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**Item-Level RFID: Future Direction – Current Status**

**RFID Item-Level Tagging for Apparel/Footwear:**

**Feasibility Study**

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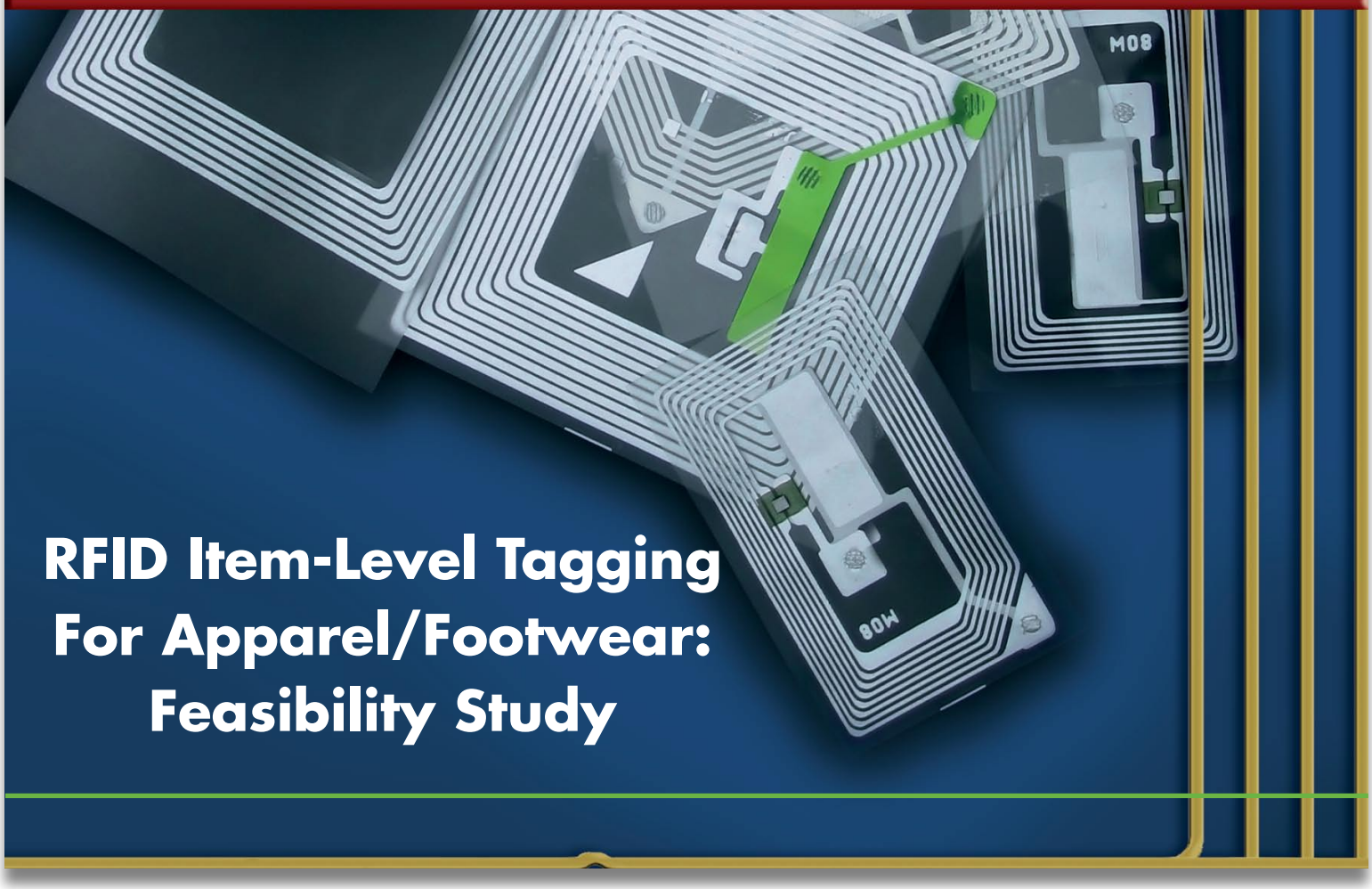

# RFID Item-Level Tagging For Apparel/Footwear: Feasibility Study


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VICS Voluntary Interindustry Commerce Solutions

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# Aknowledgements


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- **Council of Supply Chain Management Professionals (CSCMP)**
- **Voluntary Interindustry Commerce Solutions (VICS) Association**
- **Dillard's**
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# EXECUTIVE SUMMARY

This document describes a feasibility study conducted by the University of Arkansas' RFID Research Center with participation from the Council of Supply Chain Management Professionals (CSCMP), the Voluntary Interindustry Commerce Solutions (VICS) Association, Dillard's, and Procter & Gamble, wherein passive Ultra High Frequency (UHF) Gen 2 RFID tags were applied to a variety of clothing and footwear items, generally offered for retail in the apparel/footwear industry, and tested for read rate success using various test scenarios. These test scenarios were compiled with a view to emulate, as practically as possible in a laboratory environment, normal store operations within the apparel/footwear industry. *Overall, the purpose of the initial phase of this project was to explore the feasibility of RFID for apparel/footwear item-level tagging.* The project followed the general steps of: (1) identify the use cases where RFID may offer the most benefit; and (2) set up prototypes in a lab environment to investigate the feasibility of RFID for each use case. The major use cases investigated included product lifecycle management, inventory management, loss prevention, dressing room management, and point of sale.

