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ITRI-WP107-0311

Does RFID Improve Inventory Accuracy? A Preliminary Analysis

Issued:
03.11.2008

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Does RFID Improve Inventory Accuracy? A Preliminary Analysis

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DOES RFID IMPROVE INVENTORY ACCURACY?
A PRELIMINARY ANALYSIS

Executive Summary

For the adoption of RFID to continue at or beyond its current pace, it is important to investigate the business value created by the technology. In previous studies, we have shown how RFID can improve in-stock position. Other studies have shown the benefit of RFID for promotional items. In this vein of continuing to prove the business case for RFID, we examine RFID's impact on inventory accuracy. Inventory accuracy is one of the keys to an efficient and effective supply chain, yet is often referred to as the "missing link" in retail execution. Forecasting, ordering, and replenishment use inventory records as input, and the quality of these functions are impacted by inventory accuracy.

To study the impact of RFID on inventory accuracy, Wal-Mart commissioned a study to examine the store-level influence of RFID on perpetual inventory. For 23 weeks, a single category of product (air fresheners) was inventoried daily in eight test stores equipped with a new RFID-based perpetual inventory adjustment tool and eight matching control stores (without RFID). Preliminary results presented in this paper indicate that RFID does reduce inventory inaccuracy in the presence of normal business processes for on-hand adjustments (i.e., RFID as a supplement to existing manual adjustment processes).

DOES RFID IMPROVE INVENTORY ACCURACY?
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March 2008

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Introduction

Inventory accuracy is one of the keys to an efficient and effective supply chain. Forecasting, ordering and replenishment, for example, are based on an accurate inventory count. Most retailers rely upon automated ordering and replenishment systems or, at least, information from a system to provide insight into what, when, and how much to order. For these systems to be effective, retailers must have records of their on-hand inventory. Unfortunately, “retailers are not very good at knowing how many products they have in the stores” (Kang and Gershwin, 2007, p. 844). Previous studies have found that retailers only have accurate inventory information, known as perpetual inventory (PI) or what the system thinks is on hand in the store, on about 35% of their items (Raman, DeHoratius, and Ton, 2001). This means, of course, that ordering and replenishment decisions are based on a number that is wrong more often than it is right! Subsequently, inventory accuracy is often referred to the “missing link” in retail execution (Heese, 2007).

Retailers recognize the problem. A recent AMR report identified inventory accuracy as one of the top issues for grocery retailers (Landoc, Garf, and Suleski, 2006). Although it is recognized as a major obstacle to successful store execution, retailers have difficulty determining when, how, and in what magnitude inventory inaccuracy occurs (Kang and Gershwin, 2007). Because of inaccuracy, systems can order product that is unnecessary or fail to order product that is needed (DeHoratius and Raman, 2004). The net result is an estimated 10% reduction in profit due to inventory inaccuracy (Heese, 2007). To combat inaccuracy, companies can increase the frequency of physical counts, maintain additional safety stock, or identify and eliminate the source of errors (Morey, 1985). RFID can potentially help companies identify and eliminate the source of errors. Hence, the purpose of this study is to investigate the potential incremental reduction in PI inaccuracy, due to RFID, in the presence of normal business processes for on-hand adjustments (i.e., RFID as a supplement to existing manual adjustment processes). Although it seems plausible that the visibility provided by RFID can reduce inventory inaccuracy, to date, no one has tested this assertion.

Inventory Accuracy

Perpetual inventory is inherently inaccurate. Various studies have proven its fallibility; e.g., Kang and Gershwin (2007) found inventory accuracy (exact match) to be about 51% and only about 75% when relaxed to ± 5 units. Raman, DeHoratius, and Ton (2001), in a study of 370,000 products across a single chain, found 65% inaccuracy; 20% of which differed by six or more units. Likewise, in a study of 166 items from 121 stores, Gruen and Corsten (2007) found PI inaccuracy to be 55%.

When evaluating PI accuracy, there are two basic categories of inaccuracy: overstated PI and understated PI. Research has found that about half of the time, inaccurate PI is overstated (i.e., PI shows more inventory than is actually in the store, also known as phantom inventory), and about half the time inaccurate PI is understated (i.e., PI shows less than what is in the store, also known as hidden inventory) (Gruen and Corsten, 2007). Both types of PI can have a detrimental effect on the retailer. For overstated PI, the most serious and directly related problem is out of stock – the system thinks it has inventory on hand (i.e., phantom inventory), thus fails to order new inventory. For understated PI, the most pressing problem is excess inventory (i.e., hidden inventory) because the system thinks it does not have as much as it really does, thus ordering unnecessary inventory. This unnecessary inventory potentially results in excess holding costs, excessive markdowns which impact margin, reduced turns, and breakdowns in store execution (which can lead to execution-related errors such as out of stocks) due to the inefficiencies created by the extra inventory.

