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THE EFFECT OF CONVEYOR SPEED, PACKAGING MATERIALS, AND PRODUCT ON THE READABILITY OF RADIO FREQUENCY IDENTIFICATION TRANSPONDERS

By

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ABSTRACT

THE EFFECT OF CONVEYOR SPEED, PACKAGING MATERIALS, AND PRODUCT ON THE READABILITY OF RADIO FREQUENCY IDENTIFICATION TRANSPONDERS

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Since the first supplier mandates put forth by Wal-Mart and the Department of Defense, the use of (915 MHz) radio frequency identification (RFID) has been implemented into supply chains with mixed results. When working optimally, RFID can provide valuable information regarding inventory data and shipment locations. However, tag readability issues exist due to a variety of reasons: product and package interference, RFID equipment set-up locations, and even frequency allocations, depending on the country of use.

The purpose of this research is to determine if conveyor speed, packaging materials, and product have an affect on the readability of RFID transponders. The variables for this testing were conveyor speed (300 feet per minute (fpm), 600 fpm), package type (case of chips in plastic tubs, case of chips in metalized spiral wound fiberboard containers (MSWFC)), package shape (case of metal cans, case of metal bottles, and case of metal tins), product type (case of bottled ketchup, case of bottled motor oil) and tag generation (Alien Gen 1, Alien Gen 2).

The research found that conveyor speed, package type, package shape, and product type all had a significant effect on the average amount of tag reads per trial, Tag type was found to have a significant effect when testing the product effect, and package shape effect, but did not have a significant effect when testing the package type effect.

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CHAPTER 1 – INTRODUCTION

Radio Frequency Identification (RFID) technology is a tool that enables companies to efficiently track products in their supply chain. From raw material through the entire life of the product, RFID can provide valuable information regarding inventory data, shipment locations, and even product temperature.

RFID is a data collection technology that is able to communicate information from a tagged item to a computer system. For an RFID system to function properly it must be equipped with four items: a reader (also known as an interrogator), an antenna, a computer equipped with the proper software, and an RFID transponder (tag) placed on an item. Radio waves transfer data between the RFID tag and the reader, which are tuned to the same frequency.

The use of RFID in supply chain applications is currently organized by a worldwide standards organization known as EPCglobal. Undoubtedly one of the most important achievements of this organization was the completion of RFID Ultra-High Frequency (UHF) Generation 2 (Gen 2) protocol, which solved the readability problems associated with Generation 1. This protocol made it possible to read any UHF RFID tag using any UHF RFID equipment. Previously, when using Generation 1 protocol, tag readability was dependent on using one of the two main passive UHF classes, Class 0 or Class 1. A Class 1 tag could not be detected on a Class 0 reader/antenna set up and vice versa.

In the United States, RFID use is currently monitored by the Federal Communications Commission (FCC). The FCC determines both the frequency bandwidth and the power level allocated for use. These allocations have a direct effect on equipment performance and effectiveness.

The use of RFID for supply chain applications has grown immensely since the Wal-Mart mandate to their suppliers became effective January 2005. The mandate stated that the company's top 100 suppliers had to begin shipping select products headed for particular distribution centers (DCs) with RFID tags on each case and pallet. The reason for the mandate was simple: by improving product availability on the store shelves, and by being able to track the whereabouts of expected deliveries, Wal-Mart can improve store operations and increase profits. The Department of Defense (DOD) followed Wal-Mart's mandate with similar RFID requirements for their suppliers, recognizing the technology's ability improve product visibility especially in tracking dangerous and expensive supplies. Additionally, the Food and Drug Administration (FDA) has issued statements to both food retailers and the pharmaceutical industry asserting the desire for improved security within supply chains, to help prevent possible bio-terrorism attacks and to effectively recall products in the event of an emergency.

The use of RFID technology is by no means limited to the United States, as numerous retailers in countries around the world are also using RFID for supply chain applications. Companies in Europe have issued mandates similar to those of Wal-Mart and the DOD to their own suppliers. Tesco, Marks and Spencer, and Metro Group are some of Europe's largest retailers working with RFID technology in their stores and DCs. Additionally, Asian retailers and organizations throughout Japan, Singapore, South Korea, and China are working with RFID systems.

As is the case in the United States, both retailers and suppliers overseas are learning about some of the set backs inherent in RFID technology. For some implementers, RFID performance is hampered by regulations limiting the operation and frequency available for RFID readers. The frequency band allocated for UHF RFID differs from country to country and the amount of availability between 866 MHz to 956 MHz UHF band can have drastic system performance implications. Others working with the technology may find that their product or package absorbs or reflects radio waves, which can hamper their ability to meet mandates effectively, as well as their ability to use all the benefits RFID can offer.

There is no one specific method for using RFID technology, nor is there one specific solution to be applied across industries. For RFID to work most advantageously within an organization's supply chain, the implementer must think of each product on an individual level. An RFID tagged product, Product A will not function equally to a tagged Product B if there are differences in the product composition and the package system. Additionally, optimal tag type, tag location and orientation, antenna location and orientation, reader location and broadcast strength, and even the cord length between the reader and the antennae, are among the variables that implementers of the technology need to consider when trying to optimize the readability of an RFID tagged product.

In the event that a retailer has implemented RFID mandates to suppliers, both shipper and receiver must work collectively to optimize performance and usefulness in the supply chain. Specifically, the read location (where the tag is to be detected) can have a significant impact on successful RFID utilization. Suppliers will have to ensure that they have tested their product at each read point in the supply chain process in order to avoid failing to meet mandates which could lead to financial losses. Traditional read locations for RFID tags are warehouse dock doors, stretch wrappers and fork trucks, or conveyors. This thesis focuses on conveyors, since retailers such as Wal-Mart use UHF RFID systems to track product traveling on conveyors in their DCs from arrival, to storage, and to their eventual exit, bound for their destination point. With product traveling upwards of 600 feet per minute on conveyor lines, the amount of time for interaction between the mounted RFID antennae and the tagged cases is minimal. The purpose of this research is to determine the effect of conveyor speed on the readability of RFID tagged case goods in a typical warehouse environment. The null hypotheses for this research are:

- Conveyor speed will not have an influence on the average amount of tag reads per trial for RFID transponders
- Product will not have an influence on the average amount of tag reads per trial for RFID transponders on packages moving on a conveyor
- Packaging materials will not have an influence on the average amount of tag reads per trial for RFID transponders on packages while moving on a conveyor.
- Package shape will not have an influence on the average amount of tag reads per trial for RFID transponders on packages moving on a conveyor
- Tag type will not have an influence on the average amount of tag reads per trial for packages moving on a conveyor.

Although the effects of package, product and type of tag on read rates have been relatively well documented, the effect of conveyor speed, and its potential interaction with these variables has not been researched in detail. The outcome of this research will provide RFID users, whether they are implementing the technology into their own supply chain or merely meeting the mandates of retailers, with valuable information to consider when working with RFID tagged product on conveyors.

CHAPTER 2 – LITERATURE REVIEW

The Electronic Product Code

One of the most important advances aiding RFID technology and its use in industry was the development of the Auto-ID center. The Auto-ID center was a "non-profit collaboration between private companies and academia that pioneered the development of an Internet-like infrastructure for tracking goods globally through the use of RFID tags carrying Electronic Product Codes [EPC]".[1] When the Auto-ID center closed in September 2003, EPCglobal, a non-profit organization, was set up to continue the work of developing the use of RFID to produce more visibility and efficiency throughout the supply chain. EPCglobal is achieving this goal through the Electronic Product Code Network™. This network is to serve "as the global standard for immediate, automatic, and accurate identification of any item in the supply chain of any company, in any industry, anywhere in the world". [2]

The EPC is the primary information of concern stored on the RFID tag's microchip. Used for recognition, the EPC assigns a numeric identification to each packaging unit whether it is an item, case, or pallet. The number used in the EPC consists of four parts: a Header, a Manager Number, an Object Class, and a Serial Number. The Header identifies length, type, structure, version, and generation of EPC. The Manager Number identifies the company that owns the product. The Object Class Number represents the stock-keeping unit (SKU), while the Serial Number is assigned to identify each individual case. [3] The EPC by itself gives no more information about a product than a car's license plate tells you about the car. To decode information contained in a particular EPC the computer is directed to information located at an internet address. The Object Name Service (ONS) is an automated networking service that points computers to sites on the World Wide Web. Once the information is located it can be forwarded to a company's inventory or supply chain data.[2]

Generations

Assembled by more than 60 of the world's leading technology companies, EPCglobal recently presented an RFID UHF Gen 2 protocol. This protocol describes the core capabilities required to meet the performance needs set by the end user community.[4]

Until the recent ratification of a Gen 2 standard, various vendors (and their end user customers) had adopted incompatible EPC technologies (EPC Version 1), including EPC Class 0 and Class 1.[5] There are two separate components in a tag class: the air protocol (how the tags communicate) and the programming technique (how the tags get their data). Class 0 and Class 1 tags use different methods in their approach to RFID communication, and thus have different performance capabilities.[6] Class 0 tags use air protocol developed by Matrics, Inc, (Now Symbol Technologies), and Class 1 tags use air protocol developed by Alien Technologies. The implications of having two different protocols are straightforward: simply because a product is equipped with an RFID tag does not mean that it can be recognized by an RFID system. A Class 0 tag will not read on a RFID system designed for Class 1 tags. Gen 2 is an Air to Air Protocol that allows communication between the tag and reader irrespective of the equipment manufacturer.

The benefit of Gen 2 is that it offers specifications and regulations that can be applied across the world. Gen 2 offers RFID users the assurance that no matter which type of tag comes through their doors, their readers will be able to detect it. The new EPC Gen 2 standard supports an increased frequency range and regulatory requirements promoting adoption in the US, Europe and Asia. Gen 2 includes password-protected mechanisms to ensure data safety and a kill feature to ensure consumer privacy protection. [7] Gen 2 has the ability to work in dense reader environments, making it optimal for distribution centers loaded with inventory. Additionally, Gen 2 allows users to read and write data multiple times to the same RFID tag. [8]

It is thought that with a global standard set, Gen 2 will create more competition in the market place, hence lowering the price of RFID equipment and tags. Additionally, in some cases, costs of RFID materials are decreasing. "Physically, the silicon [with Gen 2] becomes smaller, and that's one of the assets that makes it cheaper," said Scott Medford, vice president of RFID at Intermec Technologies Corp., an RFID hardware and software manufacturer that participated in Gen 2 specification development. With Gen 2 comes more than just cost benefits. "It has a lot more selectivity, which means that there is less reader on reader interference. In addition, claims have been made hyping Gen 2 to be five to 10 times faster than Gen 1". [8] In most cases Gen 2 readers are capable of reading Class 0, Class 1 and Gen 2 tags, easing the transition for those moving away from Gen 1 systems.[9]

Although Gen 2 offers many positive features necessary for a global RFID deployment, some companies are reluctant to move on from Gen 1 at short notice. "In practical applications, Gen 1 and Gen 2 hardware performance will be comparable. Gen 2 has gained a lot of intrigue and interest, but it hasn't changed the fundamental laws of physics. It is still UHF, with all the benefits and drawbacks that that brings," says Tom

Pounds, vice president of corporate development at tag and reader maker Alien Technologies.[5]

Another avid participant in the Gen 2 specification development, Impinj, a Seattle- based chip manufacturer, states that Gen 2 buyers need to be aware of what type of reader is right for their application. EPCglobal plans to certify three different levels of Gen 2 compliant readers. “At the lowest level, readers will be certified to work only when there are no other readers within a 1 km radius. The next level will be for readers capable of being deployed with several readers within a 1 km radius. The highest level will be certified to work alongside 50 or more readers within a 1 km radius”. Impinj’s founder and chairman, Chris Diorio, is convinced that users have to get educated that not all EPC compliance is the same. If you can upgrade only to the lowest grade, you are not going to get multi-reader performance.[10]

The Gen 2 standard put forth by EPCglobal is royalty-free. The organization engaged legal counsel to examine claims made by Intermec Technologies, a RFID systems provider, which claims the Gen 2 spec contains intellectual property that it has patented. It was concluded that Intermec’s patents are not essential to implementing the Gen 2 standard. However, Intermec President Tom Miller concluded, “it is important to remember the claim of a royalty-free protocol does not mean the UHF RFID products will be royalty-free, we believe companies who offer UHF RFID products will still require a license to use Intermec intellectual property” .[11] It is the hope of EPCglobal and RFID companies alike that possible intellectual property battles with Intermec will not slow down the development of Gen 2 technology and implementation.