The 2x2 matrix on the next page provides an overview of the test scenarios (and associated tests) conducted during the course of this study. Mobile indicates movement; static indicates stationary. Thus, a scenario of static items/mobile reader suggests one in which the items are static (not moving) and the reader is mobile (e.g., handheld). The test scenarios and overview of findings include:

- Test Scenario I— static items/mobile reader: tests included reading clothes on various fixtures (such as rounders, z-bar, and shelf), in boxes, on peg boards, in a pile, and shoes on a shelf. In all but one situation, a 100% read rate was achieved using one or more combinations of tags and readers. In the lone exception, reading clothes on a shelf, a 99.72% read rate was achieved.
- Test Scenario II—static items/static reader: tests included a 'smart shelf' equipped with a reader and point of sale system. The smart shelf was able to read 100% of the items on the shelf for at least one tag type. The point of sale system accurately identified 100% of the items inside the defined read field (and nothing outside the field).
- Test Scenario III—mobile items/static reader: tests included moving items through a static reader portal on various transport devices such as z-bar, plastic and steel handcarts, and conveyor. Except for the situation of boxes on a conveyor at 600 feet per minute which read at 99.07%, all other situations achieved a 100% read rate using one or more combinations of tags and readers.

For all tests, apparel/footwear items were tagged with RFID tags and then stored or transported in a manner similar to that found in the apparel retail industry while RFID readers, both static and mobile, were used to read the tags. The tags were placed either alongside or covering the barcode label on each item in order to replicate current labeling schemas as closely as possible. Multiple tag types and reader types were used to provide a breadth of technologies and their respective performances.

As a feasibility study, the purpose is to provide initial proof-of-concept data and insights. Most insights are left to the reader to determine based on the data that is of most interest to him or her. However, we proffer a few broad insights from the research, as follows:

- Findings provided a wide range of read rates based on tag type and reader type. The effect of tag type was especially prevalent. Thus, it is important to choose the proper technology for your situation.
- We affixed RFID tags over existing price tags on the clothes. We believe that tag placement also plays a role in read rates; thus, it may eventually be necessary to establish guidelines or standards regarding the location of tags on items to ensure proper readability.
- Read rates degrade, in most instances, by the number of items on the fixture, in the box, etc. We varied the number of items to provide a breadth of read rates and perhaps a realistic preview of actual use. Obviously, the number of items on a fixture, in a box, etc., will vary by the company, store, or situation.
- Supplemental tests suggested that the type of clothes did not matter (i.e., pants, shirts, socks, etc.), although it is likely our sample did not contain a broad representation of all clothes and shoes.

The overall results are very encouraging and indicate a favorable outcome with most RFID read rate percentages at or near 100% with one or more tag type/reader combinations. The results suggest that optimization of certain factors, such as tag selection, reader type, antenna positioning and store employee abilities, might raise all apparel/footwear RFID read rates to or near 100%. We believe the initial phase of this project has demonstrated the feasibility of RFID for specific applications, and has the potential to satisfy many common use cases. Inventory management, in particular, appears to be a prime candidate for improvement via RFID.

# REPORT OVERVIEW

The report is structured according to the Test Scenarios outlined in the Testing Matrix below. For each Test Scenario, an overview of the tests, the description of specific tests, test results, and general observations are provided.

| Readers \ Items | Static | Mobile |
|---|---|---|
| Static | Test Scenario II:<br>- smart shelf<br>- point of sale | Test Scenario III:<br>z-bar; boxes on handcart, hand-carried, on conveyor, on steel cart |
| Mobile | Test Scenario I:<br>- clothes on rounder, on z-bar, in box, on shelf<br>- shoes on shelf | Not tested |

**Table 1: RFID Testing Matrix**

Static indicates stationary; mobile indicates movement. For example, static items/mobile reader would indicate a situation in which the items do not move (such as hanging on a fixture) and the reader moves (such as a handheld unit).

Unless otherwise noted, each test used multiple tag types and readers. Tags and readers were selected based on their availability to the general public and our prior experience with them. For this study, three tag types were used (denoted herein as tag-A, tag-B, and tag-C), four different mobile devices were used (denoted herein as handheld-1, handheld-2, handheld-3, and non-handheld-mobile-1), and three static readers were used (denoted herein as static-1, static-2, and static-3). The non-handheld-mobile-1 unit is generally used on a forklift, push cart, or other transport device; although, as noted herein, it was sometimes used manually by hand.

# TEST SCENARIO I

## *OVERVIEW*

The test scenario is defined as static items/mobile reader. The purpose of this test is to determine how well (%) items can be read on a variety of static fixtures while utilizing a mobile RFID reader. In this scenario, tagged items are placed on a fixture (e.g., rounder). An associate using a mobile device while walking around the fixture then attempts to read the items.

For this test scenario the following items were varied:

- Type of tag
- Type of fixture
- Type of readers
- Number of items on fixture

## *TESTS*

### Test Description: Rounder

For the rounder test, items were tagged and placed on the rounder fixture. An associate used a mobile reader to scan the items on the rounder by walking around the fixture while pointing the device at the items. Handheld readers were used in a sweeping motion around the fixture making sure that the reader was used in both horizontal and vertical orientations to account for tag orientation. This process allowed the associate to capture the available reads.

