Evaluation of an Innovative System for Improving Readability of Passive UHF RFID Tags Attached to Reusable Plastic Containers

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Radio frequency identification (RFID) is a contactless identification technology that has proven to work well in conjunction with reusable plastic containers (RPCs). The impact of this technology on returnable containers has been explored by several past studies. This study evaluates an innovative system for improving readability of passive UHF RFID tags in conjunction with RPCs. The system involves an energy transfer device (ETD), which when attached to the RPCs, passively transfers radio frequency signals to interior regions of a unitized load thereby improving the readability of all RFID tags attached to the RPCs. This study included an evaluation of the improvement in readability of tagged RPCs in a unitized load with forklift truck speed, product type and pallet pattern as the variables and with readability as the main control variable. It was observed that ETDs vastly improve the readability rates by nearly 97%. Results are also included in this paper describing the effects of the product type, pallet patterns and forklift truck speeds on the readability of tagged RPCs in a unitized load.

INTRODUCTION

Fresh vegetables and fruits are typically packed in various types and forms of containers to hold about 5 kg to 20 kg of net produce to facilitate their journey from farm to fork.1 While the per capita fresh fruit availability at retail in the USA has increased only slightly (2.37%) between 1989 and 2007 to 54.31 kg, the corresponding number for fresh vegetables has increased significantly (10.14%) to 84.77 kg.2,3

Fruits and vegetables along with other limited shelf life products must be distributed in an expedited manner from the farms to the retailers to preserve their freshness. Reusable plastic containers (RPCs) have emerged as one of the solutions to achieve this in an efficient and profitable manner. Some of the benefits of these shipping containers are that they are reusable, provide enhanced cooling capabilities though ventilation, are available in common footprint (60 cm x 40 cm) and different heights adopted by industry, can be knocked down when empty and can be reused approximately 30 times after sanitization.4

First introduced to the US retail trade in 1996 by Wal-Mart and HEB (Texas-based retailer), RPCs have become prevalent at all major retailoutlets.5 Recent deployment of these reusable containers has been conducted at Stater Bros. (2006), Kroger (2006) and Harris Teeter (2008) among several other retailers.5RPCs are estimated to be used to distribute 7–8% of the retail produce volume as compared to 26% using corrugated fibreboard shippers.6,7 Some estimates regarding the future of RPC employ- ment in this sector predict the market share to grow by 15–20% per year.[7]

RPCs are typically leased or rented to the users by third-party logistics companies through a closed-loop pooling system. They are made available to the growers/processors that fill and ship them to distribution centres and/or retailers. At retail, the RPCs are often put directly on the retail shelves. Figure 1 below shows the conceptual operation of these systems. Some of the larger manufacturing companies also provide the pooling services to the users.

Radio frequency identification (RFID) is a contactless identification technology that has proven to work well in conjunction with RPCs. The impact of this technology on returnable containers has been explored by several past studies. Several case studies of RFID implementations in container manage-ment have found the key benefits to reduced shrinkage, increased availability of containers or pallets, accelerated search processes for goods in the supply chain and cost savings from claims, deposits and reconciliation between retailers and growers.[8–13]

RFID technology promises to provide unrealized benefits when applied to reusable assets such as RPCs and pallets provided the tag is able to survive the multiple trips required of them. A recent study related to the deployment of RFID tags designed for single use concluded that these tags could be used in multiple use scenarios without significant deterioration in performance if positioned optimally on RPCs.[14] Another recently published study compared eight commercially available RFID tags mounted on RPCs for use in fresh produce distribution and subjected them to repeated physical and climatic cycles representing the distribution and cleaning environments and tested their effective read capa-bilities.15 It concluded that in general, the process of sanitization was more detrimental to tag readability as compared to transportation and handling and that the ideal protection method for reuse of RFID tags on reusable containers is by encapsulation of the tag or integrating it within the RPCs during their manufacturing.

With the environmental stewardship goals already implemented or being discussed by most busi-nesses and industries, the employment of RPCs has been rapidly growing. A study comparing RPCs to single-use display-ready corrugated fibreboard trays summarized that the RPCs require 39% less total energy, produce 95% less total solid waste and generate 29% less total greenhouse gas emissions.4

This study was conducted to evaluate an innovative system for improving readability of passive RFID tags attached to a unitized load of RPCs. This system, a recently published patent, allows for the RF signal to wirelessly retransmit to the interior regions of the unitized load, thereby improving the overall readability of the cases in the unitized load.