There are several known causes of inventory inaccuracy (Gruen and Corsten, 2007; Kang and Gershwin, 2007; Waller, Nachtmann, and Hunter, 2006). First, PI can be incorrectly manually adjusted by employees. For example, when an employee believes the product to be out of stock, PI may be mistakenly set to zero when, in reality, product is in the backroom. Conversely, an employee could think a case of product exists when it doesn’t and incorrectly adjust PI upward. Thus, incorrect manual adjustments can create both under and overstated PI. Second, products can be stolen, resulting in an overstated PI condition (e.g., the system thinks there are 10 items on hand, but three were stolen leaving a true on hand of only seven). Third, damaged or spoiled products, when not recorded as such, result in overstated PI. Fourth, returned products that should add inventory back to the system are occasionally not accounted for properly or are accounted for incorrectly (e.g., showing a return of product A when, in fact, product B was returned); thus, potentially creating under or overstated PI. Fifth, a store can receive mis-shipments from the distribution center, resulting in both over and understated PI (overstated for products that should have been received, but were not; understated for products received that should not have been received). Sixth, cashier error can cause both over and understated PI inaccuracy. For example, if a customer is purchasing three items of product A and three items of product B, but the cashier mistakenly enters six items of product A, then the PI for product A will be understated by three units and the PI for product B will be overstated by three units.

To compensate for inventory inaccuracy, companies can do a variety of things (Kang and Gershwin, 2007; Morey, 1985). First, safety stock can be increased. The increased safety stock helps avoid out of stock situations by keeping 'extra' inventory on hand. RFID may enable reduction of the cost of holding this extra, and unnecessary, inventory. Second, the company can perform frequent manual inventory counts. Physical audits of inventory can be disruptive to store execution, vary in accuracy, and are very costly – RFID enabled PI accuracy improvement may be a cost effective alternative. Third, to offset overstated PI, the company can build in a constant decrement equal to the amount of stock loss one thinks is occurring. The problem with this is that exact stock loss is unknown. The visibility enabled by RFID may result in greater accuracy than current methods of estimating the stock loss. Finally, the company can try to eliminate the source of errors by better inventory management, reducing theft, etc. Kang and Gershwin (2007) suggest auto-ID (RFID) as one method to help companies eliminate the source of errors.

Overview of RFID

Fundamentally, RFID is one example of a family of auto identification technologies which also includes the ubiquitous barcode. Since the mid-1970s, the retail supply chain (and many other areas) has used barcodes as the primary form of auto identification. Given the success of barcodes, the question arises ‘Why move to RFID?’ The answer lies in the numerous advantages of RFID relative to barcodes. Examples of these advantages include (Delen, Hardgrave, and Sharda, 2007): (1) RFID does not require line of sight; (2) RFID allows hundreds of tags to be identified at one time; (3) RFID allows hundreds of tags to be read per second; (4) RFID tags can store more data; and (5) the data on RFID tags can be manipulated. These advantages have prompted many companies (e.g., Wal-Mart) to aggressively pursue RFID as a way to improve the supply chain (and, thus, reduce costs and increase sales).

In its simplest form, an RFID system consists of a tag (attached to the product to be identified), an interrogator (i.e., reader), one or more antenna attached to the reader, and a computer (to control the reader and capture the data). At present, the retail supply chain has primarily been interested in using passive RFID tags. Passive tags are powered by radio waves created by a reader and transmitted via its antennas. The passive tag will remain powered only while it is within the read field. While in the read field, the powered tag will respond to the reader by reporting the data contained within.

Within Wal-Mart and other major retailers in the consumer packaged goods industry, products are being tagged primarily at the pallet and case level.

RFID Data

As a case moves from the supplier, to the retail distribution center (DC), and then on to the retail outlet, it passes through a number of RFID read fields. Readers capture and record the case’s tag data as it passes through these points. Figure 1 provides an overview of the key read points in a generic distribution center. As product is delivered to the distribution center, read portals (created by stationary readers and antennas on each side of the delivery door) capture the pallet and case data. The product is stored in the distribution center for an indeterminate amount of time, then individual cases are put on the conveyor system to begin the sorting process; the conveyor system may contain multiple read points. Finally, the individual cases are sorted and shipped out the shipping doors which contain read portals similar to the receiving doors.