**Photograph 1: Scanning a Rounder Using a Handheld Reader**

### Results—Rounder

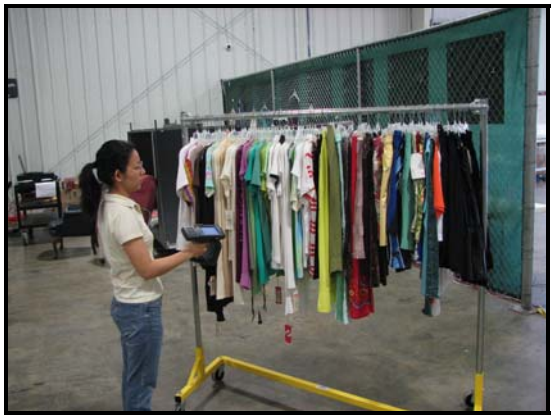
For this series of tests, a baseline number of clothes (97 in most cases) were tested. Then, the number of clothes was increased to determine the effect on read rates.

| TAG | READER | | | | | |
|---|---|---|---|---|---|---|
| | Handheld-1 | | Handheld-2 | | Handheld-3 | |
| | Total # Items | Read Rate (in %) | Total # items | Read Rate (in %) | Total # items | Read Rate (in %) |
| Tag-A | 97 | 99.38 | 97 | 100 | 97 | 100 |
| | 150 | 93.47 | 150 | 100 | 150 | 96.93 |
| | 160 | 90.00 | 160 | 98.25 | | |
| | 170 | 88.82 | 170 | 97.76 | | |
| | 180 | 89.89 | 180 | 96.33 | | |
| Tag-B | | | | | | |
| | 91 | 96.04 | 91 | 100 | 91 | 90.11 |
| | | | | | | |
| Tag-C | 97 | 99.79 | 97 | 100 | 97 | 99.38 |
| | 150 | 99.07 | 150 | 100 | 150 | 97.33 |
| | 160 | 97.25 | 160 | 100 | | |
| | 170 | 96.24 | 170 | 99.65 | | |
| | 180 | 89.89 | 180 | 98.22 | | |

**Table 2: Summary of Test Data—Rounder**

Notes:

- Handheld-3 testing discontinued at 150 due to an equipment limitation allowing only a maximum of 150 items to be read per event
- Tag-B tag testing was discontinued due to poor performance



**Photograph 2: Static Fixture—Mobile Reader Testing With Z-Bar**

**Photograph 3: Clothes Placement on Z-Bar**

## Test Description: Z-Bar

For the z-bar test, items were tagged and placed on the z-bar fixture. An associate would use a mobile device to scan the items on the z-bar. The associate would walk around the fixture while pointing the device at the fixture. Handheld readers were used in a sweeping motion around the fixture making sure that the reader was used in both horizontal and vertical orientations to account for tag orientation. This process allowed the associate to capture the available reads. See Photographs 2 and 3.

## Results—Z-Bar

For this series of tests, a baseline number of clothes was tested. Then, the number of clothes was increased to determine the effect on read rates. Because several test instances did not read 100% at the baseline, some clothes were removed until a reading of 100% (or very close) was achieved which established the baseline for that tag/reader combination (the tests then proceeded from that baseline forward by adding items).

| TAG | READER | | | | | |
|---|---|---|---|---|---|---|
| | Handheld-1 | | Handheld-2 | | Handheld-3 | |
| | Total # Items | Read Rate (in %) | Total # Items | Read Rate (in %) | Total # Items | Read Rate (in %) |
| Tag-A | 64 | 100 | | | | |
| | 69 | 100 | | | | |
| | 74 | 100 | | | | |
| | 89 | 100 | | | | |
| | 92 | 98.37 | | | | |
| | 97 | 98.97 | 97 | 100 | 97 | 100 |
| | 107 | 88.79 | 107 | 100 | 107 | 99.63 |
| | 117 | 91.97 | 117 | 100 | 117 | 98.46 |
| | 127 | 90.55 | 127 | 100 | 127 | 96.38 |
| | | | | | | |
| Tag-B | 46* | 94.30 | 46 | 100 | | |
| | | | 56 | 100 | | |
| | | | 61 | 100 | | |
| | | | 71 | 100 | 77 | 100 |
| | | | 81 | 96.54 | 82 | 99.76 |
| | | | | | 87 | 96.09 |
| | | | | | 92 | 90.00 |
| | | | | | 97 | 87.91 |
| Tag-C | 87 | 100 | | | | |
| | 92 | 98.73 | 92 | 100 | 92 | 100 |
| | 97 | 98.56 | 97 | 100 | 97 | 100 |
| | 107 | 95.14 | 107 | 100 | 107 | 100 |
| | 117 | 92.82 | 117 | 100 | 117 | 99.66 |
| | 127 | 94.49 | 127 | 100 | 127 | 97.64 |

**Table 3: Summary of Read Rates Collected from the Z-Bar**

Notes:

- Number of items to start tests were based on ability to get 100% read rate (to determine minimum start quantity)
- *Testing discontinued because of low read rates
- 127 was the maximum number of items that would fit on the Z-bar

## Test Description: Box

For the box test, items were tagged and placed in the transport box. An associate would use a mobile device to scan the items in the box by walking around the box while pointing the device at the box and move his or her arm in a sweeping motion within the vicinity of the items to capture the available reads. See Photographs 4 and 5.


**Photograph 4: Static Fixture—Mobile Reader Testing with Boxes**


**Photograph 5: Clothes Placement in Box**

## Results—Box

For this test, the number of items in a box was varied from 30 to 40 to 50.

| TAG | READER | | | | |
|---|---|---|---|---|---|
| | | Handheld-1 | Handheld-2 | Handheld-3 | Non-Handheld Mobile-1 |
| | # of Items | Read Rate (%) | Read Rate (%) | Read Rate (%) | Read Rate (%) |
| Tag-A | 30 | 100% | 100% | 100% | 100% |
| | 40 | 100% | 100% | 100% | 100% |
| | 50 | 100% | 100% | 100% | 100% |
| Tag-B | 30 | 30.67% | 97.33% | 87.33% | 90.67% |
| | 40 | N/A | N/A | N/A | N/A |
| | 50 | N/A | N/A | N/A | N/A |
| Tag-C | 30 | 100% | 100% | 100% | 100% |
| | 40 | 100% | 100% | 100% | 100% |
| | 50 | 100% | 100% | 100% | 100% |

**Table 4: Summary of Read Rates Collected from the Boxes**

Notes:

- Total number of items in box = 30, 40, & 50

## Test Description: Shelf

For the shelf test, items were tagged and placed on the shelf fixture. An associate would use a mobile device to scan the items on the shelf by walking around the fixture while pointing the device at the items. The mobile readers were used in a sweeping motion around the fixture making sure that the reader was used in both horizontal and vertical orientations to account for tag orientation. This process allowed the associate to capture the available reads. See Photograph 6.