[Insert Figure 1]

Materials

Energy transfer device (ETD). A patented system for improving the readability of RFID tags attached to RPCs by passively transferring the radio frequency (RF) signals between them was used in this study. 16 This system involves the inclusion of an ‘energy transfer device’, a coaxial transmission line, on the bottom of the RPCs that passively transfer RF signals to RFID tags not directly facing a reader antenna. While any coaxial cable that operates in the UHF range could be adapted, we used a 50 ohm impedance coaxial cable with silver-plated copper centre conductor and a braided shield and a diameter of 2.6 mm.

Figure 2 shows the ETD concept as placed on the bottom of a RPC. The lower right hand corner of the RPC is magnified to better view the ETD and RFID module. Each end of the coaxial cable has a separate length of wire soldered on to the shield which forms half of the dipole antenna. The other half of the dipole antenna is formed from the extension of the centre conductor (outer shield stripped away). An RFID module was then placed in close proximity to either length of the dipole antenna. Placing the tag close to the vertex of the two ends of the dipole maximizes the voltage captured by the antenna and increases the read distance. The length of the dipole is a function of the material on which it is placed. The length of each leg of the dipole used in this study was 6.73 cm. The ETDs were fixed on the RPCs using hot melt glue.

[Insert Figure 2]

In some applications, an RFID reader operates in a dense reader environment such as palletized load of product filled RPCs. These readers work to scan their interrogation zones for transponders which use radar cross section (RCS) modulation to backscatter information to the readers. Due to the RCS modulation the RFID communications link can be very asymmetric and while a typical reader transmits around 1 watt, only about 0.1milliwatt or less gets reflected back from the transponder.16 After propagation losses from the transponder to the reader, the signal received by the reader could be as low as 1 nanowatt for passive transponders.16 This performance can be further diminished due to nearby readers transmitting 1 watt at the same or nearby channel. The passive transference system used in this study overcomes this limitation to a great degree.

[Insert Figure 3]

The system based on the ETD concept is shown below in Figure 3. In the figure, R1–R9 represent RPCs, A–D represent reader antennas, M1–M9 represent RFID modules and ETD1–ETD9 represent energy transfer devices affixed to the RPCs. As can be seen, there is no RFID module that is more than two ETD connections away from exposure to the RF when the stack has reader antennas on any of the two opposite faces. As an example, M5 can be accessed through two ETDs via reader antenna C as well as through only one ETD from reader antenna A. There are only a few RPCs where two connections through ETDs would be required. M2 for example would require two connections to be read by reader antenna C and it would not be exposed to antenna A except when the pallet is traversing through the portal.

Figure 4 shows a flow chart illustrating an example method for managing an ETD-enabled passive transference system. It describes the technique for communicating along the path between a reader antenna and tags placed on two adjoining containers.

RFID module. Sirit Inc.'s (Toronto, Ontario, Canada) ultra high frequency (UHF) RFID inlay model IN-55, shown in Figure 2, was used for this study due to its short read range to document any enhancement to the range by adopting ETDs. This module is a small near-field antenna designed for high-value asset tracking and applications where a small form factor (16.74 mm x 13 mm) tag is required. 17 The ETDs fixed to the RPCs essentially function as dipole antennas for the IN-55 inlays thereby converting them from near-field to far-field tags. The commercial goal of the ETD concept is to get them embedded in RPCs during manufacturing so that 'smart RPCs' could be made available to users. Designed for use with NXP UCODE (Eindhoven, Netherlands) and Alien Higgs (Morgan Hill, California, USA) 3 ICs, the IN-55 has options for standard (96 bits) or additional user memory (512 bits).17 This module is rated to function in an operating temperature range of -40°C to 85°C and has data transfer rate of up to 640 kbps.