RFID Tag Classifications

A wide variety of RFID tag types currently exist, each with different capabilities. Although current RFID mandates focus on passive RFID tags, other tag types such as semi-passive and active tags exist. As opposed to passive tags, semi-passive and active tags contain their own source of power, a battery. These types of tags tend to be used for tracking large or expensive items. In contrast, passive tags are powered by the electromagnetic waves transmitted from the RFID reader. These RF waves carrying data induce a current in the tag's antenna, powering up the accompanying microchip which contains information that is sent back to the reader (**Figure 1**). Passive tags are currently being used for case and pallet application for inventory tracking purposes, but can also be used for tracking children in amusement parks, skiers on mountains, luggage in airports, and sports race timing. [12]

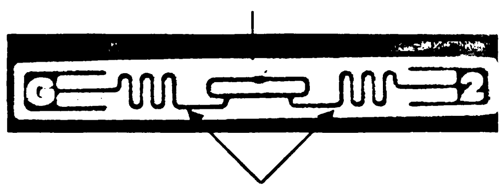


Figure 1: ALL-9440 "Gen 2 Squiggle™" Class 1 Tag with Description of Parts

Multiple variations of passive tags exist. To help understand an RFID tag's capabilities, the tags are placed into certain generations and classes. Gen 1 Class 0 RFID tags are the most basic passive tags, arriving to the end user factory programmed and in a read-only format. "Read-only is a term used to describe RFID tags that contain data that cannot be changed unless the microchip is reprogrammed electronically". [1] Gen 1 Class

0+ and Class 1 RFID tags are known as Write Once Read Many (WORM) passive tags, which allow end users to program the tag as opposed to the tag arriving preprogrammed. Gen 1 Class 0, 0+, and 1 tags have all been approved for meeting the mandates put forth by Wal-Mart and the DOD. Gen 1 Class 0 tags can contain either 64 or 96 bits of memory, while Gen 1 Class 0+ contain 96 bits of memory. Gen 1 Class 1 tags contain 96 bits of user programmable memory. [13, 14] With the current movement towards Gen 2 it is important to note the emergence of Gen 2 tags. Gen 2 tags offer 128 bits of user programmable memory.[12]

RFID in the United States

RFID technology and its use in the United States is monitored and regulated by the FCC. The FCC has set aside rules for the use of RFID in the Code of Federal Regulations, specifically 47 CFR Part 15, which is reserved for low power devices. Since these devices are low power, owners and operators do not require a license to operate the machinery. However, it is required that RFID readers must meet the FCC's emissions limitations and power restrictions. The FCC classifies RFID readers as intentional radiators, and therefore they require certification by the FCC. This certification process is generally performed by the manufacturer of the reader. After the certification process the reader is properly labeled and can be marketed and operated in the U.S. [15]

Should the purchaser of the certified reader make changes to its operational capabilities, FCC rules state that the modifying party automatically becomes responsible for complying with the FCC standards. Should the modifying party make changes to the power level or otherwise alter the equipment, they are subject to sanctions and monetary forfeitures if the reader is not recertified.

The certification process is important because it ensures the performance of RFID technology from being hampered by readers interfering with one another. The more unlicensed devices in operation, the more likely it is that interference will occur. To encourage licensing, the FCC has imposed sizeable monetary fines on various parties who operated noncompliant Part 15 devices.[16]

UHF RFID systems operating in the U.S. use a frequency allocation between 902 MHz and 928 MHz, providing 26 MHz of bandwidth. UHF readers are allowed to operate at 1 watt and can go up to 4 watt if they have directional antennae and if they hop across at least 50 channels.[15]

With the use of RFID increasing in the U.S., both federal and state governments have introduced RFID privacy bills. Most bills deal with requiring retailers to notify customers when RFID tags are on the products they are purchasing, and to remove tags at the point of sale.

The Wal-Mart Effect

Wal-Mart was the first retailer to realize the possible cost savings that could be attained by using RFID technology in its supply chain and distribution centers. In June of 2003, Wal-Mart mandated that its top 100 suppliers would have to ship selected pallets and cases RFID-tag-equipped beginning January 2005. In this trial run, Wal-Mart selected 3 of its 99 U.S. distribution centers to receive these tagged shipments. [17] By late 2005, the company extended its trial run to include a total of five distribution centers.

Later, the mandate was expanded to include an additional 200 suppliers to ship their pallets and cases RFID-tag-equipped by January 2006.

The product receiving process begins at Wal-Mart's regional distribution centers. When tagged cases and pallets arrive they are scanned by a reader and antennae set up near the distribution center's dock doors. Data about the shipment are collected and sent to Wal-Mart's operations and merchandising teams. Additionally, the supplier is notified within 30 minutes, through a website that links retailers to real time data, that a specific shipment has arrived.[18] The next step that occurs at the distribution center is pallet disassembly. Cases are removed from their pallets, placed onto conveyors, sent through another RFID read point on the conveyor line, and placed into storage. When product is needed at a Wal-Mart retail center, order pickers in DCs gather the required cased goods, and place them back onto conveyors at the end of which products are re-palletized and shipped out via truck. This re-palletizing of a variety of products allows the Wal-Mart retail center placing the order to receive exactly what they need for restocking purposes. Wal-Mart aims to read 100 percent of all tagged pallets entering through distribution center and store dock doors, as well as 100 percent of all tagged cases on conveyors within the distribution centers.[19]

After more than a year of receiving tagged shipments from suppliers, Wal-Mart determined that the technology provided a 16 percent reduction in out-of-stock merchandise and a 70 percent drop in the time it takes to receive new shipments from suppliers. The key to the vast improvements arose from in-store inventory tracking. Prior to receiving RFID tagged shipments, knowing when to restock shelves at Wal-Mart was based on visual observation. Now, Wal-Mart associates receive shelf restocking data that are linked to real time product sales. Ensuring that Wal-Mart stores are receiving the desired product from their distribution center is critical to avoiding out-of-stocks and empty shelves. Using RFID technology allows Wal-Mart to know specific details about when product arrives at their distribution centers, and how long it takes for the product to be redirected. "Wal-Mart was able to determine that a particular product arrived at its distribution center on Aug. 4, that it was put on the conveyor system five days later and that it departed shortly thereafter. Upon arrival at the store (12 hours after it left the distribution center), the product was whisked to the store's back room and moved to the sales floor the following day".[20] This type of information could help improve inventory turnover, determine distribution center efficiency, and track bottlenecks in the supply chain.

With the arrival of Gen 2 equipment and tags, Wal-Mart has decided that as of July 2006 they will no longer accept EPC Gen 1 tags on cases and pallets received from suppliers. Internal tests performed at Wal-Mart determined that EPC Class 1 Gen 2 tags showed improved performance compared to their Gen 1 predecessors. Wal-Mart polled suppliers and concluded that most could be ready to deploy Gen 2 tags by the second quarter of 2006.[21]

What's the Business Value of Reading or Not Reading a Tag?

The business-value of reading (or detecting) tags at checkpoints throughout the supply chain are numerous. For the supplier merely meeting the mandates, tag readability on both pallet and case loads are critical to ensure they receive payment for their shipments. If the retailer doesn't know it has received a supplier's shipment (the RFID tag on the pallet or case load isn't detected), the retailer doesn't know it has received any product, and therefore, would not likely pay for the product. Additionally, tag reads are crucial for the retailer because it makes them aware of product availability, and therefore, can help to avoid dreaded out-of-stock situations.

Meeting the Mandate

Suppliers to retailers such as Wal-Mart have more often than not applied a "slap and ship" approach to tagging their products with RFID tags. In this approach, placing RFID tags on the case and pallet is done in the final stages of the manufacturing and distribution process. With this "slap and ship" approach, at no point does the supplier attempt to use the RFID-tagged goods for their own internal purposes, thus creating nothing more than an additional cost to the supplier. This cost ranges from 7.9 cents for an inlay to 12.9 cents for a self-adhesive tag for orders of 1 million or more.[22] Smart suppliers will try to take advantage of the benefits of RFID, especially by tagging product early in the manufacturing process.

One such example comes from Paramount Farms, the world's largest supplier of almonds and pistachio nuts. Paramount owns 50,000 acres of orchards and processing facilities, and is responsible for growing about 60 percent of the U.S. pistachio crop. To meet its pistachio needs, Paramount also networks with nearly 400 grower partners. "In our average harvest season, incoming green product totals a half a billion pounds over a six-week period. Given this time constraint, as we increase our production goals, our efficiency and productivity must likewise increase," said Andy Anzaldo, director of grower relations at Paramount [23].

After forming a committee within Paramount to brainstorm ideas about technology features necessary to make the processing job easier, it was determined that the Grower Receiving System would need to provide multi-site distribution of information from a central server at Paramount Farms. This could easily be done in a web based environment, and allows the company's two pistachio processing plants, as well as its sales and marketing offices in Southern California, to access the system with only an Internet-compliant browser.

Productivity was enhanced by providing growers with handheld computers, access points, and RFID tag readers. Load processing time at Paramount Farms' pistachio nut farms was improved by 60 percent. As processing time decreased, Paramount noticed an increase in revenue. The receiving department became so efficient at equipment logistics that it reduced leased trailer usage by 30 percent. "We are more confident than ever of our data system's integrity and the accuracy of the information, since more of the data is collected using radio-frequency tags and barcode scanners," said Mr. Anzaldo. [23]

Paramount receives 20 million pounds of product per day for recording, weighing, pre-cleaning, sampling, and processing. RFID-tagged trailers filled with pistachios arrive and are interrogated by a reader. The reader captures the tag's unique identification number and wirelessly transmits it to the central server. The database relays the pre-recorded profile of the identified trailer back to the scale house worker's mobile computer. Now the worker knows the trailer's net weight, license plate number, equipment number, and owner name. Next, the scale house workers take the product load details. The grower name, ranch, field, product temperature, and harvest method are all sent wirelessly to the database. The trailer's gross weight is automatically retrieved from the truck weigh scale and a weight certification is printed. During processing, the nuts are cleaned. Sifters remove foreign debris such as leaves and branches. The Grower Receiving System automatically weighs the debris, subtracts it from the original load weight and sends the corrected weight to the database. [23]

Both weight and quality play a role in the amount a grower gets paid. An automatic sampler scoops 20 pounds from each 50,000-pound load for quality testing. While this sample is peeled, hulled, dried and tested, the rest of the load travels on to the main processing line, where it is mixed with the rest of the day's harvest. This mass of nuts is processed and stored within 24 hours. Sample testing determines the grade of the nut, and the pay rate to the grower. "It's imperative for us to ensure that the volume and quality we pay for is the volume and quality we receive. Our new Grower Receiving System helps us do all these things" [23].

The Paramount Farms RFID implementation is an excellent demonstration of a supplier employing RFID early in the manufacturing process to attain a return on investment (ROI). If the Wal-Mart mandate were to include products from Paramount Farms, the company's familiarity with the technology and ability to attain a profit from its use would make tagging shipments not nearly as painful as it would be to a company utilizing a "slap and ship" approach. In fact, tagging retailer-bound shipments will provide even more traceability to the Paramount Farms outgoing supply chain, shedding light on other areas of the product life cycle that could be improved. A likely impact of incorporating the use of RFID into a supply chain will be RFID working its way into the supplier's own vendor supply chain system. This will increase the demand for RFID tags and result in lowering the cost per tag.[24]

The Department of Defense

The United States DOD also recognized the benefits that RFID technology could provide in terms of logistics support, asset management, and overall supply chain optimization. Another advantage is hands-free data capture, which allows efficient recording of material transactions. In July of 2004, the DOD released requirements to their suppliers. The Defense Federal Acquisition Regulations Supplement (DFARS) became effective in November of 2005 and required suppliers to affix passive RFID tags at the case and pallet level for shipments of certain commodities to two specific locations: Susquehanna, PA, and San Joaquin, CA. The commodities included four classes of supplies: Shipments of Packaged Operational Rations, Clothing/Equipment/Tools, Personal Demand Items, and Weapon System Repair Parts.[25] In 2006 the tagging requirements added three more classes of supplies and an additional 19 locations. By 2007 all locations will be instrumented and all classes of supply will require RFID tagging.

The Food and Drug Administration

The FDA is asking food retailers for help against the war on terrorism by keeping detailed data about the food shipments in their supply chain. The agency announced that it is the responsibility of everyone in the food supply chain to keep logs of where they received food from and where they shipped it to.

If contamination in the food supply chain takes place, companies must be able to make their records available within 24 hours if the FDA has reason to believe that an article of food presents a serious threat. During his resignation speech, Tommy Thompson, Secretary of Health and Human Services, may have prompted the new policy when he made reference to the ease of attacking the country's food supply. [26]

RFID stands to play an important role in helping food retailers improve their supply chain records. "When you take a supply chain like ours, operating close to 100 facilities with products going through multiple facilities, it will obviously require some additional technology," says Scott McWilliams, CEO of Ozburn-Hessey Logistics, which deals heavily in food storage relations. With the ratification of Gen 2, RFID solution providers should be excited about the new FDA mandates. RFID is capable of being the technology of choice for food retailers, allowing them to meet FDA standards while offering improved traceability of their products in the supply chain. Food retailers, manufactures and distributors have until January 2006 to bring their operations into compliance with the ruling. [27]

The FDA has also been vocal in their desire for the pharmaceutical supply chain to become more secure, and has endorsed the use RFID to combat the growth of counterfeit drugs. A Finnish drug maker, Orion Pharma, recently performed a trial tracking passive tags on the cartons of individual bottles of drugs as they moved through the supply chain. The test stemmed from the anticipation of stricter policy in the United States with respect to tracking medication.[28] The FDA desires that each product moving through the supply chain have an electronic pedigree (e-pedigree) that shows each bottle's chain of custody. Specifically, an e-pedigree is a secure file that stores data about each move a product makes through the supply chain, thus helping reduce counterfeiting of drugs while improving supply chain safety. It is the goal of the FDA that RFID technology be used widely throughout the pharmaceutical industry by 2007 to improve security and safety. Until the Orion Pharma trial run, the only pharmaceutical companies to actively test and report data were Purdue Pharma and Pfizer. Purdue Pharma performed "the pharmaceutical industry's first electronic drug pedigree using RFID tags to match each bottle of a drug with a corresponding record detailing the drug's movement through the supply chain".[29] Pfizer's use of RFID tags concentrated on allowing wholesalers and pharmacies to verify that the product they were receiving was genuine, but did not focus on the tracking aspect utilizing e-pedigrees. [30]

European Adoption:

RFID technology is not limited to suppliers and retailers in the United States. In Europe, companies like Tesco, Marks and Spencer, and Metro Group have implemented RFID technology into their supply chains. European companies have been using RFID for tracking reusable containers for years, albeit utilizing both low frequency and high frequency. Since UHF is the accepted frequency for most pallet and case level supply chain applications, a bandwidth of 866 MHz to 956 MHz is available for use. Since regulations governing the use of the radio spectrum differ across the globe, ease of implementation and use varies accordingly. For UHF applications, the European Radio Communications Office (ERO) and the European Telecommunications Standard Institute (ETSI) of the European Union has specified a range from 865.6 MHz to 867.6 MHz. The FCC determined that companies in the United States are able to use between 902 MHz and 928 MHz. Although 26 MHz of bandwidth in the United States versus 2 MHz of bandwidth in Europe may seem insignificant, "think of data from tags as cars driving on a two-lane highway in Europe, compared to a 26-lane highway in North America. Simply put, European companies are not going to get the same performance from their UHF systems as their North American competitors".[31] John Clarke, chief technology officer of Tesco, claims the European deployment of EPC RFID is slowed greatly by regulations limiting the operation and frequency available for RFID readers. European readers use a listen-before-talk function that can limit the time a reader can operate if there is too much activity or noise in the same radio frequency spectrum. Another aspect that impedes European RFID technology functionality are the lower power limits which reduce an antenna's read field.[32]