**Photograph 6: Static Fixture—Mobile Reader Testing With Shelf**

## Results—Shelf

For this test, the number of items on the shelf was held constant (for each test).

| TAG | READER | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Handheld-1 | | Handheld-2 | | Handheld-3 | | Non-handheld Mobile-1 | |
| | # Items Read | Read Rate (in %) | # Items Read | Read Rate (in %) | # Items Read | Read Rate (in %) | # Items Read | Read Rate (in %) |
| Tag-A | 139 | 95.86 | 145 | 100 | 141 | 97.24 | 145 | 100 |
| | 138 | 95.17 | 144 | 99.31 | 143 | 98.62 | 145 | 100 |
| | 139 | 95.86 | 144 | 99.31 | 142 | 97.93 | 144 | 99.31 |
| | 140 | 96.55 | 143 | 98.62 | 142 | 97.93 | 144 | 99.31 |
| | 140 | 96.55 | 144 | 99.31 | 142 | 97.93 | 144 | 99.31 |
| | 141 | 97.24 | 144 | 99.31 | 143 | 98.62 | N/A | N/A |
| | **Avg** | **96.21** | | **99.31** | | **98.05** | | **99.59** |
| Tag-B | 70 | 48.61 | 107 | 74.31 | N/A | N/A | 115 | 79.86 |
| | 79 | 54.86 | 111 | 77.08 | N/A | N/A | 117 | 81.25 |
| | 87 | 60.42 | 109 | 75.69 | N/A | N/A | 109 | 75.69 |
| | 86 | 59.72 | 111 | 77.08 | N/A | N/A | 104 | 72.22 |
| | 85 | 59.03 | 99 | 68.75 | N/A | N/A | 107 | 74.31 |
| | 72 | 50 | N/A | N/A | N/A | N/A | N/A | N/A |
| | **Avg** | **55.44** | | **74.58** | | | | **76.67** |
| Tag-C | 141 | 97.92 | 144 | 100 | 141 | 98.6 | N/A | N/A |
| | 136 | 94.44 | 144 | 100 | 142 | 99.3 | N/A | N/A |
| | 139 | 96.53 | 144 | 100 | 139 | 97.2 | N/A | N/A |
| | 137 | 95.14 | 144 | 100 | 142 | 99.3 | N/A | N/A |
| | 141 | 97.92 | 142 | 98.61 | 141 | 98.6 | N/A | N/A |
| | **Avg** | **96.39** | | **99.72** | | **98.6** | | |

**Table 5: Read Rates Collected from the Shelf**

Notes:

- Total number of items on shelf for Tag-A test = 145
- Total number of items on shelf for Tag-B and Tag-C tests = 144, except for Handheld-3/Tag-C test = 143
- Handheld-3 test not performed on all tag types due to equipment malfunction

## Test Description: Shoes

For the shoe test, items were tagged and placed on the shelf fixture. An associate would use a mobile device to scan the items on the shelf by walking around the fixture while pointing the device at the items. The mobile readers were used in a sweeping motion around the fixture making sure that the reader was used in both horizontal and vertical orientations to account for tag orientation. This process allowed the associate to capture the available reads. See Photograph 7.

**Photograph 7: Static Fixture—Mobile Reader Testing With Shoes**

## Results—Shoes

For this test, the number of items on the shelf was held constant for each event.

| TAG | READER | | | | | |
|---|---|---|---|---|---|---|
| | Handheld-1 | | Handheld-2 | | Handheld-3 | |
| | # items read | Read Rate (in %) | # items read | Read Rate (in %) | # items read | Read Rate (in %) |
| Tag-A | 39 | 100 | 39 | 100 | 39 | 100 |
| | 39 | 100 | 39 | 100 | 39 | 100 |
| | 39 | 100 | 39 | 100 | 39 | 100 |
| | 38 | 97.44 | 39 | 100 | 39 | 100 |
| | 39 | 100 | 39 | 100 | 39 | 100 |
| | **Avg** | **99.49** | | **100** | | **100** |
| Tag-B | 37 | 94.87 | 38 | 97.44 | 36 | 92.31 |
| | 34 | 87.18 | 38 | 97.44 | 37 | 94.87 |
| | 33 | 84.62 | 38 | 97.44 | 38 | 97.44 |
| | 34 | 87.18 | 38 | 97.44 | 38 | 97.44 |
| | 31 | 79.49 | 38 | 97.44 | 38 | 97.44 |
| | **Avg** | **86.67** | | **97.44** | | **95.90** |
| Tag-C | 39 | 100 | 39 | 100 | 39 | 100 |
| | 39 | 100 | 39 | 100 | 39 | 100 |
| | 39 | 100 | 39 | 100 | 39 | 100 |
| | 39 | 100 | 39 | 100 | 39 | 100 |
| | 39 | 100 | 39 | 100 | 39 | 100 |
| | **Avg** | **100** | | **100** | | **100** |