Reader and antennas. Alien Technology's (Morgan Hill, California, USA) ALR 9900 RFID reader and four ALR 915 MHz circular polarized antennas were used to construct the portal for this study. The ALR 9900 reader supports all EPC Gen 2 (Electronic Product Code Generation 2) tag protocols for UHF tags operating between 902.25–927.25 MHz. It was connected to the host computer using a UHF connection and its signal strength conformed to the FCC (Federal Communications Commission) Part 15 guidelines. The ALR 9900 reader supports a maximum of four UHF antennas. ALR 915 MHz circular polarized antennas were used because they are less sensitive to tag orientation and they provided the appropriate distances needed for this study.18,19

[Insert Figure 4]

Reusable plastic containers (RPCs). The RPCs for this study were obtained from Polymer Logistics Inc. (Riverside, California, USA). Model 6416 was used for this study and it measured 60 x 40 x 16.5 cm with a nesting height of 33 mm and tare weight of 1.50 kg. The injection moulded RPCs were made of polypropylene and had a recommended load capacity of 15 kg.

Product/package systems. Radio frequency waves cannot penetrate and reflect off of metals making it difficult to read tags placed on their surface.20 Water and other liquids absorb RF waves, which greatly reduces the read range.20 The package content can interfere with the RF by reflecting or absorbing these waves as they travel from the tag to the reader. Highly dielectric materials (liquids) and conductors (metal), even in small amounts, can drastically change the properties of a tag antenna, reducing efficiency and shortening the read distance, sometimes to the point of becoming completely unreadable at any distance.20 Carbonated soda packaged in aluminium cans and drinking water bottled in plastic bottles was used in this study to evaluate the effect of their readability deterrent character-istics on the overall readability of the palletized loads. Thirty RPCs filled to their maximum capacities with either the soda cans (48 aluminium cans of 355 ml capacity each in single vertical orientation layer) or bottled water (30 plastic bottles of 500 ml capacity each in two horizontal orientation layers) were palletized in the column and cross stack patterns for this study as discussed in section 2.2 and shown in Figure 5.

Portal and forklift truck. A counterbalanced forklift truck was used to carry and transfer the palletized loads of product through a portal at three different speeds to simulate various driving conditions. These were 2.4 kph, 8.1 kph and 16.1 kph. A standard portal was used as described and shown with in Figure 6.

[Insert Figures 5 and 6]

Methods

The outcome variable of interest for this testing procedure was the readability of the RFID tags. Passive tags were tested with and without the presence of the ETD at palletized load level. In addition, previous studies have identified the supply chain variables that have the most significant affect on passive tag readability.[18,19,21–24] These studies were used to identify the additional variables needed to examine the performance of the ETD in real supply chain conditions. The additional variables identified include product type, pallet orientation and forklift speed. These variables were also included in the analyses as possible predictors of the readability of RFID tags.

RESULTS AND DISCUSSION

In this section, we present the results from our study starting with some preliminary exploration. As can be seen in Figure 7, a much higher percentage of RFID tags were read when an ETD was present (70.33%) than when it was not

(0.72%). Figure 7 also shows how, if at all, the overall percentage of RFID tags read differed between variations of forklift speed, product types and pallet patterns.

[Insert Figure 7]

We ran a binary logistic regression with whether an RFID tag is read as the dependent variable. The factors were presence of an ETD (yes or no), product type (cans or bottles), pallet orientation (column or cross), forklift speed (2.4 kph, 8.1 kph and 16.1 kph), and all two-way interactions. At an overall significance level of 0.05, only the interaction between product type and pallet pattern appeared to be statistically significant ($p < 0.0001$).

Next, we ran a binary logistic regression with the same dependent variable as before, but this time with the four main effects, and subsets of the six two-way interactions as factors. After, looking at all the models we picked the model with all four main effects and the two-way interaction of product type and pallet orientation. The goodness-of-fit tests for this model had p-values between 0.2 and 0.8, indicating that there is no evidence to suggest that the model is not appropriate.

We found the interaction between product type and pallet orientation to be statistically significant ($p < 0.0001$) in predicting whether an RFID tag is read. The main effects of presence of an ETD and forklift speed were also statistically significant ($p < 0.0001$). All other factors remaining the same, the odds of an RFID tag being read in the presence of an ETD are between 250.7 and 779.0 times higher than that of the same odds for when an ETD is absent, with 95% confidence level. Also, the odds of an RFID tag being read at low forklift speed (2.4kph) is between

2.0 to 3.3 times higher than the same odds at high forklift speed (16.1kph)($p <$ 0.0001). The medium speed (8.1 kph) was not found to be statistically significantly different from high forklift speed.