For U.S. companies planning to deploy RFID in Europe, testing the reader at the European frequency can be difficult while on U.S. soil, since the spectrum is currently used for police telecommunication. Conversely, European companies testing RFID readers operating at the United State's frequency can encounter interference with wireless phone handsets.[32]

European Retailers:

In April 2004 Tesco, the United Kingdom's largest retailer, started tagging cases of non-food items at its distribution center, and tracking them to their retail stores. The company's approach differs slightly from that of Wal-Mart, who had their suppliers provide the tagged product for tracking purposes. Tesco plans to have suppliers ship their goods tagged but has not set a deadline when all suppliers must tag their cases. As of April 7th 2006, 40 of 1400 Tesco stores are equipped with RFID technology. Tesco has stated that complications from using UHF RFID under European Union Regulations have slowed its attempts to make full use of the technology. Nevertheless, Tesco's research proved to them that RFID could provide "greater supply chain visibility and simpler processes for its staff, while resulting in improved product availability, better service and cheaper prices for its customers".[33]

Marks and Spencer (M&S), a United Kingdom retailer of clothing, food, and home products, began testing RFID's capabilities in 2003. The preliminary trial concentrated on placing tags on clothing items, specifically men's suits, shirts, and ties. By 2004, M&S expanded the operation to nine stores, but decided to concentrate only on tagging men's suits. After three years of testing, as of spring 2006, M&S has decided to extend the RFID trial to 53 stores and encompass additional articles of clothing. M&S has determined that by using RFID they are more aware of their inventory and have reduced the time it takes to record inventory by 7 hours per week for a single store. Additionally, constant inventory updates ensure that a full range of sizes is available for any product. In addition to finding the right size, customers are provided with an informational label advising consumers that the RFID tag on the clothing is being used by M&S for stock-control purposes. In addition to informative labels, as well as pamphlets posted around the store, M&S offers to remove the RFID tag at the checkout counter. These methods appease most issues raised by consumer privacy groups in regards to the RFID tagging of products. M&S surveys have concluded that most consumers do not even recognize the RFID tag on the items, but recognize improved product availability.[34]

The third largest retailer world-wide, Metro Group, began utilizing RFID in its supply chain in November 2004. Metro Group wanted to focus on tracking incoming and outgoing shipments, and automatic reconciliation of shipments with shipping documents across three retail sales divisions. The three divisions bring in a variety of products. Metro's Cash and Carry (groceries/general merchandise), Kaufhof (department store), and Real (hypermarket) began receiving tagged shipments from 20 suppliers in total. These shipments included groceries, general merchandise, textiles, and apparel.[35] In addition to using RFID in supply chain trials, Metro recently took up more than 30,000 square feet at a German electronics fair, allowing attendees to see the real life applications of RFID in their everyday life. Metro Group simulated a future store, which contained RFID technology on shopping carts, scales, clothing racks, and check-out stations. Other areas demonstrated RFID technology's ability to help out the consumer at home. RFID equipped washing machines, microwaves, and refrigerators were all a part of the future home demonstration, all designed to make everyday chores less time consuming.[36]

RFID in Asia:

Countries in Asia have also begun allocating UHF ranges for RFID. Through the Ministry of Public Management, Home Affairs, Posts, and Telecommunications, Japan has allocated 6 MHz of bandwidth from 950 MHz to 956 MHz for UHF reader operation. One particular Japanese electronics firm, NEC Tokin, plans to sell EPC Gen 2 readers for use in the Japanese market.[37] The company worked in part with Impinj, a Seattle-based semiconductor manufacturer. Companies in Japan have been eager to show off the future applications that RFID technology can offer. In January 2006, Mitsukoshi Ginza department store (owned by Fujitsu) performed a pilot in which 5000 pairs of jeans were tagged for inventory management and improvement of store operations. The jeans were then placed on smart shelves, which allowed employees to monitor what is available for the customer, and also what sizes they had in stock rooms. Additionally, the pilot included six smart fitting rooms, which provided the customer with information about the clothing they were trying on, what sizes were available, as well as outfit ideas and accessories that the customer might be interested in based on what they had brought into the fitting room.[38]

South Korea is another Asian country that is supporting the growth of RFID and its use in industry. Currently South Korea has set aside between 910 MHz and 914 MHz for UHF reader operation. In 2004, GS1 Korea organized an RFID pilot project with Samsung Tesco, a large Korean retailer. The objective of the pilot was to determine technical reliability using EPC standards. Benefits identified in the pilot included accelerated receiving and shipping with less human intervention.[39] Other RFID progress in South Korea is currently being provided by Sun Microsystems. The company is developing a RFID test center in Busan, South Korea, in collaboration with Busan National University (BNU). BNU is known for the focus on manufacturing in their curriculum, and Sun Microsystems hopes that the university will attract local manufacturers to the RFID test center.[40]

Singapore has recently enacted legislation that increased the spectrum for UHF RFID systems from 920 MHz through 925 MHz. Infocomm Development Authority (IDA) believes the added bandwidth will improve the performance of RFID technology in Singapore by reducing read-errors because systems will be able to select from more channels to achieve less interference. IDA has reported that over 25 companies use RFID in their supply chain, all of which have combined to invest over 16.5 million dollars in RFID projects[41].

The Chinese government has shown great interest in RFID technology, but is undecided on whether to cooperate with non- Chinese standards organizations. The Standardization Administration of China currently has plans to make its own RFID standard to protect its information security and enterprise interests, but will consider compatibility between its own and foreign standards. The Chinese government has not fully authorized frequencies for RFID use in China.[42] While standards talks continue, RFID research is being carried out throughout China. Dan Dingyi, deputy director of China Logistics Network Alliance, says that RFID had been widely adopted in a large variety of fields including anti-counterfeiting systems, traffic monitoring, logistics, and manufacturing.[43]

Retailers are also becoming involved with RFID in China. Bailian Group, one of China's largest retailers, has developed plans for the second phase of the China Implementation Reference Project. The program seeks to expand usage of EPCs and RFID. The second phase will track the movement of actual products tagged with EPC-enabled RFID tags. Bailian is talking to suppliers based on their level of interest in integrating RFID technology into the supply chain. Participating suppliers will tag shipments in their originating distribution centers, and send those shipments to a Bailian Group distribution center in Shanghai. The movement of these products will be recorded, enabling all participants to gain a more accurate view of inventory levels.[44]

RFID Read Locations:

It is evident that retailers, suppliers, and organizations are working with RFID systems across the globe. However, at what point in the supply chain implementers determine to set up an RFID system to gather data, known as read point or location, varies. In retail applications, an obvious point to set up an RFID system and collect data is by a dock door. The purpose of a dock door is to provide a medium where all products arrive and depart, making it an excellent location for tracking inventory. Generally, a portal contains, but is not limited to, four antennae positioned in various locations around the door, in order to accurately detect tags entering and exiting the facility.

A shrink wrap station is another typical data collection point. This is an excellent data capture point because most stretch wrappers offer 360 degrees of visibility of the product (more importantly, of the tags), and, the stretch wrapping process takes more time than walking through a dock door, which increases the chance that all tags are detected. Multiple stretch wrap machines exist, and how they operate determines where the RFID system will be set up. In some instances, a portal similar to that used in the dock door situation can be placed around the stretch wrapper. Other stretch wrap machines are equipped with an arm that rotates around the pallet, in which case an RFID antenna can be affixed to the arm itself.

Fork trucks, used to transport product into, out of, and within warehouse facilities, provide another medium for an RFID system placement. An antenna placed on the front of the fork truck is capable of reading the tags located on the pallet load, ensuring that drivers are carrying the correct product and placing it in the desired area, whether it is the back of a destination-bound truck, or in storage.

Of all the examples discussed, dock doors, stretch wrappers, and fork truck read locations focus on the detection of products on a unit load, like a pallet. Unit loads generally contain a large number of case loads, which contain the individual product(s). During the distribution process these case loads either need to be placed onto, or removed from, the unit load. DCs generally utilize conveyors, defined as "a mechanical apparatus that transports materials, packages, or items to be assembled from one place to another" to move the case loads to and from storage.[45] Conveyors offer an excellent location for a RFID read point by confirming that the correct case has been pulled from storage, and is bound for the correct re-palletization area.

Types of Conveyors

Conveyors generally operate by using either gravity or power to move an object from point to point. A wide variety of conveyors exist, each performing a specialized function. Some of the most common types of conveyor are those containing either a belt or roller bars.

A belt conveyor is composed of either "fabric, rubber, plastic, leather, or metal which operates over suitable drive, tail end and bend terminals".[46] Belt conveyors are versatile, provide a continuous flow of product, and are low maintenance. They are mainly used for carrying units, cartons, and bags. However, a modern-day example is the use of the belt conveyor as a people mover in high traffic areas such as airport terminals.

Roller conveyors tend to use gravity for product movement. On a roller conveyor the load is supported over a series of rolling bars, turning on fixed bearings that are mounted between side rails at fixed intervals. Product moving on a roller conveyor requires three rollers under the load at all times. Product movement is controlled by gravity; therefore, heavy loads on roller conveyors can be dangerous, they could accelerate beyond control. Slides in parks for children are often built in roller bar conveyor form, because the acceleration due to gravity can be a source of excitement[46].

A wide variety of other conveyor types exists, including bucket, chain, chute, pneumatic, screw, vibrating, and wheel conveyors. Although they are mainly used for material handling, conveyors also function throughout society as people movers. Ski chair lifts on mountains are another functional example[14].

Conveyor Use and Research

It is almost inevitable that a package will travel on a conveyor at some point during the manufacturing and distribution process. Since tracking product movement is one of the key aspects of RFID, it is important to determine if RFID antennae are able to track tagged packages on conveyors. Cases on a Wal-Mart conveyor can travel up to 600 feet per minute. Being able to read tagged cases on conveyors is important because it ensures that Wal-Mart stores are receiving exactly what they ordered from their distribution centers. Supply chain analysts have concluded that achieving 100 percent readability on conveyors is not always possible, especially when the cases contain product or packaging with high water or metal content.[47] Recent figures indicate that Wal-Mart is currently reading 95% of tagged cases traveling on conveyor, which is 5% less than their goal.

In a study performed by the RFID Alliance laboratory at Kansas University, RFID researchers brought tagged cases into an operational Kansas City distribution center and studied case readability on a conveyor. Testing was conducted on five cased goods:

paper, bottled water, canned food, dishwasher detergent, and liquid hand soap. Tags were placed on cases at a position that gave the best tag performance although how this was determined was not discussed. The test was performed on a conveyor equipped with a flat metal sled covered by a belt, which operated at 204 feet per minute (fpm). For this test, the researchers placed three different tags on three different cases of the same product. They randomly selected the tags but placed them at the same optimal position. Two types of readers were used for the test, the Matrics AR400 reader and the Alien 9780 reader. Each reader was connected to three antennae arranged so that one was on each side of the conveyor 5' apart and one was 42" above the conveyor pointing down. The reason the antennae were set up in this manner was to closely simulate what is being done by major retailers.

The results of the study were not released; however, the RFID Alliance Group did make some general hypotheses about the relationship between conveyor line speed and the readability of RFID tags. The group hypothesizes that, as line speed increases, tag performance will decrease because the tag is in the reader field for a shorter period of time. Specifically, the group claims that, to achieve the same read rates at 600 fpm as at 200 fpm, the reader's power settings would need to be increased by as much as 4 to 5 dB.[48]

Previous Testing and Research Gap

Over the past five years a number of theses focusing on various aspects of RFID have been completed. Some have focused on the RFID tag itself: its performance capabilities design and implementation, failure modes, and enhanced anti-collision protocol.[49-53] Research has also been performed on the effect of RFID in supply chain management, in a warehouse environment, and for mobile object tracking. [54-56]

As knowledge of tag functionality increased, it became important to understand the interaction between the tag and the product it was placed on. At Michigan State University, John Onderko studied the performance of an RFID transponder placed on refrigerated and frozen beef loin packages. The testing compared RFID systems operating at different frequencies (13.56 MHz and 915 MHz) in combination with two beef loin muscle conditions (frozen versus refrigerated). The author concluded that in the 915 MHz frequency range RFID systems communicated through frozen packages, but experienced loss of data when communicating through a refrigerated package. He also concluded that the 13.56 MHz frequency range experienced no loss of data when transmitting through a package of refrigerated or frozen beef. This research determined that the product and its state both have an effect on the readability of RFID tags.[57]

Another Michigan State Graduate, Jeffrey Tazelaar, expanded on Onderko's work by studying the effect of tag orientation and package content on the readability of RFID tags. Tazelaar "utilized a pallet load of 48 corrugated cases, each tagged with a UHF Class 0 RFID tag".[22] He compared five different tag locations and 5 different products, walking the pallet load through a simulated warehouse RFID portal. His research determined that both tag orientation and product type have a significant effect on tag readability.[58]

As knowledge on the effect of product on readability of RFID tags grew, another area of research that had not been explored was the effect of the number of antennae and their configuration had on the readability of cased goods. Thomas Crawforth of

Michigan State University determined that "there was a significant difference in the read rate of reads for both number and location of antennae" when encompassing case contents (empty cases, rice and water), and tag type (Alien Class 1 and Symbol Class 0) as variables in his research.[22]

Among the research being done across industry and at universities, there appears to be a noticeable gap in published literature. This gap involves the relationship between conveyor speed and the effect of both the package and the product on the readability of RFID transponders. Conveyor speed and package readability have been tested in one study only (RFID Alliance lab at Kansas University discussed previously), but the producers of the work determined "there were too many unconstrained variables to make the results transferable to other environments"[48].

