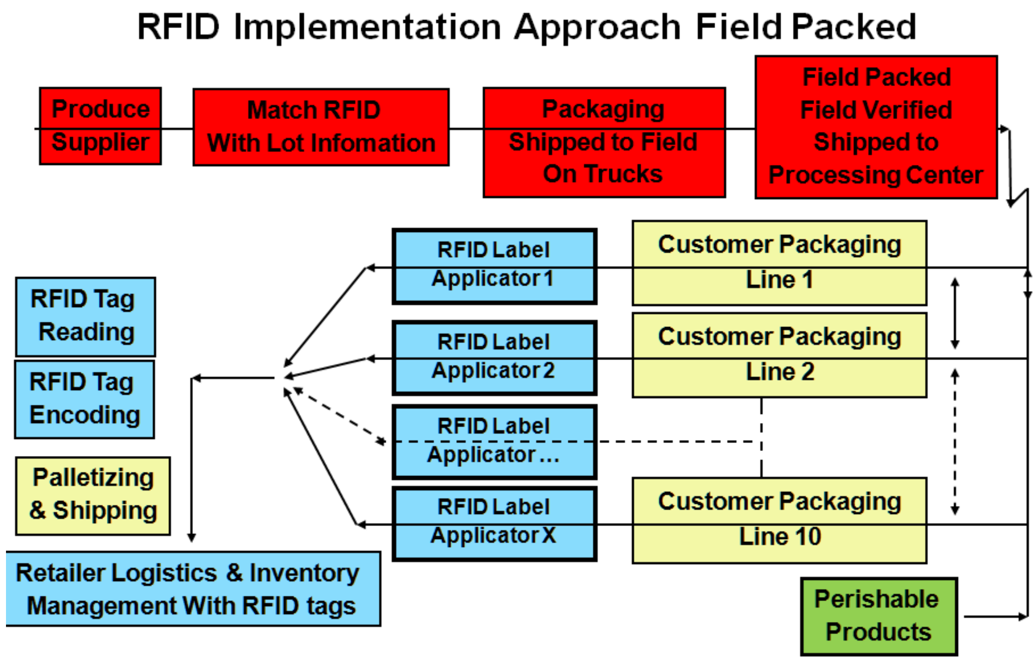
Appendix: Economic Benefits: Reduced Life Cycle Cost and Greater Reliability

As these findings reflect, RFID tags can be positioned on reusable containers to identify automatically the container and the contents while providing immediate location and trace back information. These findings streamline the material handling costs and reduce the time and energy needed to implement and maintain a RFID system.

Until now a RFID implementation required a complex infrastructure made up of a printer, a RFID tag applicator to put the tags on corrugated boxes and a validation and verification reader to confirm the information placed on the tag. In a modern processing plant with 10 production lines, there would a need for 10 printers and 10 RFID tag applicators at a minimum. A standard print and apply RFID applicator, which includes a printer, can cost between $40,000 and $100,000. A production level printer costs at least $5,000. These costs do not include hardware installation, software purchases, and software installation and maintenance costs. Depending on the plant layout, costs could average at least $50,000 per line. The graphic below illustrates typical RFID implementation workflow:



Not only are there significant expenses in consumable RFID tags at an approximate cost of 10 cents each, there are also substantial operational costs. Like all printers, RFID printers need constant maintenance. Also, RFID labels can easily jam creating operational delays and inefficiencies. Rarely are RFID tags printed with 100% accuracy 100% of the time, thereby affecting labor costs. Furthermore, to keep the printer labeling operation uninterrupted, each system needs to have a critical spare parts inventory as well as have people ready to perform routine maintenance. Moreover, from a time and material standpoint these costs savings are amplified when compared to a field produce packing operation as the following graphic illustrates;



In this field packing example, RFID tags with the assigned farm parcel or lot information must be affixed to the cartons. Each RFID tag will need to associate field and harvest date information before the cartons are sent to the field for harvest. Once the products are harvested the applied RFID data must be confirmed before or prior to being received at the processing center or cold storage distribution facility. These containers will be sorted by grade as they move down the packaging line. Order changes based on market demands may cause new RFID tags to be re-written or applied until the final verification stage prior to shipping. This process is much more complex and less reliable than a system without printers or labelers.

In the reusable scenario, RFID enabled containers are, shipped to the field. The purchase order information, field, harvest date, grade, and many other data points can be collected into a database. The filled RFID reusable containers enter the processing center and await assignment to a customer. Once the customer is identified, the containers can pass by a RFID reader where this information can be encoded and verified on the unique RFID tag. Containers are then aggregated on to pallets and loaded on a truck. Immediately, the data can be sent electronically via an advanced shipping notice to the retailer or food service receiver.
Containers with rewriteable RFID tags simplify the process and yields greater reliability as shown in the chart below:

RFID Reusable Label Container Approach