Additionally, our data suggest that stacking beverage cans in column stack pattern rather than cross stack pattern results in higher odds of the RFID tags being read by about 2.0 times and that stacking bottled water in cross stack rather than column stack patterns results in higher odds of the RFID tags being read by about 1.7 times. Since this interaction is statistically significant, we do not interpret the coefficients of the main effects of product type and pallet orientation.

Table 1 shows the parameter estimates (using maximum likelihood estimation) from the binary logistic regression model with whether an RFID tag is read as the dependent variable and all four main effects and the two-way interaction of product type and pallet orientation as factors.

As mentioned earlier, 70.33% of tags were read when an ETD was present; meaning 29.67% were not read. We wanted to investigate if any additional factors might be predictive of tag readability in the presence of an ETD. For the tags with ETD, we ran a binary logistic regression with whether a tag was read as a dependent variable. The factors were forklift speed (2.4 kph, 8.1kph and 16.1kph), product type (cans or bottles), pallet orientation (column or cross), the interaction of product type and pallet orientation, tier number indicating location of tag (1=top to 6=bottom) and antenna orientation (facing towards tag, facing away from tag). Table 2 and Figure 8 represent the binary logistic regression analysis and percentage of tags read as related to the location of tags in reference to the reader antenna orientation, respectively.

[Insert Table 1 and 2]

In addition to forklift speed and the product type-pallet orientation interaction, at an overall significance level of 0.05, both tier number and antenna orientation were found to be statistically significant ($p < 0.0001$). We are 95% confident that when the tag is facing the antenna (as opposed to away), the odds of the tag being read is between 2.42 and 4.06 times higher. Also, the odds of a tag on the top tier (as opposed to the bottom tier) being read was found to be significantly lower (0.3 84); we found that the odds of a tag on the second highest tier being read (as opposed to the bottom tier) is significantly higher (1.507). Tiers 3, 4 and 5 were not found to be significantly different from tier 6.

[Insert Figure 8]

CONCLUSIONS

RFID technology is constantly evolving with the promise to provide more than adequate readability of all tags placed on assets. This study evaluated the effectiveness of the ETD concept to enhance readability of tagged RPCs in a unitized load based on product type, forklift truck speed and pallet pattern and concludes the following:

The ETD concept explored in this study greatly enhances the opportunities for adapting RFID for reusable packages. An overall improvement of 96.68% in the readability of RFID tags was observed with the ETD attached to the RPCs in the unitized load. As a worst case scenario, the RPCs for our study were packed to the maximum capacities with the two types of products. This is usually not the case for actual shipments and further improvements in readability may be realized.

As shown in several past studies, the lowest speed used to move the palletized load through a portal increased the probability of reading the tags applied to the RPCs. The medium speed of 8.1 kph was not found to be significantly different than the high speed of 16.1 kph.

Optimum pallet pattern selections depend on the type of product-package system. For bottled water, the best type of pallet pattern was the cross stack (two times better than column stack pattern) and for the beverage cans, the best type of pallet pattern observed was the column stack (1.7 times better than cross stack pattern).

The factors used in this study need to be considered and experimented with prior to finalizing any specifications for adopting RFID in distribution to yield optimum efficiencies in the supply chain.