This research focuses on two conveyor speeds commonly used in industry; 600 feet per minute and 300 feet per minute. Determining merely the influence of speed on the readability of RFID tags is a test in itself; however, for suppliers and retailers of goods, more valuable information can be gathered by placing the tags on actual products. By using multiple products, testing of three additional variables is possible: product effect (ketchup and motor oil), package effect (potato chips in plastic tub and potato chips in metalized tub) and package shape (metal bottles, metal cans and metal tins). Additionally, the type of tag used was the fifth and final variable in the research performed, comparing a Gen 1 tag to a Gen 2 tag. These two tag types were chosen because at the time this research was performed Gen 2 tags were available, however, most mandates pertaining to RFID in the supply chain only required a Gen 1 tag.

CHAPTER 3 – METHODOLOGY

The following section discusses the materials and equipment necessary to perform the aforementioned research testing. In total, seven different consumer goods products were used to evaluate the effect of the five variables tested. To test the product effect a case of ketchup was comparted to a case of motor oil. To test the package effect, a case of potato chips in a metalized spiral wound fiberboard container was compared to a case of potato chips in plastic tubs. To test the effect of package shape, three products were used; a case of metal cans, a case of metal tins, and a tray of metal bottles.

Throughout the testing of the seven products, both the tag type and equipment used were held constant throughout the entire testing procedure. Two procedures were performed on the cases. Prior to the converyor testing, it was necessary to determine the optimal tag location on each package. After this was complete the consumer goods products were tested on the conveyor set-up to determine the tagged product's readability while moving down the conveyor at speed. Upon completion of testing, a statistical analysis of variables was performed to determine the overall effect of the five variables on case readability.

Materials

Product Effect

The case of ketchup was made from B flute corrugated board, with the outside dimensions of the case measuring 16" x 9.5" x 7.5".The box manufacturer tested the case determining a 32 pounds per inch (lbs/in) edge crush test, a size limit of 75" and a gross weight limit of 65 pounds (lbs). The case held 16 bottles, each containing 20 ounces (oz) of ketchup packaged in a polyethylene terephthalate (PETE bottle) with a polypropylene (PP) lid **(Figure 2)**.

A

B

C

Figure 2: (A) Case of Ketchup, (B) Lay-out of Bottles in Case, (C) Individual Bottle

The case of motor oil was made from B Flute corrugated board, with the outside dimensions of the case measuring 13.25" x 9.75" x 9.25". The box manufacturer tested the box determining a 44 lbs/in edge crush test, a size limit of 95" and a gross weight limit of 95 lbs. The case contained 12 one- quart bottles of motor oil packaged in high density polyethylene (HDPE) with a PP lid **(Figure 3)**.

A

B

C

Figure 3: (A) Case of Motor Oil, (B) Lay-out of Bottles in Case, (C) Individual Bottle

Package Effect

The case containing the potato chips in plastic tubs consisted of B flute 1/8" thick corrugated board with the outside dimensions of the case measuring 14.75" x 9" x 6.75". The box manufacturer tested the box determining a 26 lbs/in edge crush test, with a size limit of 50" and a gross weight limit of 35 lbs. The case contained 36 tubs, each holding 0.81 oz. of potato chips. (29.16 total oz) **(Figure 4)**.

A

B

C

Figure 4: (A) Case of Potato Chips, (B) Lay-out of Tubs in Case, (C) Individual Tub

The case of potato chips in metalized spiral wound fiberboard containers (MSWFC) was made of E flute 1/16” thick corrugated board with the outside dimensions of the case measuring 16” x 9” x 9.5”. The box manufacturer tested the box determining a 23 lbs/in edge crush test, with a size limit of 40” and a gross weight limit of 20 lbs. The case contained 14 MSWFC each holding 6 oz. of potato chips per tub (84 oz total) **(Figure 5)**.

A

B

C

Figure 5: (A) Case of Potato Chips, (B) Lay-out of MSWFC in Case, (C) Individual MSWFC

Package Shape Effect

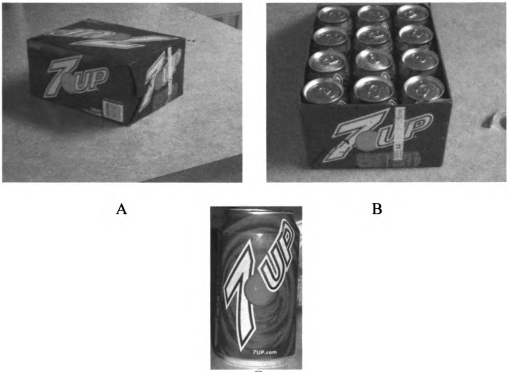
The aluminum bottles were packaged in an E flute tray with the outside dimensions of the tray measuring 10.5" x 8" x 3", with the bottles extending 8" above the tray, which was shrink wrapped with a polyolefin film. The tray held 12 bottles containing 18 fluid oz. of a liquid energy drink **(Figure 6)**.

A B

C

Figure 6: (A) Tray of Bottles, (B) Lay-out of Bottles in Tray, (C) Individual Bottle

The aluminum cans were packaged in a paperboard case (1.6 points) with the outside dimensions of the case measuring 10.25" x 7.75" x 5". The case held 12 cans each containing 12 fluid oz. of a lemon lime soda **(Figure 7)**.

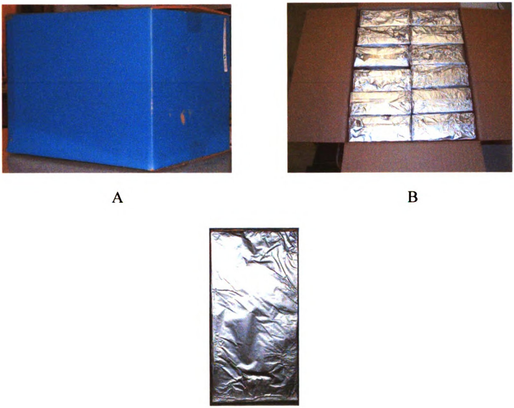


A B

C

Figure 7: (A) Case of Cans, (B) Lay-out of Cans in Case, (C) Individual Can

The aluminum tins were packaged in a B flute corrugated board case with the outside dimensions of the case measuring 13" x 10" x 10". The case contained 12 boxes of facial tissue wrapped in aluminum foil (.0007" thick) to simulate a traditional candy tin **(Figure 8)**.



A B

C

Figure 8: (A) Case of Tins, (B) Lay-out of Tins in Case, (C) Individual Tin

Equipment and Software:

The reader was an Alien ALR-9780 Reader (Alien Technologies, Morgan Hill, Ca) **(Figure 9)**. It is a Gen 2 reader, able to read and send data from Electronic Product Code (EPC) Gen 1 and Gen 2 Class 1 tags to a computer for analysis using a RS-232 computer interconnection cable. The ALR-9780 is a 4-port reader, capable of connecting to four ultra high frequency (UHF) antennae. During the data collection process, the software used was Alien Gateway V2.15.08. To determine the optimal tag location for each product, RFID Tag Locator software V01.00.04 from Cape Systems (South

Plainfield, NJ) was used. The results of the optimal tag location testing is discussed in Chapter 4.

Figure 9: ALR-9780 Reader

Four Alien ALR-9610-AC circularly polarized antennae were used because they are less sensitive to tag orientation, and the read distance required was not large enough to require linear antennae (**Figure 10**).

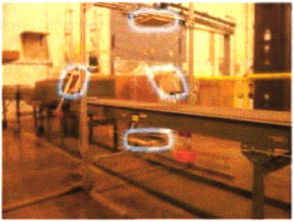


Figure 10: ALR-9610-AC Antenna

The tags were an EPC Class 1 Gen 1 ALL-9340-02 "Squiggle™ 2" and an EPC Class 1 Gen 2 ALL-9440 "Gen2 Squiggle™". Each tag measured 4" x 1/2". These two tags types were chosen because they offered a comparison between Gen 1 and Gen 2 tag capabilities. Specifications for both tags claim the ability to work well on most packaging products (corrugated board, plastic, and paper), while the Gen 2 tag is claimed to perform well when used with package systems involving metal and/or water (**Figure 11**).

A B

Figure 11: (A) Back of Gen 1 Tag (top) and Gen 2 Tag (bottom). (B) Front of Gen 1 Tag (top) Gen 2 Tag (bottom)

The conveyor (Buschman Conveyors (Cincinnati, OH) was 10' long and 31.5" wide. Conveyor speed was controlled by a converted Weslo treadmill (Colorado Springs, CO). A skate-wheel conveyor was positioned at the end of the Buschman conveyor to slow and stop the product. The speed of the conveyor was monitored by a Computak tachometer Model 8203 by Cole-Parmer Instrument Company (Vernon Hills, IL).

The antennae were placed on the left (1), right (3), top (2) (facing down towards the conveyor), and bottom (4) (facing up towards the conveyor) sides of the conveyor (**Figure 12**). The horizontal distance from the center of the conveyor belt to the center of the side antennae was 20.75". The vertical distance from the top of the conveyor to the center of the side antennae was 8". Both side antennae were angled 30 degrees down towards the conveyor. The vertical distance from the top of the conveyor belt to the top antenna was 30", and to the bottom antennae was 12".

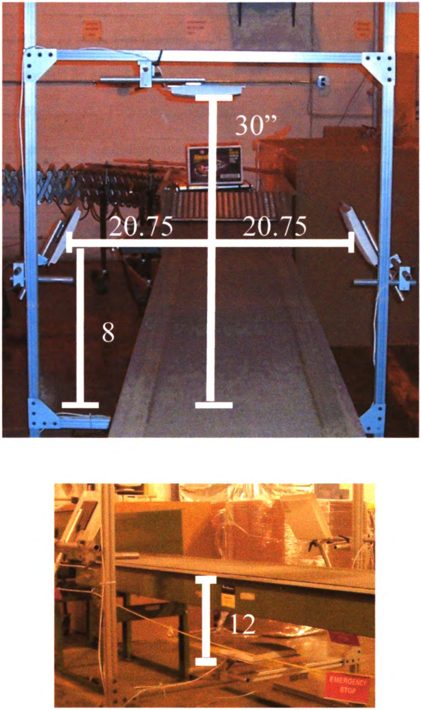
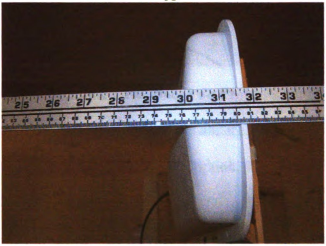


Figure 12: Antennae Locations Surrounding Conveyor

Procedure for Determining Optimal Tag Location

Testing was conducted using one Alien ALR-9610-AC circularly polarized antenna mounted on a wooden stand 36" from the center of the antenna to the floor. Each of the products tested was placed on top of a 30.5" stand, composed of 3 empty corrugated boxes stacked on top of one another, and located at 90 degrees and 30" away from the antenna **(Figure 13)**. This corrugated stand provided adequate line of sight between the antenna and the tagged product, in addition to being a medium in which RF waves are neither absorbed nor reflected, thus ensuring the stand had no effect on the outcome of the test. With each product tested, the face of the case and the front of the antenna were kept 30" apart, following the instructions for case testing provided in the Cape Systems user manual (version V01.00.04).

A



B

Figure 13: Case and Anna Set-up for Cape Systems RFID Tag Locator Software

For each product, two sides of the case were selected to determine an optimal tag location: a front face of the case (representing the width of the case) and a side face of the case (representing the length of the case). Each face to be tested was equipped with a 1" x 1" grid drawn on a piece of paper that was taped to the face of the case to be tested. The center of the tag was placed at the intersection of each horizontal and vertical line. The tag was moved from intersection to intersection for each new trial run (**Figure 14**).

Figure 14: Example Grid Placed on Front Face of Case

Once the case and antenna were set up, the dimensions of the case were entered in the software's Case Setup page. The Hotspot test option, which brings up a 3-dimensional version of the product, was selected. The software creates a 1" x 1" grid on each face of the case **(Figure 15)**. The face representing the width of the case and the closest size tag (1" x 4") were selected from the on screen options. On the 3-dimensional on-screen image, an intersection was selected that allowed for the tag to fit completely on the case without overhang, and the actual tag was placed in the same location on the product to be tested.

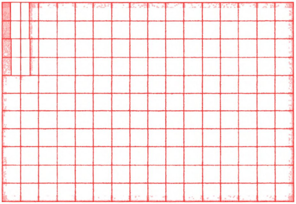


Figure 15: Example Tag Location on Package Face

The tag was placed on the package vertically, the antenna was activated, and results were recorded at each grid intersection. When each intersection had been tested, the tag was moved to the length side of the case, and the test was repeated. After completion of both sides of the case, the tag was repositioned horizontally on the case, and both the width and length side of the case was tested again. Upon determining the optimal tag location, a pin was used to penetrate through the grid and mark the box. The grid was then removed from the package and the pin hole represented the place for which the center of the tag was placed during conveyor testing.

Procedure for Testing RFID Tagged Case Loads on Conveyor

The seven types of product were tested in an off-campus warehouse **(Figure 16).** Besides the product, package and shape variations in each case, two additional variables were tested: speed (600 and 300 feet per minute (fpm)) and tag type (a Generation 1 tag and a Generation 2 tag). Each test, which consisted of 30 trials, began with the activation of the RFID equipment through the Alien software. Next, the tagged case located outside of the antennae read field was placed on the moving conveyor belt operating at speed. The orientation of the case on the belt was such that the tag on the case was in the direct line of sight with one of the side antennae. The product traveled down the conveyor, passed through the antenna portal read field, and eventually moved out of the read field when it was swept onto the skate wheel conveyor and brought to a halt. Each product underwent 120 trials using two conveyor speeds and two tag types. Two types of results were recorded; whether the tag was detected or not, and the number of times the tag was detected. These results were stored in a Microsoft Excel file.