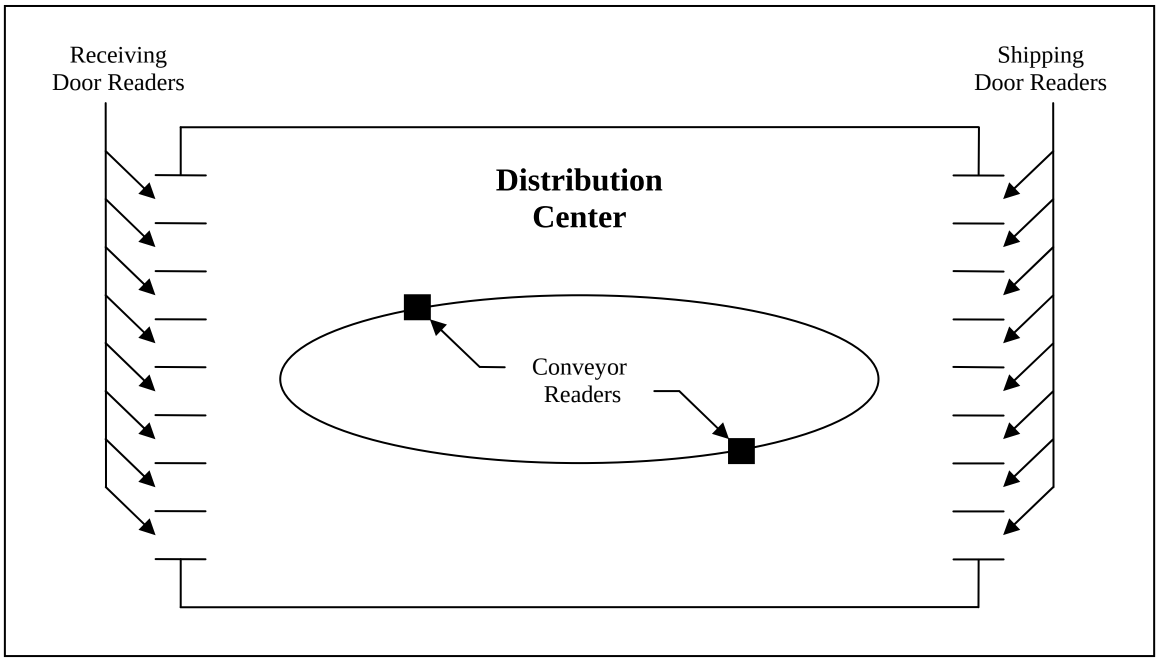

Figure 1. Generic Distribution Center Read Points

Figure 1 provides the read points most cases experience as they move through a general merchandise DC. The actual reads for a single case may vary depending on the type of product (e.g., bagged pet foods are not placed on conveyors) and the type of DC it enters (refrigerated/grocery DCs are different from general merchandise; e.g., grocery DCs have stretch wrap machines where readers can be placed, but may not have conveyors).

At the store level, the readers are located in the backroom area – no fixed readers are on the sales floor (see Figure 2). Receiving doors have read portals similar to those found at the DC dock doors and capture reads from the individual cases as they are unloaded from the truck. The product then moves to the sales floor (where readers are placed next to the doors going to the sales floor) or onto backroom shelving. Eventually, all products should be moved to the sales floor and the empty cartons returned through the sales floor doors (a second read is captured at this point) and placed into the box crusher for disposal (the last read point).

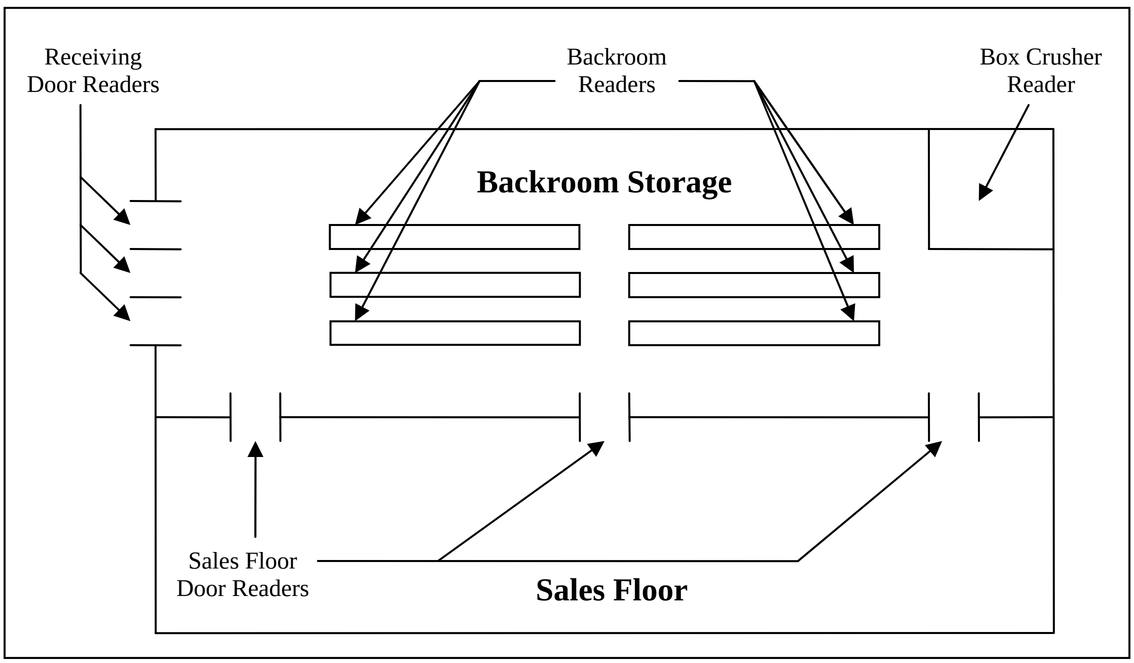

Figure 2. Generic Retail Store Read Points

Table 1 traces the movements of a single case of product (SGTIN: 0023800.341813.500000024) from its arrival at the distribution center to its end of life at the box crusher. This particular case of product arrived at distribution center 123 on August 4, was put on the conveyor system on August 9, and departed shortly thereafter.