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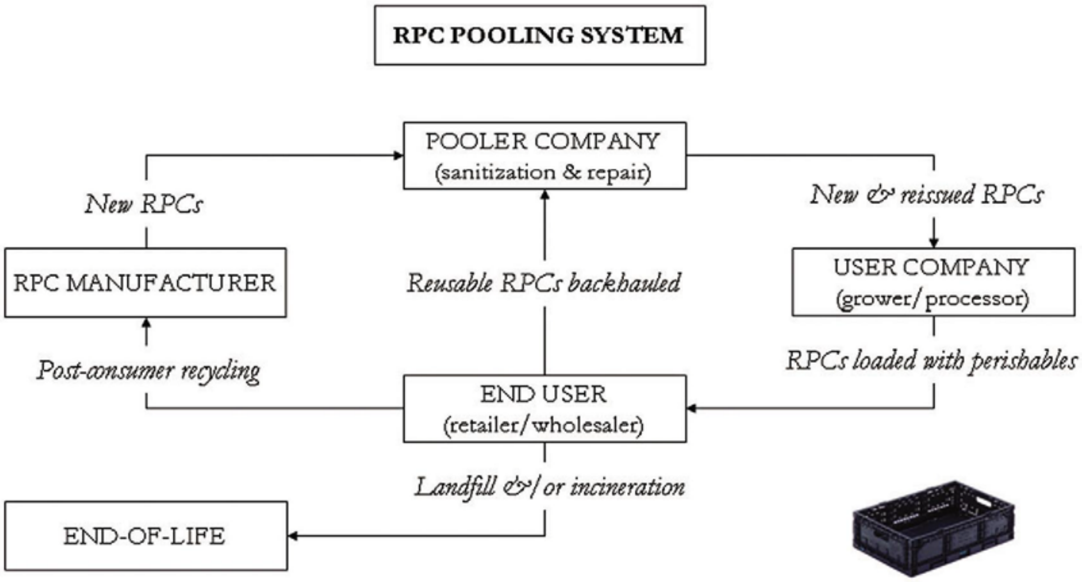

Figure 1. Reusable plastic container pooling system.

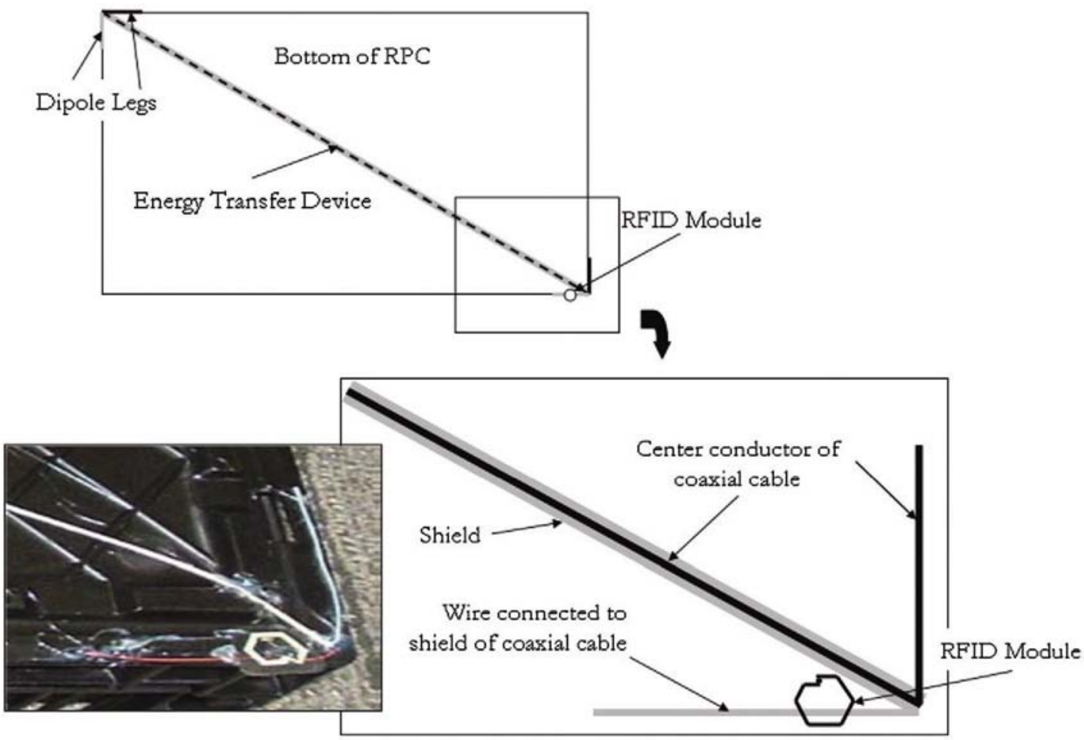

Figure 2. Placement of ETD and RFID module on a RPC.