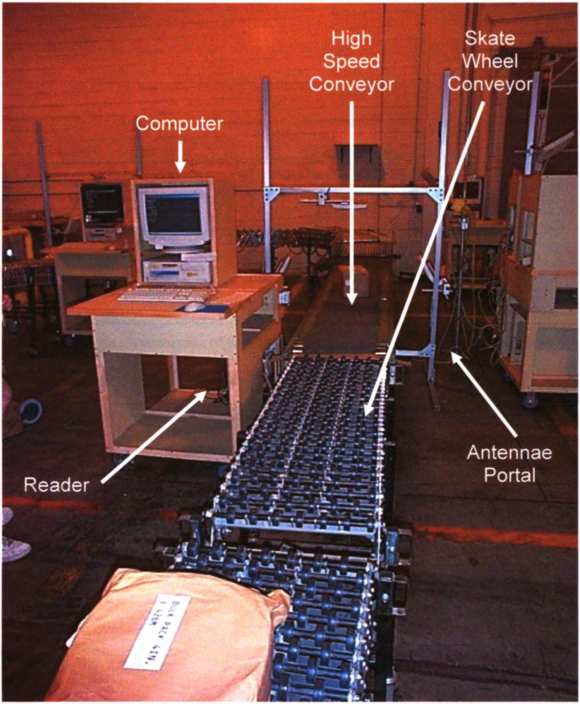


Figure 16: Warehouse with Conveyor and RFID Set-up

Statistical Analysis

With the assistance of the Center for Statistical Training and Consulting (CSTAT) a 3 way Analysis of Variance (ANOVA) model was used to test the normality of residuals. SAS Glimmix was the version of software used. For a valid comparison to be made, it was necessary to use the data showing the number of times the product was detected. It would not be statistically valid, nor very interesting, if comparisons were made by assessing whether the product was detected or not, being that six out of seven products were detected in every trial of every test.

The research performed in the 3 tests had 3 main effectors. One of the effectors was conveyor speed, consisting of two levels (300fpm and 600fpm). The second effecter was tag type, consisting of two levels (Gen1 and Gen2). The third effecter was the package or product itself. For the product effect test, the effecter was the product itself, consisting of two levels (ketchup and motor oil). For the package effect test, the effecter was the package, consisting of two levels (plastic tubs and MSWFC). For the effect of package shape, the effecter was shape, consisting of three levels (metal cans, metal bottles and metal tins).

CHAPTER 4 – RESULTS

Hotspot Test Results

The Hotspot test determines whether a tag is in a good or bad location by measuring the level of attenuation at which a tag responds. Signal attenuation is defined as "the weakening of RF energy from an RFID tag or a reader".[1] The higher the attenuation value recorded when a tag responds, the lower the amount of power being delivered to the tag from the antenna. The range of power used by the software to detect the passive tag ranged from 15 dB to 0 dB, with 15 dB representing an optimal situation in which the antenna had to put out very little power to receive a signal back from the tag and 0 dB representing the tag not sending a response signal. As the tag is moved from intersection to intersection within the grid, attenuation values are recorded for each tag location. The value then correlates to a certain color which appears on the screen at the intersection of interest **(Figure 17)**. A tag attenuation response between 0-8 dB provides a color response ranging from bright red to bright white. A response between 8-15 dB provides a color response ranging from bright white moving to bright green. In general, a red response is a poor location to place a tag, a white response is an okay position to place a tag, and a green response is an excellent location to place a tag. The variance in color is due to a variety of interference possibilities due to packaging materials or product content.

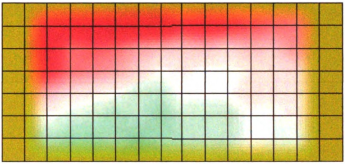


Figure 17: Example RFID hotspot test outcome for one side of a case

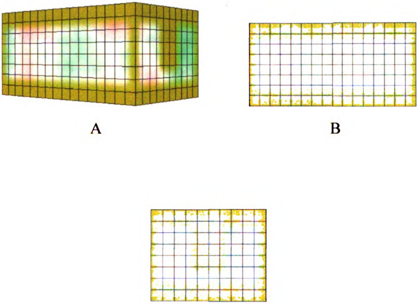
Results for each of the seven products were recorded, testing two tag orientations on two adjoining faces of each case, a width and a length. From the data obtained, an optimal tag location and orientation was determined for each product. The results for the Hotspot test revealed similarities regarding each of the seven products. Although testing was performed with two tag orientations, the vertical tagging proved to be optimal for each product. Additionally, the width face, either end 5 or end 6 according to ASTM D 775, Standard Test Method for Drop Test for Loaded Boxes, of the case proved to be an equal or better tag location than length face of the case. To keep the testing consistent, the tag was placed on the width face of the case for each of the seven products.

Product Effect Results from Hotspot Testing

For the case of ketchup the center of the tag was affixed on end 6 of the case, 8" from uppermost left corner of the width face, and down 3" from the top of the width face **(Figure 18)**.

Figure 18: Tag Location on Ketchup Case

This location was determined to be optimal because it produced an attenuation level of 12 dB, which the software depicted as a bright green in that location **(Figure 19)**.



A B

C

Figure 19: Hotspot Test Output for Case of Ketchup, (A) Length and Width View of Case, (B) Length View of Case, (C) Width View of Case

For the case of motor oil the center of the tag was affixed on end 6 of the case, 1" from uppermost left corner of the width face, and down 2" from the top of the width face **(Figure 20)**.

Figure 20: Tag Location on Motor Oil Case

This location was determined to be optimal because it produced an attenuation level of 10 dB, which the software depicted as a very light green in that location **(Figure 21)**.

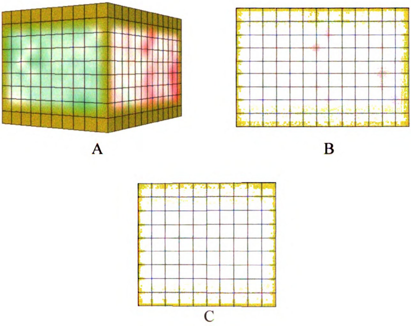


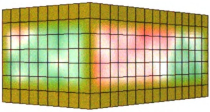
Figure 21: Hotspot Test Output for Case of Motor Oil, (A) Length and Width View of Case, (B) Length View of Case, (C) Width View of Case

Package Effect Results From Hotspot Testing

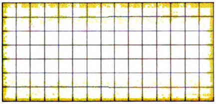
For the case of potato chips in plastic tubs the center of the tag was affixed on end 5 of the case, 4” from uppermost left corner of the width face, and down 2” from the top of the width face **(Figure 22)**.

Figure 22: Tag Location on Case of Chips in Plastic Tubs

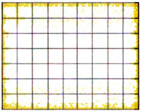
This location was determined to be optimal because it produced an attenuation level of 10 dB, which the software depicted as a very light green in that location **(Figure 23)**.



A



B



C

Figure 23: Hotspot Test Output for Case of Potato Chips in Plastic Tubs, (A) Length and Width View of Case, (B) Length View of Case, (C) Width View of Case

For the case of potato chips in metalized spiral-wound fiberboard containers (MSWFC) the center of the tag was affixed on end 6 of the case, 4" from uppermost left corner of the width face, and down 3" from the top of the width face **(Figure 24)**.

Figure 24: Tag Location on Case of Chips in MSWFC

This location was determined to be optimal because it produced an attenuation level of 13 dB, which the software depicted as a bright green in that location **(Figure 25)**.

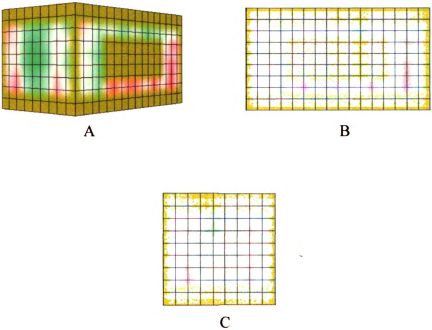


Figure 25: Hotspot Test Output for Case of Potato Chips in MSWFC, (A) Length and Width View of Case, (B) Length View of Case, (C) Width View of Case

Package Shape Effect Results From Hotspot Testing

For the case of aluminum cans the center of the tag was affixed on end 6 of the case, 5" from uppermost left corner of the width face, and down 2" from the top of the width face **(Figure 26)**.

Figure 26: Tag Location on Case of Cans

This location was determined to be optimal because it produced an attenuation level of 4 dB, which the software depicted as a pinkish white in that location **(Figure 27)**.

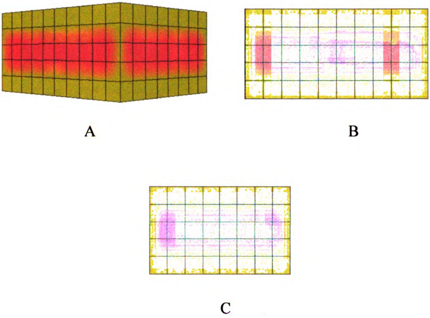


Figure 27: Hotspot Test Output for Case of Cans, (A) Length and Width View of Case, (B) Length View of Case, (C) Width View of Case

For the tray of aluminum bottles the center of the tag was affixed on end 6 of the tray, 3" from uppermost left corner of the width face, and down 6" from the top of the width face **(Figure 28)**.

Figure 28: Tag Location for Tray of Bottles

This location was determined to be optimal because it produced an attenuation level of 8 dB, which the software depicted as a bright white in that location **(Figure 29)**.

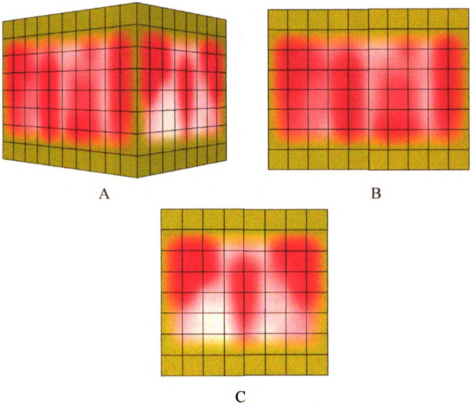


Figure 29: Hotspot Test Output for Tray of Bottles, (A) Length and Width View of Case, (B) Length View of Case, (C) Width View of Case

For the case of aluminum tins the center of the tag was affixed on end 6 of the case, 9" from uppermost left corner of the width face, and down 2" from the top of the width face **(Figure 30)**.

Figure 30: Tag Location for Case of Tins

At no point during the Hotspot test was there ever a dB level greater than 0 recorded, therefore the tag location was determined by using a location on the case that had been a traditional tag location in previous research testing, the upper right hand corner of the case **(Figure 31)**.

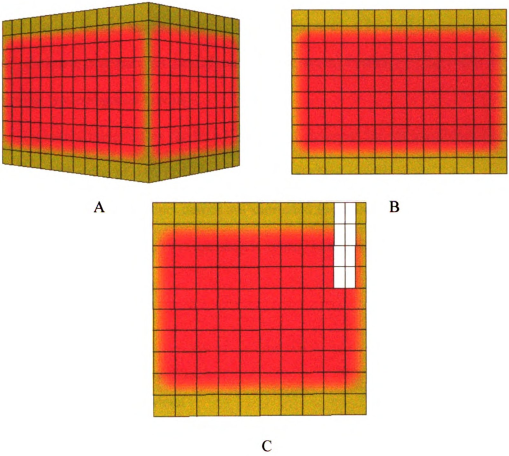


Figure 31: Hotspot Test Output for Case of Tins, (A) Length and Width View of Case, (B) Length View of Case, (C) Width View of Case

Statistical Analysis of Conveyor Effect

To statistically analyze the results of the conveyor test, results (number of reads per trial) were taken from the Microsoft excel file, and put into the SAS Glimmix software. The results for each case tested were calculated and compared.

In the tables depicted below there are a variety of terms and corresponding values displayed. For the purpose of this research, the values of most significance are located under the Estimate column, and either the Pr > F or Pr > |t| columns.

The values under the Estimate column refer to either the average number of tag reads per trial or, in the case the table is titled "Differences of Product Least Square Means", Estimate is defined as the difference in the average number of tag reads per trail between the two compared products.

The values under either the Pr > F or Pr > |t| represent the statistical significance of the data. A P-value of 0.01 or lower indicates statistical significance.

Within the tables product names are shortened to a more concise term, the list of the product and the shortened term are shown below, in addition to definitions for terms of table column headings.

Terminology

Chips in Plastic Tubs: Plastic

Chips in MSWFC: Metal

Den DF: Degrees of freedom of the denominator

DF (Degrees of Freedom): Any of the unrestricted, independent random variables that constitute a statistic.

Effect: The variable or variables affecting the number of tag reads per trial

Estimate: 1.) The average number of tag reads per trial, or 2.) In the case the table is titled "Differences of Product Least Square Means", Estimate is defined as the difference in the average number of tag reads per trail between the two compared products.

Fixed Effects:

- Product (Ketchup, Motor oil)
- Speed (300 feet per minute (fpm), 600 fpm)
- Tag (Gen 1, Gen 2)
- Product x Speed (Ketchup (300 fpm, 600 fpm)) x (Motor Oil (300 fpm, 600 fpm))
- Product x Tag (Ketchup (Gen 1, Gen 2)) x (Motor Oil (Gen 1, Gen 2))

- Tag x Speed (300 fpm (Gen 1, Gen 2)) x (600 fpm (Gen 1, Gen 2))
- Product x Speed x Tag (Ketchup (Gen 1, Gen 2) (300 fpm, 600 fpm)) x (Motor Oil (Gen 1, Gen 2) (300 fpm, 600 fpm)

F-Value: Mean Square for effect divided by mean square for error

Ketchup: Ketchup

Least Square Means: average, this is the best method for calculating the average statistically

MD: Mean Difference between the average number of tag reads per trial between the subjects being compared.