**Table 6: Read Rates Collected from the Shoes**

Note:

- Total number of items = 39

## *SUMMARY AND INSIGHTS—TEST SCENARIO I*

In all situations a 100% read rate was achieved using one or more combinations of tags and readers. Not all tests produced 100% read rates, but at least one test per situation produced a 100% read rate. This finding is both encouraging and insightful. It is encouraging because 100% was achievable. It is insightful because not all situations produced 100%, suggesting influence on read rates from such things as tag type, reader type, tag location, fixture type, and number of clothes. For example, although certain brands or models of handheld readers output linear or elliptical read fields, and a distinct orientation preference is seen in instances where these readers are used with tags displaying an orientation preference, it was found that the shape of many fixtures and sometimes random pattern of tags on hanging garments often rendered a sweeping, horizontal and vertical movement scanning pattern unnecessary.

Although this test scenario focused on the effectiveness (i.e., read rate) of RFID, there is also an efficiency perspective. To provide a brief glimpse into the efficiency gains from RFID, inventory for the rounder (with 97 items) was taken using a barcode reader. The process took approximately nine minutes. Taking inventory with RFID reduced the amount of time to as little as 7 seconds.

# TESTING SCENARIO II

## *OVERVIEW*

The test scenario is defined as static items/static reader. The purpose of this test is to determine how well (%) items can be read on a static fixture while utilizing a static RFID reader. In this scenario, tagged items are placed on a fixture (e.g., shelf or table), and then read by the static reader attached to the fixture.

**Photograph 8: Smart Shelf**

For this test scenario the following items were held constant:

- Type of fixture (shelf only)
- Type of reader (only 1 type of reader was used per fixture)

For this test scenario the following items were varied:

- Number of items on fixture
- Type of tag

## *TESTS*

### Test Description: Smart Shelf

For the smart shelf test, the items were tagged and placed on the shelf fixture. The antennae are embedded in zones within the shelves with each shelf then attached to the reader. The reader is set to take reads every 15 seconds. A test consisted of removing and/or replacing items on multiple shelves, and noting the read rate. The test was designed to emulate the movement of these items during daily actions of shoppers/associates.

| TEST | SHIRTS (Tag-C) | | | SHOES (Tag-C) | | |
|---|---|---|---|---|---|---|
| | # Items On Shelf | # Items Read | Read Rate (in %) | # Items On Shelf | # Items Read | Read Rate (in %) |
| **1** | 23 | 23 | 100 | 7 | 7 | 100 |
| **2** | | | | | | |
| **3** | | | | | | |
| **4** | 21 | 21 | 100 | 5 | 5 | 100 |
| **5** | 22 | 22 | 100 | 6 | 6 | 100 |
| **6** | 21 | 21 | 100 | 5 | 5 | 100 |
| **7** | 17 | 17 | 100 | 4 | 4 | 100 |
| **8** | 15 | 15 | 100 | 1 | 1 | 100 |
| **9** | 19 | 19 | 100 | 5 | 5 | 100 |
| **10** | 18 | 18 | 100 | 4 | 4 | 100 |
| **11** | 19 | 19 | 100 | 5 | 5 | 100 |
| **12** | | | | | | |
| **13** | 21 | 21 | 100 | | | |
| **14** | 15 | 15 | 100 | 0 | 0 | 0.00 |
| **15** | 12 | 12 | 100 | | | |
| **16** | | | | 3 | 3 | 100 |
| **17** | 0 | 0 | n/a | 0 | 0 | n/a |

**Table 7: Summary of Read Rates Collected from Smart Shelf**

## Results—Smart Shelf

For this test, associates removed and added clothing and shoes on the smart shelf to simulate customer behavior. In total, 17 different shopping scenarios were tested. Table 6 shows the data collected from the 17 smart shelf tests.

**Photograph 9: Point of Sale Cylinder**

## Test Description: Point of Sale (POS)

For the POS test, the portal was a sales desktop with a reader and antenna. This test was performed using a static reader and one antenna. A cylinder made of aluminum was constructed and placed around the antenna (see Photograph 9). This was done to funnel the radio frequency field into a more precise read zone required for a practical POS application.

The reader's power setting was reduced from maximum power, 30 dBm, to the lowest setting capable of being entered through the user interface, 15 dBm. This reduced the read field to the area shown in Photograph 10. The masking tape describes the boundary of the read field. The height of the field from the top of the counter is approximately 1.5 feet in free space. The read field still expands slightly outward as it moves away from the top of the cylinder, but the circumference to which it expands is greatly reduced, which is desired.

**Photograph 10: Demarcated Read Area on Sales Desk Surface**

## Results—Point of Sale (POS)

For this test, various amounts of clothes were placed on the POS table to determine reading accuracy.

| TAG | Total # Items | # Items Read | Read Rate (in %) |
|---|---|---|---|
| Tag-A | 5 | 5 | 100 |
| | 10 | 10 | 100 |
| | 15 | 15 | 100 |
| | 20 | 18 | 90.00 |
| Tag-C | 5 | 5 | 100 |
| | 10 | 10 | 100 |
| | 15 | 15 | 100 |
| | 20 | 20 | 100 |

**Table 8: Read Rates from Point of Sale**

Note:

- For Tag-A, 20-items—height of 2 items exceeded 1.5 feet read range; thus, items were not read

## *SUMMARY AND INSIGHTS—TEST SCENARIO II*

Using fixed readers for smart shelves and point of sale appears to work very well. All of our tests suggested a near perfect read percentage with the proper tag. For the smart shelf test, tag-B did not perform well—as we have seen in prior tests. However, tag-C performed flawlessly. In the point of sale application, with the exception of 2 tags being outside the read field and not reading, read rates were 100%.