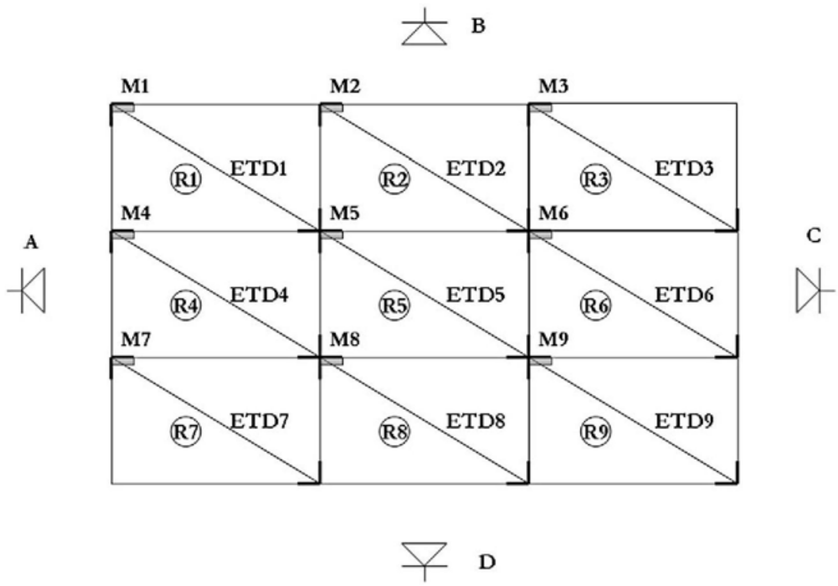

Figure 3. An example of a passive transference system using ETDs.

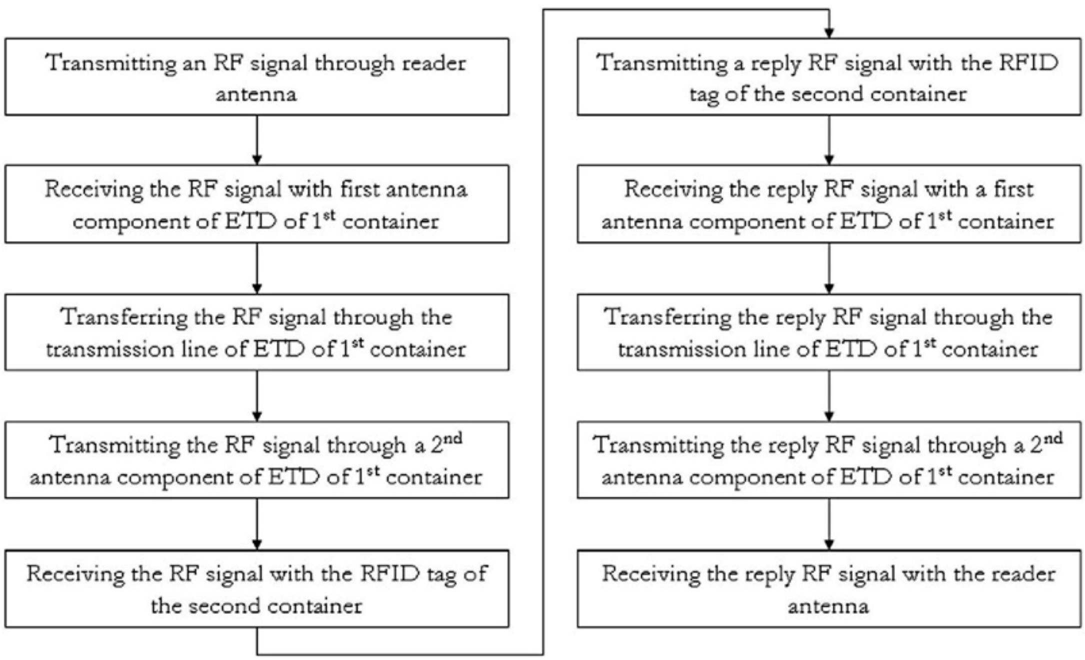

Figure 4. Technique for communicating along the path between reader antenna and tag.