Metal Bottles: Bottles

Metal Cans: Cans

Metal Tins: Tins

Motor Oil: Oil

Num DF: Degrees of freedom of the numerator

Pr > F: Calculation of the P-value (probability to reject null hypothesis) for F-test.

Product: One of the consumer goods being tested

Product: The consumer good being compared to the first product

Pr > |t|: Calculation of the P-value for the t-test.

Standard Error: The estimated standard deviation of the sample mean

t-Value: The ratio of the difference between the sample mean and the given number to the standard error of the mean

Product Effect Results:

Ketchup

In Trial 1, the case traveled on the conveyor at 300 feet per minute (fpm) equipped with a Gen 1 tag. Over the 30 trials, there were 2,875 instances in which the tag was detected. On average there were 95.83 tag reads per trial with a standard deviation of 12.9.

In Trial 2, the case traveled on the conveyor at 600 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 1,206 instances in which the tag was detected. On average there were 40.2 tag reads per trial with a standard deviation of 12.1.

In Trial 3, the case traveled on the conveyor at 300 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 3,831 instances in which the tag was detected. On average there were 127.7 tag reads per trial with a standard deviation of 13.6.

In Trial 4, the case traveled on the conveyor at 600 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 1,023 instances in which the tag was detected. On average there were 34.1 tag reads per trial with a standard deviation of 7.4.

Motor Oil

In Trial 1, the case traveled on the conveyor at 300 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 5,974 instances in which the tag was detected. On average there were 199.1 tag reads per trial with a standard deviation of 40.2.

In Trial 2 the case traveled on the conveyor at 600 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 2,243 instances in which the tag was detected. On average there were 74.4 tag reads per trial with a standard deviation of 18.5.

In Trial 3, the case traveled on the conveyor at 300 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 6,685 instances in which the tag was detected. On average there were 222.8 tag reads per trial with a standard deviation of 14.5.

In Trial 4, the case traveled on the conveyor at 600 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 1,803 instances in which the tag was detected. On average there were 60.1 tag reads per trial with a standard deviation of 8.1.

Statistical Analysis of the Product Effect Test

Table 1 depicts the results from testing the fixed effects involved in testing the product effect on tag readability.

Table 1: Tests of Fixed Effects for Product Effect

Type III Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Product	1	232	704.85	<.0001
Speed	1	232	2008.70	<.0001
Tag	1	232	13.00	0.0004
Product*Speed	1	232	201.20	<.0001
Product*Tag	1	232	2.83	0.0937
Speed*Tag	1	232	60.85	<.0001
Product*Speed*Tag	1	232	0.00	0.9945

The following results refer specifically to each row of results in Table 1.

Row 1. Statistical analysis output concluded that product (ketchup or motor oil) had a significant effect on the average number of tag reads per trial.

Row 2. Statistical analysis output concluded that speed (300 fpm or 600 fpm) had a significant effect on the average number of tag reads per trial.

Row 3. Statistical analysis output concluded that tag type (Gen 1 or Gen 2) had a significant effect on the average number of tag reads per trial.

Row 4. Statistical analysis output concluded that product by speed had a significant interaction effect on the average number of tag reads per trial.

Row 5. Statistical analysis output concluded that product by tag **did not have** a significant interaction effect on the average number of tag reads per trial.

Row 6. Statistical analysis output concluded that speed by tag had a significant interaction effect on the average number of tag reads per trial.

Row 7. Statistical analysis output concluded that product by speed by tag **did not have** a significant interaction effect on the average number of tag reads per trial.

Table 2 shows the statistical analysis output concluded that product type had a significant effect on the average amount of tag reads per trial, with the case of motor oil averaging 64.7 more tag reads per trial than the case of ketchup

Table 2: Average Number of Tag Reads Per Trial and Difference Between Means, by Product Type

Product Least Squares Means					
Product	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	74.4583	1.7223	232	43.23	<.0001
Oil	139.13	1.7223	232	80.78	<.0001
MD	-64.6667	2.4358	232	-26.55	<.0001

Table 3 shows that statistical analysis output concluded that conveyor speed had a significant effect on the average number of tag reads per trial, with 300 fpm averaging 109.2 more tag reads per trial than 600 fpm.

Table 3: Average Number of Tag Reads Per Trial and Difference Between Means, by Conveyor Speed

Speed Least Squares Means					
Speed	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
300	161.38	1.7223	232	93.70	<.0001
600	52.2083	1.7223	232	30.31	<.0001
MD	109.17	2.4358	232	44.82	<.0001

Table 4 shows that statistical analysis output concluded that tag type had a significant effect on the average number of tag reads per trial, with Gen 2 averaging 8.8 more tag reads per trial than Gen 1.

Table 4: Average number of tag reads per trial and difference between means by tag generation

Tag Least Squares Means					
Tag	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	102.40	1.7223	232	59.45	<.0001
Gen2	111.18	1.7223	232	64.55	<.0001
MD	-8.7833	2.4358	232	-3.61	0.0004

Table 5 shows the statistical analysis output of the interaction between the product and a conveyor speed.

Table 5: Average Number of Tag Reads Per Trial, Product by Speed

Product*Speed Least Squares Means						
Product	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	**300**	111.77	2.4358	232	45.89	<.0001
Ketchup	**600**	37.1500	2.4358	232	15.25	<.0001
Oil	**300**	210.98	2.4358	232	86.62	<.0001
Oil	**600**	67.2667	2.4358	232	27.62	<.0001

The following results refer specifically to each row of results in Table 5.

- Row 1. The case of ketchup moving at 300 fpm averaged 111.8 reads per trial
- Row 2. The case of ketchup moving at 600 fpm averaged 37.2 reads per trial
- Row 3. The case of motor oil moving at 300 fpm averaged 211 reads per trial
- Row 4. The case of motor oil moving at 600 fpm averaged 67.3 reads per trial

Table 6 shows the statistical analysis output of the interaction between the two way interaction between the two products and the two speeds.

Table 6: Difference in Average Number of Tag Reads Per Trial Between Product by Speed

Differences of Product*Speed Least Squares Means								
Product	**Speed**	**_Product**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	**300**	**Ketchup**	**600**	74.6167	3.4447	232	21.66	<.0001
Oil	**300**	**Oil**	**600**	143.72	3.4447	232	41.72	<.0001
Ketchup	**300**	**Oil**	**300**	-99.2167	3.4447	232	-28.80	<.0001
Ketchup	**300**	**Oil**	**600**	44.5000	3.4447	232	12.92	<.0001
Ketchup	**600**	**Oil**	**300**	-173.83	3.4447	232	-50.46	<.0001
Ketchup	**600**	**Oil**	**600**	-30.1167	3.4447	232	-8.74	<.0001

The following results refer specifically to each row of results in Table 6.

- Row 1. Comparing the case of ketchup moving at 300 fpm versus the case of ketchup moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup at 300 fpm averaging 74.6 more tag reads per trial.
- Row 2. Comparing the case of motor oil moving at 300 fpm versus the case of motor oil moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil at 300 fpm averaging 143.7 more tag reads per trial.
- Row 3. Comparing the case of ketchup moving at 300 fpm versus the case of Motor oil moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil at 300 fpm averaging 99.2 more tag reads per trial.

- Row 4. Comparing the case of ketchup moving at 300 fpm versus the case of Motor oil moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup at 300 fpm averaging 44.5 more tag reads per trial.
- Row 5. Comparing the case of ketchup moving at 600 fpm versus the case of Motor oil moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil at 300 fpm averaging 173.8 more tag reads per trial.
- Row 6. Comparing the case of ketchup moving at 600 fpm versus the case of motor oil moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil at 600 fpm averaging 30.1 more tag reads per trial.

Table 7 shows the statistical analysis output of the interaction between the product and the tag type.

Table 7: Average Number of Tag Reads Per Trial, Product by Tag Generation

Product*Tag Least Squares Means						
Product	**Tag**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	**Gen1**	68.0167	2.4358	232	27.92	<.0001
Ketchup	**Gen2**	80.9000	2.4358	232	33.21	<.0001
Oil	**Gen1**	136.78	2.4358	232	56.16	<.0001
Oil	**Gen2**	141.47	2.4358	232	58.08	<.0001

The following results refer specifically to each row of results in Table 7.

- Row 1. The case of ketchup with a Gen 1 tag averaged 68 reads per trial.
- Row 2. The case of ketchup with a Gen 2 tag averaged 81 reads per trial.
- Row 3. The case of motor oil with a Gen 1 tag averaged 136.8 reads per trial.
- Row 4. The case of motor oil with a Gen 2 tag averaged 141.5 reads per trial.

Table 8 shows the statistical analysis output of the interaction between the two way interaction between the two products and the two tag types.

Table 8: Difference in Average Number of Tag Reads Per Trial Between Product by Tag Generation

Differences of Product*Tag Least Squares Means								
Product	Tag	_Product	_Tag	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	Ketchup	Gen2	-12.8833	3.4447	232	-3.74	0.0002
Oil	Gen1	Oil	Gen2	-4.6833	3.4447	232	-1.36	0.1753
Ketchup	Gen1	Oil	Gen1	-68.7667	3.4447	232	-19.96	<.0001
Ketchup	Gen1	Oil	Gen2	-73.4500	3.4447	232	-21.32	<.0001
Ketchup	Gen2	Oil	Gen1	-55.8833	3.4447	232	-16.22	<.0001
Ketchup	Gen2	Oil	Gen2	-60.5667	3.4447	232	-17.58	<.0001

The following results refer specifically to each row of results in Table 8.

- Row 1. Comparing the Gen 1 tag on ketchup versus the Gen 2 tag on ketchup, there was a significant difference between the average number of tag reads per trial, with the Gen 2 tag on ketchup averaging 12.9 more tag reads per trial.
- Row 2. Comparing the Gen 1 tag on motor oil versus the Gen 2 tag on motor oil, there **was not** a significant difference between the average number of tag reads per trial, with the Gen 2 tag on motor oil averaging 4.7 more tag reads per trial.
- Row 3. Comparing the Gen 1 tag on ketchup versus the Gen 1 tag on motor oil, there was a significant statistical difference in the number of tag reads with the Gen 1 tag on motor oil averaging 68.8 more tag reads per trial.
- Row 4. Comparing the Gen 1 tag on ketchup versus the Gen 2 tag on motor oil, there was a significant statistical difference in the number of tag reads with the Gen 2 tag on motor oil averaging 73.5 more tag reads per trial.

- Row 5. Comparing the Gen 2 tag on ketchup versus the Gen 1 tag on motor oil, there was a significant statistical difference in the number of tag reads with the Gen 1 tag on motor oil averaging 55.9 more tag reads per trial.
- Row 6. Comparing the Gen 2 tag on ketchup versus the Gen 2 tag on motor oil, there was a significant statistical difference in the number of tag reads with the Gen 2 tag on motor oil averaging 60.6 more tag reads per trial.

Table 9 shows the statistical analysis output of the interaction between tag type and conveyor speed.

Table 9: Average Number of Tag Reads Per Trial, Tag Generation by Speed

Speed*Tag Least Squares Means						
Tag	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	147.48	2.4358	232	60.55	<.0001
Gen2	**300**	175.27	2.4358	232	71.96	<.0001
Gen1	**600**	57.3167	2.4358	232	23.53	<.0001
Gen2	**600**	47.1000	2.4358	232	19.34	<.0001

The following results refer specifically to each row of results in Table 9.

- Row 1. The case with a Gen 1 tag moving 300 fpm averaged 147.5 reads per trial.
- Row 2. The case with a Gen 2 tag moving 300 fpm averaged 175.3 reads per trial.
- Row 3. The case with a Gen 1 tag moving 600 fpm averaged 57.3 reads per trial.
- Row 4. The case with a Gen 2 tag moving 600 fpm averaged 47.1 reads per trial.

Table 10 shows the statistical analysis output of the two way interaction between the tag type and conveyor speed.

Table 10: Difference In Average Number of Tag Reads Per Trial Between Tag Generation by Speed

Differences of Speed*Tag Least Squares Means								
Tag	**Speed**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	**Gen2**	**300**	-27.7833	3.4447	232	-8.07	<.0001
Gen1	**300**	**Gen1**	**600**	90.1667	3.4447	232	26.18	<.0001
Gen1	**300**	**Gen2**	**600**	100.38	3.4447	232	29.14	<.0001
Gen2	**300**	**Gen1**	**600**	117.95	3.4447	232	34.24	<.0001
Gen2	**300**	**Gen2**	**600**	128.17	3.4447	232	37.21	<.0001
Gen1	**600**	**Gen2**	**600**	10.2167	3.4447	232	2.97	0.0033

The following results refer specifically to each row of results in Table 10.

- Row 1. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 27.8 more tag reads per trial.
- Row 2. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 1 tag at 300 fpm averaging 90.2 more tag reads per trial.
- Row 3. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 1 tag at 300 fpm averaging 100.4 more tag reads per trial.

- Row 4. Comparing the Gen 2 tag moving at 300 fpm versus the Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 118 more tag reads per trial.
- Row 5. Comparing the Gen 2 tag moving at 300 fpm versus the Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 128.2 more tag reads per trial.
- Row 6. Comparing the Gen 1 tag moving at 600 fpm versus the Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 1 tag at 600 fpm averaging 10.2 more tag reads per trial.

Table 11 shows the statistical analysis output of the interaction between the product, tag type, and conveyor speed.

Table 11: Average Number of Tag Reads Per Trial, Product by Tag Generation by Speed

Product*Speed*Tag Least Squares Means							
Product	**Tag**	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	**Gen1**	**300**	95.8333	3.4447	232	27.82	<.0001
Ketchup	**Gen2**	**300**	127.70	3.4447	232	37.07	<.0001
Ketchup	**Gen1**	**600**	40.2000	3.4447	232	11.67	<.0001
Ketchup	**Gen2**	**600**	34.1000	3.4447	232	9.90	<.0001
Oil	**Gen1**	**300**	199.13	3.4447	232	57.81	<.0001
Oil	**Gen2**	**300**	222.83	3.4447	232	64.69	<.0001
Oil	**Gen1**	**600**	74.4333	3.4447	232	21.61	<.0001
Oil	**Gen2**	**600**	60.1000	3.4447	232	17.45	<.0001

The following results refer specifically to each row of results in Table 11.