It arrived at store 987 about 12 hours after leaving the DC, where it stayed for two days before going to the sales floor, returned about 45 minutes later, and then went to the box crusher for ultimate disposal.

Location	EPC	Date/time	Reader
DC 123	0023800.341813.500000024	08-04-07 23:15	inbound
DC 123	0023800.341813.500000024	08-09-07 7:54	conveyor
DC 123	0023800.341813.500000024	08-09-07 8:23	outbound
ST 987	0023800.341813.500000024	08-09-07 20:31	inbound
ST 987	0023800.341813.500000024	08-11-07 15:01	sales floor
ST 987	0023800.341813.500000024	08-11-07 15:47	sales floor
ST 987	0023800.341813.500000024	08-11-07 15:49	box crusher

Table 1. Sample RFID Data

Using RFID to Improve Inventory Accuracy

The data contained on a tag is fairly simple, and the read points are primarily discrete and prescribed. For this study, to reflect retail's general practice, use of RFID was examined at the pallet and case level (no individual items were tagged for this study). Yet, the potential is that data from an RFID-enabled environment, at the pallet and case level, can help improve processes. For example, previous studies have demonstrated RFID's utility in reducing out of stocks (Hardgrave, Waller, and Miller, 2005; 2006).

In this study, we are interested in RFID's ability to improve inventory accuracy. Essentially, with RFID, stores will know what cases have been delivered to the store, taken to the sales floor, or stocked in the backroom. Combined with point-of-sale data, a much more accurate view of inventory – both on the shelf and in the backroom – can be provided. As product is sold, PI can be updated based upon a knowledge of items on the shelf (from point-of-sale data) and RFID-generated information of product in the backroom (i.e., tag reads in the backroom).

Given the sources of PI problems indicated earlier, how can RFID help? (See Table 2.) To improve inventory accuracy, RFID can be used to generate automatic inventory adjustments based on case receipts and case pack quantity. Additionally, RFID can be used to verify the accuracy of manual adjustments made by store personnel. With manual adjustments, one common mistake made by store personnel is to enter a quantity of zero when they believe no product exists in the store, yet, a case may be 'hidden' in the backroom. An incorrect 'zero' quantity causes two problems: (1) the inventory count is now understated; and (2) an order is issued by the system for unnecessary product. With RFID, the system will know if the product is in the backroom. Reduction in incorrect manual adjustments improves both overstated and understated PI problems.

PI inaccuracy causes	**Results in overstated PI?**	**Results in understated PI?**	**Can case-level[1] RFID reduce the error?**
Incorrect manual adjustment	Yes	Yes	Yes
Theft	Yes	No	Partial
Damaged/spoiled	Yes	No	Partial
Improper returns	Yes	Yes	No
Mis-shipment from DC	Yes	Yes	Yes
Cashier error	Yes	Yes	No

Table 2. PI Inaccuracy and RFID Remedies

[1] Only case-level tagging is considered here; item-level tagging is expected to correct other sources of PI inaccuracy. The situation of case pack size = 1 (i.e., case = item), if used on the sales floor and point of sale, would be considered item-level tagging and is not considered here.

For stolen items (i.e., unknown stock loss), RFID has the potential to partially help at the case level. For example, a case of product taken out the back door might indicate possible theft (RFID would read the box as it passes through the door). This insight can be used to adjust PI by the quantity of units associated to the case. However, RFID's ability to help improve PI at the pallet and case level by reducing or accounting for stolen items is limited. The biggest benefit related to stolen items will occur when RFID is used at the item level; thus, providing better insight into when individual items are stolen.

Similar to stolen items, RFID can help track damaged/spoiled goods only to the extent that the full case is put into the trash compactor containing an RFID reader. When this occurs, PI could be adjusted accordingly. At item level, RFID can help identify individual items as they are put into the trash compactor or other disposal units.

Returns create understated and overstated PI inaccuracy when not handled properly (e.g., two items are returned but not added to the PI count). At the pallet and case level, there is little RFID can do to help this situation. If individual items are tagged, then the system could read the items and adjust the counts as necessary.

Mis-shipments from the DC create both overstated and understated PI inaccuracies and can be corrected using RFID at the case level. Consider two potential scenarios. First, the wrong truck arrives at the wrong store. Without RFID, there is no way of knowing this error occurred until the truck is unloaded and the shipment verified. With RFID, as the truck is unloaded and boxes are sent through an RFID portal, the system could indicate (with a visual or audible signal) that the shipment was in error and either correct the receipts or provide an alert to reroute the load to its proper destination.