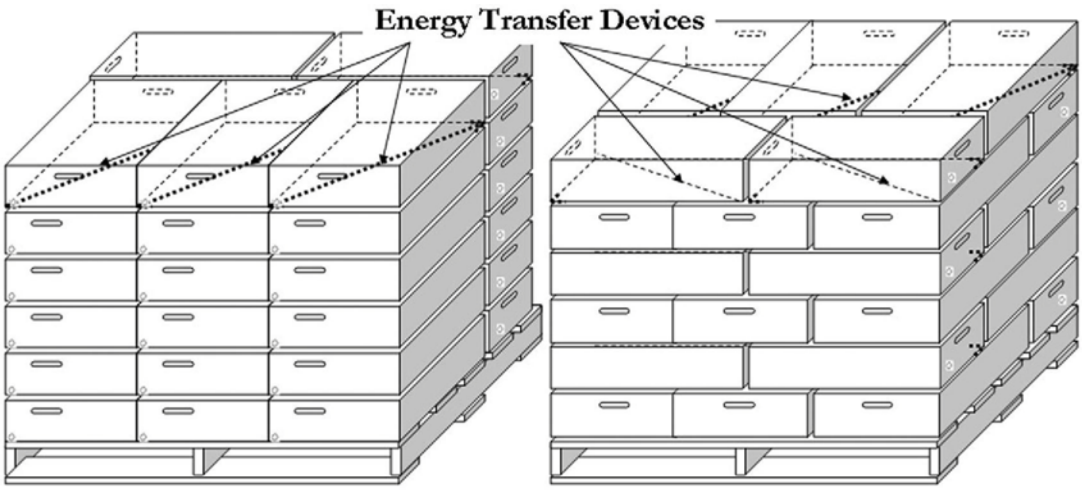

Figure 5. Placement of ETDs and palletizing patterns.

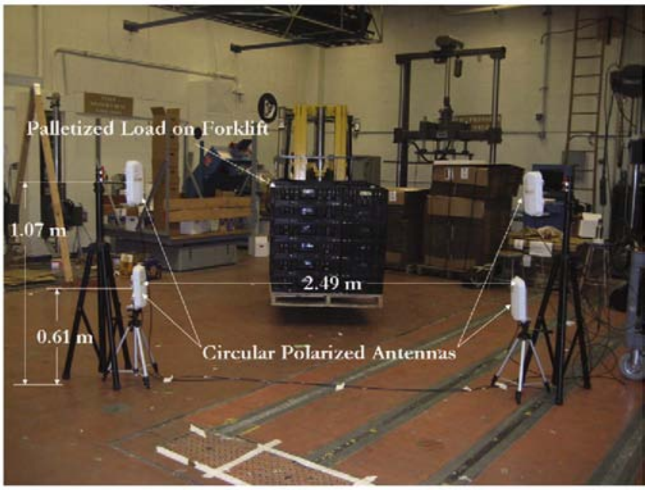

Figure 6. Portal set-up.

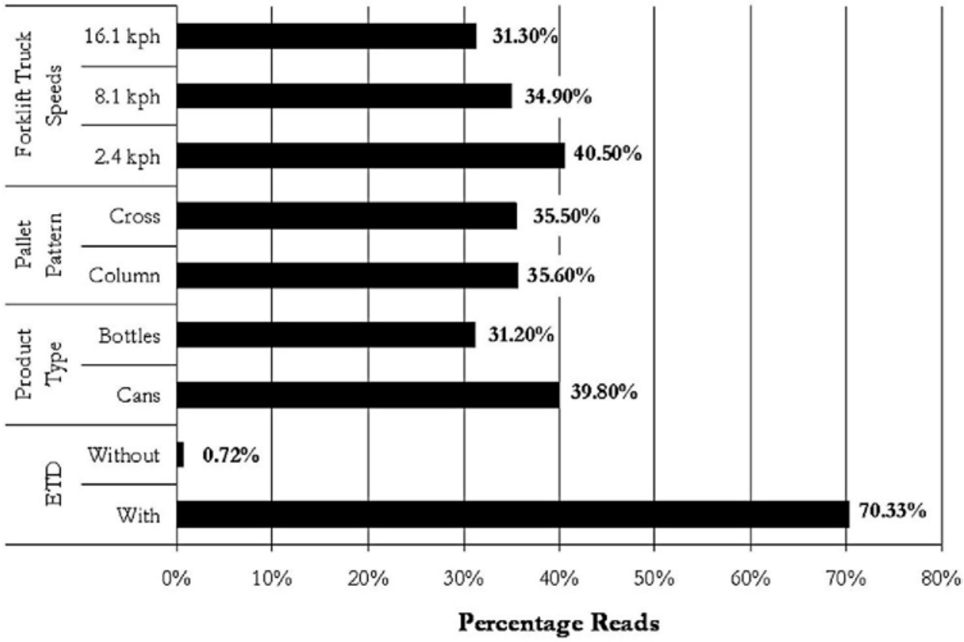

Figure 7. Percentage of RFID tags read.