**Photograph 11: Point of Sale**

### POS Information

The overall test results from the point of sale scenarios listed above were very positive. In addition to the data reported herein, additional qualitative experiments consisted of various "real-world" enactments designed to stress test the physical capabilities of this POS system in methods typical to those seen during average checkout activities. The premise behind this testing is that a POS system by nature needs to read 100% of only the group of sales items intended for checkout.

While the reader was actively scanning for tags, tagged items were hung on the extendable bar built in as an extension of the desk and designed for exactly this purpose. This scenario might arise when an associate is checking a customer out while another associate is hanging items on this bar for some other customer (see photograph 11). The reader did not read these items although items placed within the demarcated pricing zone almost directly alongside were able to be read and appropriately tallied for sale. This is a positive result and the reader power remained unchanged at 15 dBm. Of course, software logic that would allow an associate to optionally include or exclude certain items becomes an additional source for decision making at this level.

**Photograph 12: Point of Sale**

Four or five items were placed in the checkout section of the sales desk, as if some customer were purchasing them and an associate had placed them in the pricing zone. A separate and different customer holding items that they intended to purchase then approached the sales desk and held their items against the outer side of the desk as if they were merely resting against the unit while waiting to check out (see photograph 12). The reader did not read these tags but did read the tags placed within the demarcated pricing zone. This is again a positive result, and the reader power remained unchanged at 15 dBm.

# TESTING SCENARIO III

## *OVERVIEW*

The test scenario is defined as mobile items/fixed reader. The purpose of this test is to determine how well (%) items can be read while moving merchandise through an RFID-enabled static portal. In this scenario, tagged items are placed on a transport device (such as a z-bar or handcart). If a transport box is used, tagged items are placed into a transport box (or boxes) and the box(es) are placed on a cart or hand-carried by an associate. The mobile merchandise is then moved (pushed, pulled, or carried) through the fixed reader portal 30 times in order to collect a large sample of read rates. The portal consists of two sets of two antennae (except for the static-3 reader which consisted of one set of 2 antennae) placed in stands so as to simulate various openings.

For this test scenario the following items will be varied:

- Type of tag
- Type of transport
- Type of readers
- Number of items on transport device

## *TEST DESCRIPTIONS*

### Test Description: Transport Type Z-Bar

For the z-bar test, the portal was configured in compliance with EPCglobal Dynamic Door Portal Test Specification standards (set at 10 feet apart). See Photographs 13 and 14. For testing, an associate would push the z-bar through the portal 30 times at a constant speed.

**Photograph 13: Portal for Testing with Z-Bar**

**Photograph 14: Clothes Placement on Z-Bar**

## Results—Z-Bar

For this test, various quantities of clothes were hung on the z-bar (with plastic and wire hangers) and pulled through the portal 30 times for each quantity of clothes. For each reader / tag combination, clothes were removed until a 100% read rate was achieved or the read rate decreased rather than improved. This quantity then became the baseline for the next reader with that tag type.

| TAG | READER | | | | | |
|---|---|---|---|---|---|---|
| | Static-1 | | Static-2 | | Static-3 | |
| | # clothes | Read Rate (in %) | # clothes | Read Rate (in %) | # clothes | Read Rate (in %) |
| Tag-A | 89 | 98.35 | | | | |
| | 84 | 99.10 | | | | |
| | 79 | 99.62 | | | | |
| | 74 | 99.50 | | | | |
| | 69 | 99.86 | | | | |
| | 64 | 100 | 64 | 99.32 | | |
| | 69* | 100 | 59 | 100 | 59 | 94.97 |
| | 74* | 99.86 | | | 54 | 98.27 |
| | | | | | 54~ | 98.77 |
| | | | | | 49 | 99.60 |
| | | | | | 44 | 100 |
| Tag-B | 91 | 79.10 | | | | |
| | 81 | 84.65 | | | | |
| | 71 | 86.71 | | | | |
| | 61 | 94.48 | | | | |
| | 56 | 96.49 | | | | |
| | 46 | 98.77 | 46 | 98.26 | 46 | 46.00 |
| Tag-C | 97 | 93.33 | | | | |
| | 92 | 98.55 | | | | |
| | 87 | 99.62 | | | | |
| | 82 | 99.11 | 82 | 99.80 | | |
| | | | 77 | 99.83 | 77 | 63.77 |
| | | | 72 | 100 | 38 | 89.30 |

**Table 9: Summary of 30-Run Read Rate Averages from Tagged Items on Z-Bar**

Notes:

- *Portal moved from 10 to 7 feet
- ~ Removed 5 tags with horizontal tag orientation located near hanger
- Tag-B tests discontinued due to poor performance
- Static-3 portal contained only 2 antennae per specifications from the manufacturer Static-1 and static-2 had 4 antennae

For efficiency, the first reader chosen for the Z-Bar testing was the one which has consistently displayed a slightly higher degree of performance in past testing engagements in the lab environment. Decrementing the number of clothing items for this reader by five random items at a time will result in a higher read rate inflection point than obtainable in the consecutive readers used in this test, thereby avoiding unnecessary duplication of effort when testing with thirty runs per each multiple of five. This results in the cascading item totals seen in the table listing read rates per tag type.

It should further be noted that unless any single tag displayed consistently poor performance due to an internal technological malfunction, which was rare, every tag read at least once over the course of all test runs. This means that RFID reading redundancies within an implemented system might allow for read rates of 100% over the course of physical product distribution.