Second, for individual cases that were incorrect (rather than the entire truckload), the system would read and know what was received automatically instead of relying on the shipment documentation from the DC or manual barcode scanning.

Currently, RFID (at the pallet and case level) cannot counteract cashier error. Eventually, when items are tagged, this problem will be alleviated as items are read automatically rather than individually scanned by a cashier.

Overall, RFID has the ability to improve PI when used at the pallet and case level. In the future, with item level tagging, additional root causes of PI inaccuracy can be attenuated or eliminated.

Research Methodology

Scope

To investigate the impact of RFID on inventory accuracy, eight test stores and a matching set of eight control stores were used. Test stores were selected from the existing set of approximately 1000 RFID-enabled Wal-Mart stores. Control stores were then chosen based on a set of criteria used to determine a comparable profile, including demographics, size of stores (square footage), annual sales, the absence of known impacts such as annual inventories, remodels / resets, markets trials and other known disruptions. The sample contained a mixture of Supercenter and Neighborhood Market store formats.

Daily Inventory

From May through October 2007 (23 weeks), inventory in the air freshener category was hand-counted daily in all 16 stores. This daily inventory was necessary to determine the accuracy of PI during the study. A single category was chosen to provide the opportunity to tag all cases in that category (approximately 300 distinct items[2]). A national inventory auditing group was contracted to perform the counting.

The daily inventory of a particular store started at approximately the same time each day and the auditors followed the same pattern (i.e., start at bottom left, work to the right, then up). Thus, the same items were counted at approximately the same time each day in each store to eliminate any fluctuations in PI due to the time of day. Stores were generally counted between the hours of 4:00pm and 8:00pm.

Treatment

Test stores were equipped with RFID technology (readers/antennas) at various backroom locations (i.e., receiving doors, sales floor doors, box crusher). Control stores had no RFID technology. Test stores were provided with a 'PI-adjustment' (i.e., auto-PI) system that automatically adjusted understated PI. Other than the auto-PI system in the test stores (which worked automatically without human intervention), no additional PI manipulations were introduced as part of this study. That is, both sets of stores operated as business as usual and store personnel were instructed to carry out their jobs in the same way they would in normal situations. Thus, RFID (via auto-PI) served as a supplement to their existing process of adjusting inventory with the results of the study showing how effective RFID is beyond existing processes. Control stores were left untouched (i.e., no auto-PI adjustments) and store personnel were also not instructed to modify (increase, decrease) or stop their manual adjustments. To establish a baseline for PI accuracy, inventory was counted for 10 weeks before auto-PI was turned on.

[2] Approximately 98% of the items were tagged (at the case level); those that were not tagged were excluded from the study.

As discussed earlier, PI can become inaccurate by either being over or understated. For this study, Wal-Mart chose to manipulate only one side of the PI equation – i.e., understated PI (the situation where PI is less than actual on-hand inventory). Recall that understated PI is caused by such things as manual adjustments, errors when processing returns or sales, and mis-shipments from the DC or vendor. Using a series of business rules based on RFID data (from receiving doors and sales floor doors) and point of sale, the system made adjustments to PI automatically. No human intervention was necessary to correct PI (i.e., no special inventory or other manipulations were involved). For example, if PI indicated an on-hand quantity of zero, but the system registers a case of product (e.g., case pack size of twelve) in the backroom (i.e., an RFID read at the receiving door), then PI was adjusted.

Results

By Treatment

To determine the effect of RFID in the test stores, PI accuracy was calculated for each product for each day during the study's baseline and treatment periods by comparing the daily physical inventory count (i.e., on-hand) against the system's PI. For purposes of analysis, PI accuracy is divided into three categories: perfect (PI = on-hand); close (PI is within ± 2 units of on-hand); inaccurate (PI off by more than 2 units). Unless otherwise noted, we focus on the 'inaccurate' category.

During the course of the study, the PI inaccuracy in the test stores declined, as expected. However, an examination of only the test stores does not tell the entire story – to account for any changes that may have occurred without RFID, the control stores must also be considered. As shown in Figure 3, understated PI inaccuracy in the test stores decreased 13%, relative to the control stores. That is, the change in control stores was factored into the change in the test stores.[3] Specifically, the 13% is calculated by the following formula:

([Test stores post inaccuracy – Control stores post inaccuracy] – [Test stores pre inaccuracy – Control stores pre inaccuracy])[4].