Table 1. Parameter estimates from the binary logistic regression analysis for factors predicting whether an RFID tag is read (*Reference = RFID tag not read*).

	Estimate	SE (Estimate)	*p*-value
Constant	–2.0960	0.1425	<0.0001
ETD present? (Reference = no)			
Yes	3.0456	0.1446	<0.0001
Product type (Reference = water bottles)			
Cans	0.4321	0.0542	<0.0001
Pallet orientation (Reference = cross)			
Column	0.0489	0.0539	0.3642
Forklift speed (Reference = 10 mph)			
1 mph	0.5127	0.0792	<0.0001
5 mph	–0.0840	0.0742	0.2577
Product type × Pallet orientation (Reference = water bottles × Cross)			
Cans × Column	0.3092	0.0540	<0.0001
$n = 120$			

Table 2. Parameter estimates from the binary logistic regression analysis for factors predicting whether an RFID tag is read (*Reference = RFID tag not read*), when an ETD is present.

	Estimate	SE (Estimate)	*p*-value
Constant	0.6768	0.0669	<0.0001
Product type (Reference = water bottles)			
Cans	0.5217	0.0583	<0.0001
Pallet orientation (Reference = cross)			
Column	0.0905	0.0577	0.1168
Forklift speed (Reference = 10 mph)			
1 mph	0.5853	0.0852	<0.0001
5 mph	–0.0961	0.0789	0.223
Product type × Pallet orientation (Reference = water bottles × Cross)			
Cans × Column	0.3081	0.0579	<0.0001
Antenna placement (Reference = away)			
Facing	0.571	0.0662	<0.0001
Tier number (Reference = 6, bottom)			
1	–0.8795	0.1178	<0.0001
2	0.4887	0.1348	0.0003
3	0.1168	0.1265	0.3556
4	0.0977	0.1261	0.4387
5	0.0977	0.1261	0.4387
n = 144			

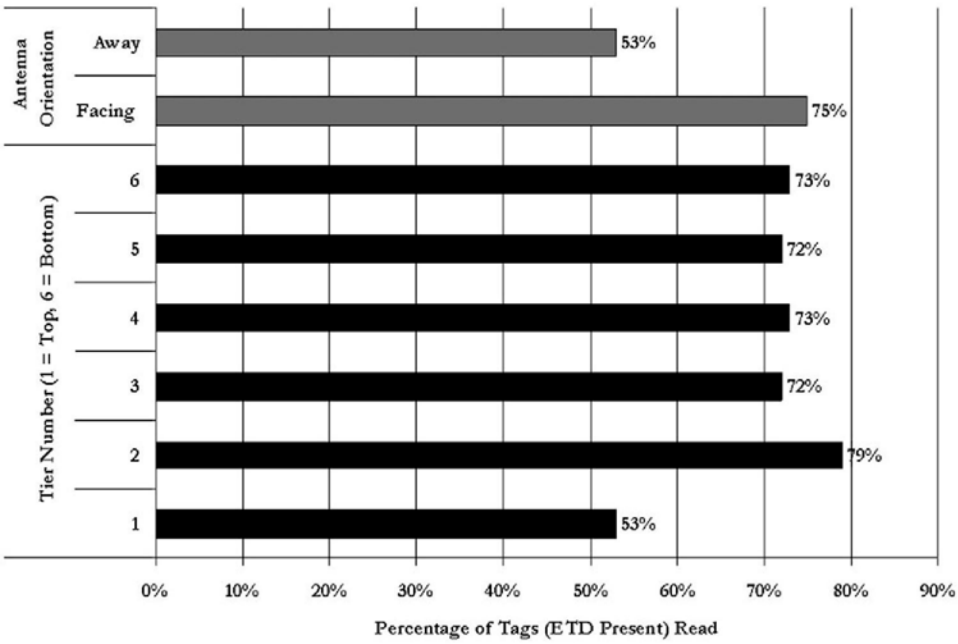

Figure 8. Percentage of RFID tags read as related to pallet tiers and reader antenna orientation.