## Test Description: Transport Type Box

For the box test, the portal was configured in compliance with EPCglobal Dynamic Door Portal Test Specification and EPCglobal Dynamic Conveyor Portal Test Specification standards. The first box test consisted of two boxes on one handcart per level which was moved through the portal (see Photograph 15). The second box test consisted of a single box of items hand carried through the portal by an associate (see Photograph 16). The third box test consisted of boxes being transported at three different speeds (600, 400, and 200 feet per minute) on the conveyor (see Photograph 17). The fourth box test consisted of boxes on a steel cart (see Photograph 18).

**Photograph 15: Testing With Boxes on Handcart**

**Photograph 16: Testing With Hand Carried Box**

**Photograph 17: Box on Conveyor Passing Through Portal**

**Photograph 18: Boxes on Steel Cart**

## Results—Boxes on Handcart

For this test, a fixed number of items in two boxes were placed on a plastic handcart – one on the top shelf, one on the bottom. The handcart was then pulled through the portal 30 times at a constant speed. If 100% read rate was not achieved, clothes were removed until 100% was achieved or it was not longer practical to remove additional items.

| TAG | READER | | | | | |
|---|---|---|---|---|---|---|
| | Static-1 | | Static-2 | | Static-3 | |
| | # items | Read Rate (in %) | # items | Read Rate (in %) | # items | Read Rate (in %) |
| Tag-A | 72 | 99.80 | 72 | 99.86 | 72 | 35.00 |
| | 67 | 100 | 67 | 100 | 72* | 68.01 |
| | | | | | 72 | 50.23 |
| | | | | | 67 | 51.34 |
| | | | | | 47 | 55.39 |
| Tag-B | 72 | 30.00 | 72 | 30.00 | 72 | 30.00 |
| | 11 | 50.00 | 11 | 50.00 | 11 | 50.00 |
| | 6 | 50.00 | 6 | 50.00 | 6 | 50.00 |
| Tag-C | 61 | 94.08 | | | | |
| | 46 | 96.71 | 46 | 97.23 | 46 | 64.45 |

**Table 10: Summary of 30-Run Read Rate Averages from Tagged Items in Boxes on the Handcart**

Starting points:

- Tag-A: box 1 = 31, box 2 = 41
- Tag-B: box 1 = 31, box 2 = 41
- Tag-C: box 1 = 31, box 2 = 30

Notes

- Antenna lowered for re-test

## Results—Hand-Carried Boxes

For this test, items were placed in a box in quantities of 10, 20, and 30 and hand-carried 30 times through the portal.

| TAG | # Items in Box | READER | | |
|---|---|---|---|---|
| | | Static-1 | Static-2 | Static-3 |
| | | Read Rate (in %) | Read Rate (in %) | Read Rate (in %) |
| Tag-A | 10 | 100 | 100 | N/A |
| | 20 | 100 | 100 | N/A |
| | 30 | 100 | 99.89 | N/A |
| Tag-B | 10 | 30.67 | 59.67 | N/A |
| | 20 | 16.00 | 39.83 | N/A |
| | 30 | 10.33 | 35.56 | N/A |
| Tag-C | 10 | 100 | 100 | N/A |
| | 20 | 98.00 | 100 | N/A |
| | 30 | 93.89 | 100 | N/A |

**Table 11: Summary of Tagged Items in Hand-Carried Boxes**

## Results—Boxes on Conveyor

For this test, a box with 36 items was placed on the conveyor and passed through the conveyor portal 30 times. The conveyor speed was then changed from 200 feet per minute (fpm) to 400fpm and the process repeated and then to 600fpm and the process repeated.

| TAG | Conveyor Speed | Reader Type | | |
|---|---|---|---|---|
| | | Static-1 | Static-2 | Static-3 |
| Tag-A | 200fpm | 99.91% | 100% | 90.83% |
| | 400fpm | 99.44% | 99.44% | 86.39% |
| | 600fpm | 98.52% | 99.07% | 78.43% |
| Tag-C | 200fpm | 96.20% | 96.20% | 77.87% |
| | 400fpm | 90.46% | 90.09% | 68.80% |
| | 600fpm | 87.87% | 84.17% | 64.54% |

**Table 12: Boxes on Conveyor**

Notes:

- Each box contained 36 tagged items for all conveyor tests.
- Each test consisted of 30 runs.

## Results—Boxes on Steel Cart

This test was conducted using the static portal and tag types A and C. These tests were conducted to determine the possible effects a steel cart such as the one depicted in Photograph 18 might have on read rates. Metal has the capability of reflecting and/or detuning radio frequency (RF) energy. Six boxes were placed on the steel cart. Two sets of three boxes were loaded with 12, 24, and 36 items tagged with tag-A and tag-C used for each set of 3. The steel cart was then run through the portals 30 times at a constant speed.

Based on the results of this test, the steel cart does not appear to adversely affect the read rates (compared to the read rates obtained using the plastic hand cart – see section 3.3.2).

| TAG | Total # of Items | READER | | | | | |
|---|---|---|---|---|---|---|---|
| | | Static-1 | | Static-2 | | Static-3 | |
| | | # of Items Read | Read Rate (in %) | # of Items Read | Read Rate (in %) | # of Items Read | Read Rate (in %) |
| Tag-A | 72 | 72 | 100% | 71 | 98.61% | 58 | 80.56% |
| Tag-C | 72 | 63 | 87.50% | 67 | 93.06% | 48 | 66.67% |