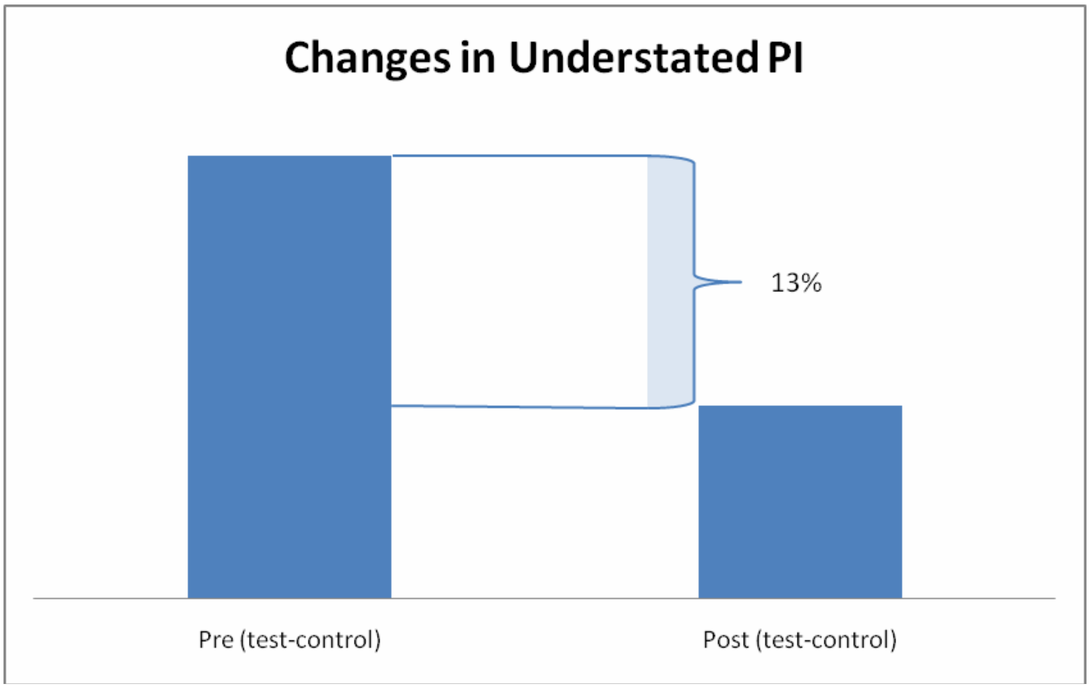

Figure 3. PI Improvement (Decrease in Inaccuracy)

The 13% change represents a significant decrease in PI inaccuracy from pre to post auto-PI deployment and a *real* reduction in the number of items with inaccurate PI.

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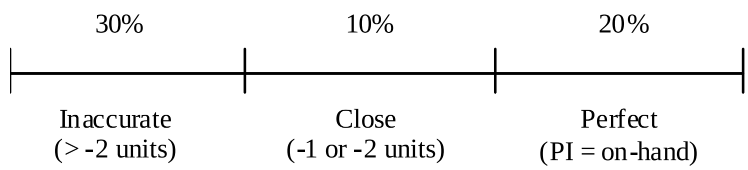
[3] Wal-Mart considers the precise indication of their inventory accuracy to be confidential. Thus, in an effort to show the improvement in PI due to RFID, yet conceal the actual accuracy of both the test and control stores, only the end result (13%) is shown.

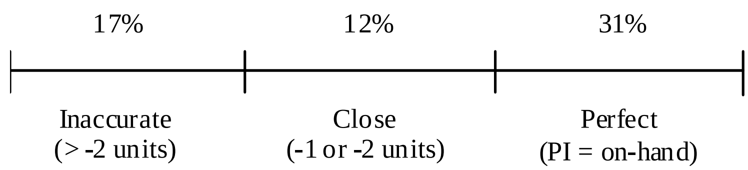
[4] The same value can be derived by using the formula: *([Test stores post inaccuracy – Test stores pre inaccuracy] – [Control stores post inaccuracy – Control stores pre inaccuracy])*

To understand the significance of the 13% decrease in inaccuracy and how it should be interpreted, consider the following example[5]:

Understated PI *before* auto-PI …



Understated PI *after* auto-PI …



As illustrated in this example, about 30% of the items had understated PI that was inaccurate, 10% were close, and 20% were perfect. After auto-PI was implemented, the percentage of items with inaccurate PI (off by more than two units) dropped 13% (from 30% to 17%, in this example), and the close and perfect categories increased to absorb the 13% decrease in the inaccurate category (in this example, 2% went to the close category and 11% went to the perfect category). Assuming 300 items, as found in the air freshener category, 90 items would have had inaccurate PI before auto-PI (i.e., 300 x 30%) whereas only 51 items would have inaccurate PI after auto-PI.

As the above example suggests, a decline of 13% is significant and impressive. To further put the 13% decline in perspective, we can compare this change with the

[5] Example values are fictitious and are used for illustration purposes only. The pattern of results, however, is consistent with actual results.