- Row 1. The case of ketchup with a Gen 1 tag moving 300 fpm averaged 95.8 reads per trial.
- Row 2. The case of ketchup with a Gen 2 tag moving 300 fpm averaged 127.7 reads per trial.
- Row 3. The case of ketchup with a Gen 1 tag moving 600 fpm averaged 40.2 reads per trial.
- Row 4. The case of ketchup with a Gen 2 tag moving 600 fpm averaged 34.1 reads per trial.
- Row 5. The case of motor oil with a Gen 1 tag moving 300 fpm averaged 199.1 reads per trial.

- Row 6. The case of motor oil with a Gen 2 tag moving 300 fpm averaged 222.8 reads per trial.
- Row 7. The case of motor oil with a Gen 1 tag moving 600 fpm averaged 74.4 reads per trial.
- Row 8. The case of motor oil with a Gen 2 tag moving 600 fpm averaged 60.1 reads per trial.

Ketchup-Ketchup Interactions

Table 12 shows the statistical analysis output of the three-way interaction between the case of ketchup, tag type, and conveyor speed.

Table 12: Difference in Average Number of Tag Reads Per Trial Between Product (Ketchup) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	300	Ketchup	Gen2	300	-31.8667	4.8715	232	-6.54	<.0001
Ketchup	Gen1	300	Ketchup	Gen1	600	55.6333	4.8715	232	11.42	<.0001
Ketchup	Gen1	300	Ketchup	Gen2	600	61.7333	4.8715	232	12.67	<.0001
Ketchup	Gen2	300	Ketchup	Gen1	600	87.5000	4.8715	232	17.96	<.0001
Ketchup	Gen2	300	Ketchup	Gen2	600	93.6000	4.8715	232	19.21	<.0001
Ketchup	Gen1	600	Ketchup	Gen2	600	6.1000	4.8715	232	1.25	0.2118

The following results refer specifically to each row of results in Table 12.

- Row 1. Comparing the case of ketchup with a Gen 1 tag moving at 300 fpm versus the case of ketchup with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 2 tag moving at 300 fpm averaging 31.8 more tag reads per trial.
- Row 2. Comparing the case of ketchup with a Gen 1 tag moving at 300 fpm versus the case of ketchup with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 1 tag moving at 300 fpm averaging 55.6 more tag reads per trial.
- Row 3. Comparing the case of ketchup with a Gen 1 tag moving at 300 fpm versus the case of ketchup with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 1 tag moving at 300 fpm averaging 61.7 more tag reads per trial.
- Row 4. Comparing the case of ketchup with a Gen 2 tag moving at 300 fpm versus the case of ketchup with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 2 tag moving at 300 fpm averaging 87.5 more tag reads per trial.
- Row 5. Comparing the case of ketchup with a Gen 2 tag moving at 300 fpm versus the case of ketchup with a Gen 2 tag moving at 600 fpm, there was a

significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 2 tag moving at 300 fpm averaging 93.6 more tag reads per trial.

- Row 6. Comparing the case of ketchup with a Gen 1 tag moving at 600 fpm versus the case of ketchup with a Gen 2 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 1 tag moving at 600 fpm averaging 6.1 more tag reads per trial.

Ketchup Oil Interactions

Table 13 shows the statistical analysis output of the three-way interaction between the two products, a tag, and a conveyor speed.

Table 13: Difference in Average Number of Tag Reads Per Trial Between Product (Ketchup and Motor Oil) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	300	Oil	Gen1	300	-103.30	4.8715	232	-21.20	<.0001
Ketchup	Gen1	300	Oil	Gen2	300	-127.00	4.8715	232	-26.07	<.0001
Ketchup	Gen1	300	Oil	Gen1	600	21.4000	4.8715	232	4.39	<.0001
Ketchup	Gen1	300	Oil	Gen2	600	35.7333	4.8715	232	7.34	<.0001
Ketchup	Gen2	300	Oil	Gen2	300	-95.1333	4.8715	232	-19.53	<.0001
Ketchup	Gen2	300	Oil	Gen1	600	53.2667	4.8715	232	10.93	<.0001
Ketchup	Gen2	300	Oil	Gen2	600	67.6000	4.8715	232	13.88	<.0001
Ketchup	Gen2	300	Oil	Gen1	300	-71.4333	4.8715	232	-14.66	<.0001
Ketchup	Gen1	600	Oil	Gen1	300	-158.93	4.8715	232	-32.63	<.0001
Ketchup	Gen1	600	Oil	Gen2	300	-182.63	4.8715	232	-37.49	<.0001
Ketchup	Gen1	600	Oil	Gen1	600	-34.2333	4.8715	232	-7.03	<.0001
Ketchup	Gen1	600	Oil	Gen2	600	-19.9000	4.8715	232	-4.08	<.0001

Table 13 (cont'd)

Ketchup	Gen2	600	Oil	Gen1	300	-165.03	4.8715	232	-33.88	<.0001
Ketchup	Gen2	600	Oil	Gen2	300	-188.73	4.8715	232	-38.74	<.0001
Ketchup	Gen2	600	Oil	Gen1	600	-40.3333	4.8715	232	-8.28	<.0001
Ketchup	Gen2	600	Oil	Gen2	600	-26.0000	4.8715	232	-5.34	<.0001

The following results refer specifically to each row of results in Table 13.

- Row 1. Comparing the case of ketchup with a Gen 1 tag moving at 300 fpm versus the case of motor oil with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of oil with a Gen 1 tag moving at 300 fpm averaging 103.3 more tag reads per trial.

- Row 2. Comparing the case of ketchup with a Gen 1 tag moving at 300 fpm versus the case of motor oil with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 300 fpm averaging 127 more tag reads per trial.
- Row 3. Comparing the case of ketchup with a Gen 1 tag moving at 300 fpm versus the case of motor oil with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 1 tag moving at 300 fpm averaging 21.4 more tag reads per trial.
- Row 4. Comparing the case of ketchup with a Gen 1 tag moving at 300 fpm versus the case of motor oil with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 1 tag moving at 300 fpm averaging 35.7 more tag reads per trial.
- Row 5. Comparing the case of ketchup with a Gen 2 tag moving at 300 fpm versus the case of motor oil with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 300 fpm averaging 95.1 more tag reads per trial.

- Row 6. Comparing the case of ketchup with a Gen 2 tag moving at 300 fpm versus the case of motor oil with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 2 tag moving at 300 fpm averaging 53.3 more tag reads per trial.
- Row 7. Comparing the case of ketchup with a Gen 2 tag moving at 300 fpm versus the case of motor oil with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of ketchup with a Gen 2 tag moving at 300 fpm averaging 67.6 more tag reads per trial.
- Row 8. Comparing the case of ketchup with a Gen 2 tag moving at 300 fpm versus the case of motor oil with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 300 fpm averaging 71.4 more tag reads per trial.
- Row 9. Comparing the case of ketchup with a Gen 1 tag moving at 600 fpm versus the case of motor oil with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 300 fpm averaging 158.9 more tag reads per trial.
- Row 10. Comparing the case of ketchup with a Gen 1 tag moving at 600 fpm versus the case of motor oil with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 300 fpm averaging 182.6 more tag reads per trial.

- Row 11. Comparing the case of ketchup with a Gen 1 tag moving at 600 fpm versus the case of motor oil with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 600 fpm averaging 34.2 more tag reads per trial.
- Row 12. Comparing the case of ketchup with a Gen 1 tag moving at 600 fpm versus the case of motor oil with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 600 fpm averaging 19.9 more tag reads per trial.
- Row 13. Comparing the case of ketchup with a Gen 2 tag moving at 600 fpm versus the case of motor oil with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 300 fpm averaging 165 more tag reads per trial.
- Row 14. Comparing the case of ketchup with a Gen 2 tag moving at 600 fpm versus the case of motor oil with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 300 fpm averaging 188.7 more tag reads per trial.
- Row 15. Comparing the case of ketchup with a Gen 2 tag moving at 600 fpm versus the case of motor oil with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 600 fpm averaging 40.3 more tag reads per trial.
- Row 16. Comparing the case of ketchup with a Gen 2 tag moving at 600 fpm versus the case of motor oil with a Gen 2 tag moving at 600 fpm, there was a

significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 600 fpm averaging 26 more tag reads per trial.

Oil-Oil Interactions

Table 14 shows the statistical analysis output of the three-way interaction between the case of motor oil, a tag, and a conveyor speed.

Table 14: Difference in Average Number of Tag Reads Per Trial Between Product (Motor Oil) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Oil	Gen1	300	Oil	Gen2	300	-23.7000	4.8715	232	-4.87	<.0001
Oil	Gen1	300	Oil	Gen1	600	124.70	4.8715	232	25.60	<.0001
Oil	Gen1	300	Oil	Gen2	600	139.03	4.8715	232	28.54	<.0001
Oil	Gen2	300	Oil	Gen1	600	148.40	4.8715	232	30.46	<.0001
Oil	Gen2	300	Oil	Gen2	600	162.73	4.8715	232	33.41	<.0001
Oil	Gen1	600	Oil	Gen2	600	14.3333	4.8715	232	2.94	0.0036

The following results refer specifically to each row of results in Table 14.

- Row 1. Comparing the case of motor oil with a Gen 1 tag moving at 300 fpm versus the case of motor oil with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 300 fpm averaging 23.7 more tag reads per trial.
- Row 2. Comparing the case of motor oil with a Gen 1 tag moving at 300 fpm versus the case of motor oil with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 300 fpm averaging 124.7 more tag reads per trial.
- Row 3. Comparing the case of motor oil with a Gen 1 tag moving at 300 fpm versus the case of motor oil with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 300 fpm averaging 139 more tag reads per trial.
- Row 4. Comparing the case of motor oil with a Gen 2 tag moving at 300 fpm versus the case of motor oil with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 300 fpm averaging 148.4 more tag reads per trial.
- Row 5. Comparing the case of motor oil with a Gen 2 tag moving at 300 fpm versus the case of motor oil with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 2 tag moving at 300 fpm averaging 162.7 more tag reads per trial.
- Row 6. Comparing the case of motor oil with a Gen 1 tag moving at 600 fpm versus the case of motor oil with a Gen 2 tag moving at 600 fpm, there was a

significant statistical difference in the number of tag reads, with the case of motor oil with a Gen 1 tag moving at 600 fpm averaging 14.3 more tag reads per trial.

Package Effect Results

Chips in Plastic Tubs

In Trial 1, the case traveled on the conveyor at 300 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 6,681 instances in which the tag was detected. On average there were 222.7 tag reads per trial with a standard deviation of 23.96.

In Trial 2, the case traveled on the conveyor at 600 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 1,869 instances in which the tag was detected. On average there were 62.3 tag reads per trial with a standard deviation of 22.14.

In Trial 3, the case traveled on the conveyor at 300 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 6,753 instances in which the tag was detected. On average there were 225.1 tag reads per trial with a standard deviation of 15.59.

In Trial 4, the case traveled on the conveyor at 600 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 1,750 instances in which the tag was detected. On average there were 58.3 tag reads per trial with a standard deviation of 9.49.

Chips in MSWFC

In Trial 1, the case traveled on the conveyor at 300 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 2,739 instances in which the tag was detected. On average there were 91.3 tag reads per trial with a standard deviation of 14.9.

In Trial 2, the case traveled on the conveyor at 600 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 969 instances in which the tag was detected. On average there were 32.3 tag reads per trial with a standard deviation of 14.7.

In Trial 3, the case traveled on the conveyor at 300 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 2,694 instances in which the tag was detected. On average there were 89.8 tag reads per trial with a standard deviation of 7.5.

In Trial 4, the case traveled on the conveyor at 600 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 820 instances in which the tag was detected. On average there were 27.3 tag reads per trial with a standard deviation of 6.7.

Statistical Analysis of the Package Effect Test

Table 15 depicts the results from testing the fixed effects involved in testing the product effect on tag readability.

Table 15: Tests of Fixed Effects for Package Effect

Type III Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Product	1	232	1664.89	<.0001
Speed	1	232	3120.44	<.0001
Tag	1	232	1.00	0.3182
Product*Speed	1	232	656.00	<.0001
Product*Tag	1	232	0.37	0.5424
Speed*Tag	1	232	1.50	0.2221
Product*Speed*Tag	1	232	0.13	0.7184

The following results refer specifically to each row of results in Table 15.

Row 1. Statistical analysis output concluded that package type (plastic tubs, MSWFC) had a significant effect on the average number of tag reads per trial.

Row 2. Statistical analysis output concluded that speed (300 fpm or 600 fpm) had a significant effect on the average number of tag reads per trial.

Row 3. Statistical analysis output concluded that tag type (Gen 1 or Gen 2) **did not have** a significant effect on the average number of tag reads per trial.

Row 4. Statistical analysis output concluded that product by speed had a significant effect on the average number of tag reads per trial.

Row 5. Statistical analysis output concluded that product by tag **did not have** a significant interaction effect on the average number of tag reads per trial.

Row 6. Statistical analysis output concluded that speed by tag **did not have** significant interaction effect on the average number of tag reads per trial.

Row 7. Statistical analysis output concluded that product by speed by tag **did not have** a significant interaction effect on the average number of tag reads per trial.

Table 16 shows the statistical analysis output concluded that package type had a significant effect on the average amount of tag reads per trial, with the case of potato chips in plastic tubs averaging 81.9 more tag reads per trial than the case of MSWFC.

Table 16: Average Number of Tag Reads Per Trial and Difference Between Means, by Product Type

Product	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	60.1833	1.4197	232	42.39	<.0001
Plastic	142.11	1.4197	232	100.09	<.0001
MD	-81.9250	2.0078	232	-40.80	<.0001

Table 17 shows that statistical analysis output concluded that conveyor speed had a significant effect on the average number of tag reads per trial, with 300 fpm averaging 112.2 more tag reads per trial than 600 fpm.