**Table 13: Summary of Read Rates from Boxes on Steel Carts**

# *SUMMARY AND INSIGHTS—TEST SCENARIO III*

## Z-Bar

The Z-Bar was loaded with tagged items from the rounders and tested in the static reader portals. Five items were randomly removed or added between each testing interval of 30 runs where after another 30 runs were tested. This was done in order to characterize the inflection point at which read rates changed from less than 100% to 100%, or vice versa. Tag yield rates—the percentage of tags on a stock role which under-perform due to some technical malfunction—were not adjusted for this testing. This was done in an attempt to prevent artificially sterile data being captured and to maintain a true representation of tag treatment, handling, and decay. Tag failure due to particularly rough treatment during testing, while very rare, is uncontrollable and sometimes difficult to diagnose when a tag underperforms intermittently. While this inflection point is to a small degree a function of tag failure, it is more a function of reader and tag type, as well as tag density. The entire set of runs was not duplicated with each reader. Instead the inflection point for each successive reader was found through either incrementing or decrementing the number of items hanging on the Z-Bar following the initial reader's result.

## Boxes

The boxes underwent four separate testing scenarios within the category of static readers. As with the Z-Bar, each test consisted of sets of 30 runs through the static portals. The number of tagged items was similarly increased or decreased in an attempt to find an inflection point between read rates of 100% and read rates of less than 100%. The number of items added or removed varied based on the rates returned by the readers during the previous test set. Since

tag type B performed poorly, large amounts of clothing were removed between test sets. Certain tests were discontinued due to poor read rates being returned.

Testing boxes on the hand cart was primarily conducted to ascertain read rates from tagged items in boxes that are moving through a portal suboptimal for its purpose. The angle of attack of the antennae and flat, 'laying-down' orientation of the tags within the boxes, as well as the distance between these tags and the antennae, all describe a worst case scenario for read rates on this product. With some of the tag types, the returned read rates were substantially higher than anticipated.

Although testing hand carried boxes through the portal subjects the tags to a similar suboptimal environment as testing on the hand cart, the overall read rates were much higher due to the lower number of items within each box.

The boxes were tested on the conveyor, with 36 tagged items on hangers, at speeds of 600, 400, and 200 feet per minute. In this testing there is an additional antenna above the box, as well as the antennae on the sides of the box as it moves along the conveyor. The conveyor transport platform consisted of a belt over a solid sheet of steel, prohibiting the use of a fourth antenna below the conveyor. The boxes moved in a single straight line through the portal with no rotation or angling of the box before, during, or after the portal. The only variable altered was the conveyor speed which was measured with a tachometer after each adjustment between sets.
The boxes were also placed on a steel cart in order to determine the effect such a large body of steel might have on overall tag readability. The boxes used during the conveyor test were unchanged and used in the steel cart tests in addition to four extra boxes, two of which contained 24 tagged items, and two of which contained 12 tagged items totaling 144 tagged items. Half of these items were tagged with tag-A, and half were tagged with tag-C. The tag types were separated by box. The steel cart was pulled through the each of the static portals 30 times. In total, tag-A read 100% with the static-1 reader.

## Tag Shadowing

We saw a few occurrences during our testing of 'tag shadowing'. Tag shadowing occurs when multiple tags reside in such close proximity that they touch or overlap, aligning with each other and not reading accurately. The result of tag shadowing is that one or multiple such tags cannot be read on a consistent basis. Tag placement plays a role in tag shadowing. If the tags are placed such that multiple tags reside in a touching and overlapping fashion, read rates will be impacted. However, unlike boxes stacked on a pallet for transport, items of clothing which are hanging on a Z-Bar such as these undergo a degree of motion that provides an aspect of randomness which has the possibility of allowing every tag to read.

# TESTING ENVIRONMENT AND CONTROLS

All tests were conducted on site at the University of Arkansas' RFID laboratory. No environmental aspects of the lab were altered for these tests. While spectral noise levels were monitored and maintained, aspects such as lab temperature and humidity, which are both uncontrolled, remained subject to the elements for the duration of these tests.

All portal tests consisted of 30 runs.

An attempt was made to prevent tester bias from affecting the collection of all tag reads. In the course of evaluating read rates to determine how a test should proceed, each tester often had to know how many tags they were attempting to read during a test. In practice, however, this might often not be the case. Associates using RFID equipment to take inventory or search for a current total number of tags on any particular fixture may be unaware of the total number of tags they need to discover. This is particularly true for handheld reading where the actions of the associate have the greatest propensity to influence the capture of tag data. For this reason, the handhelds were set to make an audible beep with every new tag discovered, and all testers were asked to refrain from checking the total number of tags read until after it seemed reasonable that no more tags would be read during that test, based upon this audible feedback. Performing a "reasonable" test in this manner was compared with a double blind test performed by two unsuspecting corporate guests in the lab. These guest testers returned read rates with no significant difference to those for which data was captured by lab testers.

# Item-Level RFID: Future Direction – Current Status

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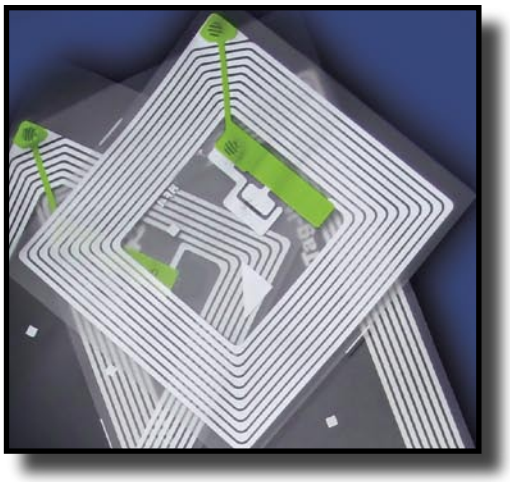


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