expected change (based on industry averages). As illustrated earlier, PI accuracy is generally between 35% and 50% (Gruen and Corsten, 2007; Kang and Gershwin, 2007). Let us, therefore, assume that PI accuracy is generally about 50%. Furthermore, we will assume that a large retailer will do a physical inventory one time per year and that the accuracy of this inventory is 100%[6]. From previous studies, then, we know that PI accuracy decreases over time (between physical inventories) (Kang and Gershwin, 2007). Therefore, during the year following a physical inventory count, PI is expected to deteriorate by about 50% (from 100% accuracy at physical inventory time to around 50%), resulting in approximately a 4% deterioration per month (50% / 12 months = ~4%). Also, as suggested earlier, understated and overstated are equally likely to occur. Subsequently, understated PI would be expected to deteriorate by about 2% per month (4% / 2 = 2%). Thus, based on previous studies using industry averages, the typical retailer could expect understated PI to deteriorate by about 2% per month (or, stated another way, PI inaccuracy to grow about 2% per month). Now, contrast this expected change (based on industry averages), with the findings in this study. During the study period, test store inaccuracy (relative to control stores) *decreased* 13% -- industry averages would suggest inaccuracy should have *grown* by 10% (2% per month x 5 months). Although these numbers are not directly comparable due to 13% being a relative measure and the 10% being an absolute measure, they do provide some insight into the importance of the 13% decline in inaccuracy.

[6] Note: it is unlikely that a physical inventory will yield 100% accuracy (DeHoratius and Raman, 2004; Kang and Gershwin, 2007), but we chose an estimate in this case that will yield a conservative outcome.

Manual Adjustments

One indication of the effectiveness of auto-PI is the decrease in inaccuracy, as previously demonstrated (Figure 3). A second indication of effectiveness is a reduction in manual adjustments. As indicated earlier, manual adjustments were allowed to continue during the course of the study. Thus, we can examine the quantity of manual adjustments for the pre and post auto-PI periods[7]; if auto-PI is doing its job, then manual adjustments should decrease.

As shown in Figure 4, manual adjustments in the test stores decreased from 3.4 manual adjustments per week per store to 2.0. Overall, RFID-enabled auto-PI reduced understated PI by 13% while simultaneously reducing the number of manual adjustments.

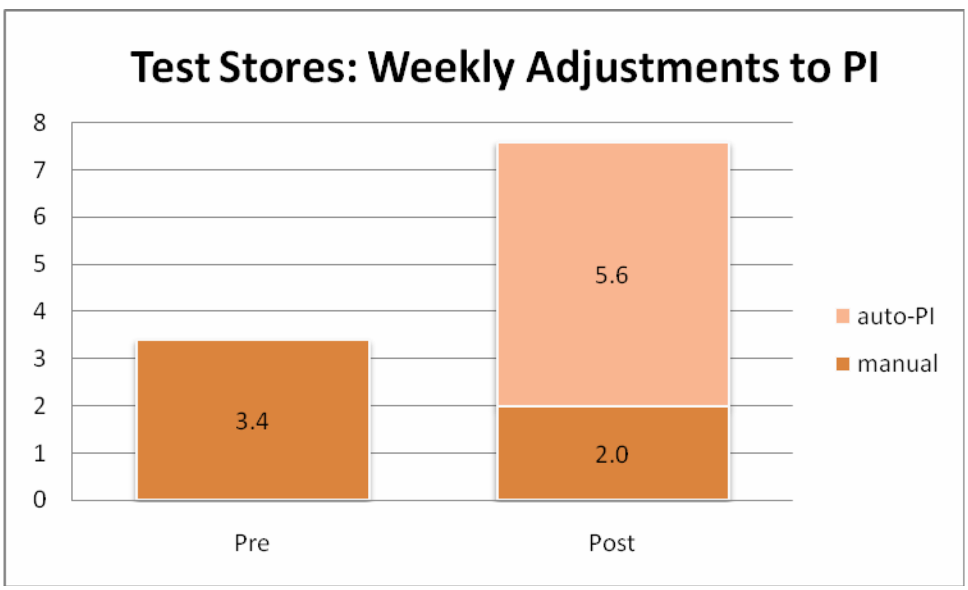


Figure 4. Average Weekly Adjustments to Understated PI (Test Stores)

[7] As indicated previously, the control stores did not receive treatments; rather, the same time frames are used across the two groups to provide a comparison.

The reduced manual adjustments were replaced by auto-PI adjustments (also shown in Figure 4). The total number[8] of auto-PI adjustments introduced during the study (approximately 5.6 per week per store) more than offset the decrease in manual adjustments and resulted in lower PI inaccuracy. Keep in mind also that the additional auto-PI adjustments (5.6 per week per store) were performed automatically without human intervention.

Discussion

The evidence presented herein is a preliminary surface-level analysis and is meant to provide initial insight into the effects of RFID on inventory accuracy. RFID appears to be making a difference. Simply by using RFID reads on cases that have entered the backroom, Wal-Mart was able to automatically adjust understated PI. As a result, the percentage of understated items off by more than two units declined by 13% (in the test stores, relative to the control stores). One could, however, argue that RFID is not needed to improve PI – one could simply increase the number of physical inventories and associated manual adjustments to keep PI accurate. This argument is logically sound – except, at what cost? Auto-PI almost doubled the number of adjustments being made. To double the number of manual adjustments would substantially increase the labor dedicated to this task and, thus, distract from stocking shelves or assisting customers, for example. Instead, as demonstrated in this study, PI accuracy was improved with no additional labor.

[8] Figure 5 shows the total number of adjustments; not the total number of products adjusted. It was possible that any particular product could be adjusted multiple times during the week.

Why is this RFID-enabled reduction in PI inaccuracy important? Understated PI can cause the system to order unnecessary inventory. This unnecessary inventory, in the form of safety stock ordered to cover the uncertainties in the supply chain, costs suppliers and retailers money and decreases the efficiency of the supply chain. Inventory inaccuracy is a form of uncertainty in the system. The (Q,R) inventory policy used by many retailers (where Q items is ordered when R items [reorder point] is reached) provides low stockouts and low inventory *if* PI is accurate (Kang and Gershwin, 2007). Because PI is often inaccurate, additional inventory is held to lower the risk of stockouts. The 13% decrease in PI inaccuracy found in this study can reduce inventory. What is the value of a reduction in inventory? For Wal-Mart and its suppliers, the payback is measured in millions of dollars.

In addition to reducing the PI inaccuracy based on RFID data, an RFID-enabled supply chain offers the opportunity to reduce those things that cause inaccuracy. As discussed earlier, item-level RFID provides additional opportunities to improve PI, beyond the benefits from tagging at the pallet and case level. For example, in the future using RFID, the checkout process can be more efficient and effective when every item has its own unique identifier. Unknown stock loss, one of the root causes of out of stock, can be known with more certainty. Ultimately, an improvement in overall PI accuracy could result in reduced stockouts and, thus, increased sales.

Overall, this study has examined and demonstrated how RFID can reduce PI inaccuracy. With more accurate PI, supply chains may be expected to operate more efficiently, resulting in lower costs, higher levels of in-stock, higher sales, and increased customer satisfaction.

Conclusion

Inventory accuracy is one of the keys to an efficient and effective supply chain (i.e., ordering, replenishment, etc. are based on an accurate inventory count). Yet, inventory accuracy is often poor -- about 65% wrong – thus, more wrong than it is right. RFID is a technology that provides promise in improving inventory accuracy. Subsequently, this study examined a very difficult and important question: does RFID improve inventory accuracy? To answer this question, the improvement in PI was studied during a 23-week period in eight test stores using a new RFID-based perpetual inventory adjustment tool and a matching set of eight control stores. The results suggest that, indeed, RFID is making a difference. Understated PI inaccuracy declined by about 13% in the test stores, relative to control stores, with no additional labor. Furthermore, manual adjustments declined in the test stores.

References

DeHoratius, N., and Raman, A., "Inventory Record Inaccuracy: An Empirical Analysis," University of Chicago Graduate School of Business Working Paper, August 2004, available at: http://bctim.wustl.edu/calendar/mediafiles/IRI04.pdf

Delen, D., Hardgrave, B., and Sharda, R., "RFID for Better Supply-Chain Management Through Enhanced Information Visibility," *Production and Operations Management*, 16 (5), September-October 2007, 613-624.

Gruen, T.W., and Corsten, D., *A Comprehensive Guide to Retail Out-of-Stock Reduction in the Fast-Moving Consumer Goods Industry*, 2007, available at: http://www.gmabrands.com/publications/docs/2007/OOS_fullreport.pdf

Kang, Y., and Gershwin, S.B., "Information Inaccuracy in Inventory Systems: Stock Loss and Stockout," *IIE Transactions*, 37, 2007, 843-859.

Hardgrave, B., Waller, M. and Miller, R., "Does RFID Reduce Out of Stock? A Preliminary Analysis," White Paper, Information Technology Research Institute, Sam M. Walton College of Business, University of Arkansas, 2005, available at: http://itri.uark.edu/research/display.asp?article=ITRI-WP058-1105

Hardgrave, B., Waller, M. and Miller, R., "RFID's Impact on Out of Stocks: A Sales Velocity Analysis," White Paper, Information Technology Research Institute, Sam M. Walton College of Business, University of Arkansas, 2006, available at: http://itri.uark.edu/research/display.asp?article=ITRI-WP068-0606

Heese, H.S., "Inventory Record Inaccuracy, Double Marginalization and RFID Adoption," *Production and Operations Management*, 16 (5), September-October 2007, 542-553.

Landoc, S., Garf, R., and Suleski, J., "Top 10 Grocery IT Imperatives: It Really is Now or Never," AMR Research, March 8, 2006, available at: http://www.acornsys.com/resources/downloads/top-10-grocery-imperatives.pdf

Morey, R.C., "Estimating Service Level Impacts from Changes in Cycle Count, Buffer Stock, or Corrective Action," *Journal of Operations Management*, 5 (4), 1985, 411-418.

Raman, A., DeHoratius, N., and Ton, Z., "Execution: The Missing Link in Retail Operations," *California Management Review*, 43 (3), 2001, 136-152.

Waller, M.A., Nachtmann, H., and Hunter, J., "Measuring the Impact of Inaccurate Inventory Information on a Retail Outlet," *The International Journal of Logistics Management*, 17 (3), 2006, 355-376.