Table 17: Average Number of Tag Reads Per Trial and Difference Between Means by Conveyor Speed

Speed Least Squares Means					
Speed	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
300	157.23	1.4197	232	110.74	<.0001
600	45.0667	1.4197	232	31.74	<.0001
MD	112.16	2.0078	232	55.86	<.0001

Table 18 shows that statistical analysis output concluded that tag type **did not have** a significant effect on the average number of tag reads per trial, with Gen 1 averaging 2 more tag reads per trial than Gen 2.

Table 18: Average Number of Tag Reads Per Trial and Difference Between Means by Tag Type

Tag Least Squares Means					
Tag	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	102.15	1.4197	232	71.95	<.0001
Gen2	100.14	1.4197	232	70.54	<.0001
MD	2.0083	2.0078	232	1.00	0.3182

Table 19 shows the statistical analysis output of the interaction between the product and a conveyor speed.

Table 19: Average Number of Tag Reads Per Trial, Product by Speed

Product*Speed Least Squares Means						
Product	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**300**	90.5500	2.0078	232	45.10	<.0001
Metal	**600**	29.8167	2.0078	232	14.85	<.0001
Plastic	**300**	223.90	2.0078	232	111.51	<.0001
Plastic	**600**	60.3167	2.0078	232	30.04	<.0001

The following results refer specifically to each row of results in Table 19.

- Row 1. The case of MSWFC moving at 300 fpm averaged 90.6 reads per trial.
- Row 2. The case of MSWFC moving at 600 fpm averaged 29.8 reads per trial.
- Row 3. The case of plastic tubs moving at 300 fpm averaged 223.9 reads per trial.
- Row 4. The case of plastic tubs moving at 600 fpm averaged 60.3 reads per trial.

Table 20 shows the statistical analysis output of the two way interaction between the two products and the two speeds.

Table 20: Difference in Average Number of Tag Reads Per Trial Between Product by Speed

Differences of Product*Speed Least Squares Means								
Product	**Speed**	**_Product**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**300**	**Metal**	**600**	60.7333	2.8395	232	21.39	<.0001
Plastic	**300**	**Plastic**	**600**	163.58	2.8395	232	57.61	<.0001
Metal	**300**	**Plastic**	**300**	-133.35	2.8395	232	-46.96	<.0001
Metal	**300**	**Plastic**	**600**	30.2333	2.8395	232	10.65	<.0001
Metal	**600**	**Plastic**	**300**	-194.08	2.8395	232	-68.35	<.0001
Metal	**600**	**Plastic**	**600**	-30.5000	2.8395	232	-10.74	<.0001

The following results refer specifically to each row of results in Table 20.

- Row 1. Comparing the case of MSWFC moving at 300 fpm versus the case of MSWFC moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC at 300 fpm averaging 60.7 more tag reads per trial.
- Row 2. Comparing the case of plastic tubs moving at 300 fpm versus the case of plastic tubs moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of Plastic Tubs at 300 fpm averaging 163.6 more tag reads per trial.
- Row 3. Comparing the case of MSWFC moving at 300 fpm versus the case of plastic tubs moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs at 300 fpm averaging 133.4 more tag reads per trial.

- Row 4. Comparing the case of MSWFC moving at 300 fpm versus the case of plastic tubs moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC at 300 fpm averaging 30.2 more tag reads per trial.
- Row 5. Comparing the case of MSWFC moving at 600 fpm versus the case of plastic tubs moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs at 300 fpm averaging 194.08 more tag reads per trial.
- Row 6. Comparing the case of MSWFC moving at 600 fpm versus the case of plastic tubs moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs at 600 fpm averaging 30.5 more tag reads per trial.

Table 21 shows the statistical analysis output of the interaction between product and tag type.

Table 21: Average Number of Tag Reads Per Trial, Product by Tag Generation

Product*Tag Least Squares Means						
Product	**Tag**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**Gen1**	61.8000	2.0078	232	30.78	<.0001
Metal	**Gen2**	58.5667	2.0078	232	29.17	<.0001
Plastic	**Gen1**	142.50	2.0078	232	70.97	<.0001
Plastic	**Gen2**	141.72	2.0078	232	70.58	<.0001

The following results refer specifically to each row of results in Table 21.

- Row 1. The case of MSWFC with a Gen 1 tag averaged 61.8 reads per trial.
- Row 2. The case of MSWFC with a Gen 2 tag averaged 58.6 reads per trial.
- Row 3. The case of plastic tubs with a Gen 1 tag averaged 142.5 reads per trial.
- Row 4. The case of plastic tubs with a Gen 2 tag averaged 141.7 reads per trial.

Table 22 shows the statistical analysis output of the two way interaction between the product and tag type.

Table 22: Difference In Average Number of Tag Reads Per Trial Between Product by Tag Type

Differences of Product*Tag Least Squares Means								
Product	**Tag**	**_Product**	**_Tag**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**Gen1**	**Metal**	**Gen2**	3.2333	2.8395	232	1.14	0.2560
Plastic	**Gen1**	**Plastic**	**Gen2**	0.7833	2.8395	232	0.28	0.7829
Metal	**Gen1**	**Plastic**	**Gen1**	-80.7000	2.8395	232	-28.42	<.0001
Metal	**Gen1**	**Plastic**	**Gen2**	-79.9167	2.8395	232	-28.14	<.0001
Metal	**Gen2**	**Plastic**	**Gen1**	-83.9333	2.8395	232	-29.56	<.0001
Metal	**Gen2**	**Plastic**	**Gen2**	-83.1500	2.8395	232	-29.28	<.0001

The following results refer specifically to each row of results in Table 22.

- Row 1. Comparing the Gen 1 tag on a MSWFC versus the Gen 2 tag on a MSWFC, there **was not** a significant difference between the average number of tag reads per trial, with the Gen 1 tag on MSWFC averaging 3.2 more tag reads per trial.

- Row 2. Comparing the Gen 1 tag on plastic tubs versus the Gen 2 tag on plastic tubs, there **was not** a significant difference between the average number of tag reads per trial, with the Gen 1 tag on plastic tubs averaging 0.78 more tag reads per trial.
- Row 3. Comparing the Gen 1 tag on MSWFC versus the Gen 1 tag on plastic tubs, there was a significant statistical difference in the number of tag reads with the Gen 1 tag on plastic tubs averaging 80.7 more tag reads per trial.
- Row 4. Comparing the Gen 1 tag on MSWFC versus the Gen 2 tag on plastic tubs, there was a significant statistical difference in the number of tag reads with the Gen 2 tag on plastic tubs averaging 79.9 more tag reads per trial.
- Row 5. Comparing the Gen 2 tag on MSWFC versus the Gen 1 tag on plastic tubs, there was a significant statistical difference in the number of tag reads with the Gen 1 tag on plastic tubs averaging 83.9 more tag reads per trial.
- Row 6. Comparing the Gen 2 tag on MSWFC versus the Gen 2 tag on plastic tubs, there was a significant statistical difference in the number of tag reads with the Gen 2 tag on plastic tubs averaging 83.2 more tag reads per trial.

Table 23 shows the statistical analysis output of the interaction between tag type and conveyor speed.

Table 23: Average Number of Tag Reads Per Trial, Tag Generation by Speed

Speed*Tag Least Squares Means						
Tag	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	157.00	2.0078	232	78.19	<.0001
Gen2	**300**	157.45	2.0078	232	78.42	<.0001
Gen1	**600**	47.3000	2.0078	232	23.56	<.0001
Gen2	**600**	42.8333	2.0078	232	21.33	<.0001

The following results refer specifically to each row of results in Table 23.

- Row 1. The case with a Gen 1 tag moving 300 fpm averaged 157 reads per trial.
- Row 2. The case with a Gen 2 tag moving 300 fpm averaged 157.5 reads per trial.
- Row 3. The case with a Gen 1 tag moving 600 fpm averaged 47.3 reads per trial.
- Row 4. The case with a Gen 2 tag moving 600 fpm averaged 42.8 reads per trial.

Table 24 shows the statistical analysis output of the two way interaction between the tag type and conveyor speed.

Table 24: Difference In Average Number of Tag Reads Per Trial Between Tag Generation by Speed

Differences of Speed*Tag Least Squares Means								
Tag	**Speed**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	**Gen2**	**300**	-0.4500	2.8395	232	-0.16	0.8742
Gen1	**300**	**Gen1**	**600**	109.70	2.8395	232	38.63	<.0001
Gen1	**300**	**Gen2**	**600**	114.17	2.8395	232	40.21	<.0001
Gen2	**300**	**Gen1**	**600**	110.15	2.8395	232	38.79	<.0001
Gen2	**300**	**Gen2**	**600**	114.62	2.8395	232	40.37	<.0001
Gen1	**600**	**Gen2**	**600**	4.4667	2.8395	232	1.57	0.1171

The following results refer specifically to each row of results in Table 24.

- Row 1. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 2 tag moving at 300 fpm, there **was not** a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 0.5 more tag reads per trial.
- Row 2. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 1 tag at 300 fpm averaging 109.7 more tag reads per trial.
- Row 3. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 1 tag at 300 fpm averaging 114.2 more tag reads per trial.
- Row 4. Comparing the Gen 2 tag moving at 300 fpm versus the Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 110.2 more tag reads per trial.

- Row 5. Comparing the Gen 2 tag moving at 300 fpm versus the Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 114.6 more tag reads per trial.
- Row 6. Comparing the Gen 1 tag moving at 600 fpm versus the Gen 2 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the Gen 1 tag at 600 fpm averaging only 4.5 more tag reads per trial.

Table 25 shows the statistical analysis output of the interaction between the product, tag type, and conveyor speed.

Table 25: Average Number of Tag Reads Per Trial, Product by Tag Generation by Speed

Product*Speed*Tag Least Squares Means							
Product	**Tag**	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**Gen1**	**300**	91.3000	2.8395	232	32.15	<.0001
Metal	**Gen2**	**300**	89.8000	2.8395	232	31.63	<.0001
Metal	**Gen1**	**600**	32.3000	2.8395	232	11.38	<.0001
Metal	**Gen2**	**600**	27.3333	2.8395	232	9.63	<.0001
Plastic	**Gen1**	**300**	222.70	2.8395	232	78.43	<.0001
Plastic	**Gen2**	**300**	225.10	2.8395	232	79.28	<.0001
Plastic	**Gen1**	**600**	62.3000	2.8395	232	21.94	<.0001
Plastic	**Gen2**	**600**	58.3333	2.8395	232	20.54	<.0001

The following results refer specifically to each row of results in Table 25.

- Row 1. The case of MSWFC with a Gen 1 tag moving 300 fpm averaged 91.3 reads per trial.

- Row 2. The case of MSWFC with a Gen 2 tag moving 300 fpm averaged 89.8 reads per trial.
- Row 3. The case of MSWFC with a Gen 1 tag moving 600 fpm averaged 32.3 reads per trial.
- Row 4. The case of MSWFC with a Gen 2 tag moving 600 fpm averaged 27.3 reads per trial.
- Row 5. The case of plastic tubs with a Gen 1 tag moving 300 fpm averaged 222.7 reads per trial.
- Row 6. The case of plastic tubs with a Gen 2 tag moving 300 fpm averaged 225.1 reads per trial.
- Row 7. The case of plastic tubs with a Gen 1 tag moving 600 fpm averaged 62.3 reads per trial.
- Row 8. The case of plastic tubs with a Gen 2 tag moving 600 fpm averaged 58.3 reads per trial.

Metal-Metal Interactions

Table 26 shows the statistical analysis output of the three-way interaction between the case of MSWFC, tag type, and conveyor speed.

Table 26: Difference in Average Number of Tag Reads Per Trial Between Product (MSWFC) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	Gen1	300	Metal	Gen2	300	1.5000	4.0156	232	0.37	0.7091
Metal	Gen1	300	Metal	Gen1	600	59.0000	4.0156	232	14.69	<.0001
Metal	Gen1	300	Metal	Gen2	600	63.9667	4.0156	232	15.93	<.0001
Metal	Gen2	300	Metal	Gen1	600	57.5000	4.0156	232	14.32	<.0001
Metal	Gen2	300	Metal	Gen2	600	62.4667	4.0156	232	15.56	<.0001
Metal	Gen1	600	Metal	Gen2	600	4.9667	4.0156	232	1.24	0.2174

The following results refer specifically to each row of results in Table 26.

- Row 1. Comparing the case of MSWFC with a Gen 1 tag moving at 300 fpm versus the case of MSWFC with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 1 tag moving at 300 fpm averaging 1.5 more tag reads per trial.
- Row 2. Comparing the case of MSWFC with a Gen 1 tag moving at 300 fpm versus the case of MSWFC with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 1 tag moving at 300 fpm averaging 59 more tag reads per trial.
- Row 3. Comparing the case of MSWFC with a Gen 1 tag moving at 300 fpm versus the case of MSWFC with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 1 tag moving at 300 fpm averaging 63.9 more tag reads per trial.
- Row 4. Comparing the case of MSWFC with a Gen 2 tag moving at 300 fpm versus the case of MSWFC with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 2 tag moving at 300 fpm averaging 57.5 more tag reads per trial.
- Row 5. Comparing the case of MSWFC with a Gen 2 tag moving at 300 fpm versus the case of MSWFC with a Gen 2 tag moving at 600 fpm, there was a

significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 2 tag moving at 300 fpm averaging 62.4 more tag reads per trial.

- Row 6. Comparing the case of MSWFC with a Gen 1 tag moving at 600 fpm versus the case of MSWFC with a Gen 2 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 1 tag moving at 600 fpm averaging 5 more tag reads per trial.

Metal-Plastic Interactions

Table 27 shows the statistical analysis output of the three-way interaction between the two products, a tag, and a conveyor speed.

Table 27: Difference in Average Number of Tag Reads Per Trial Between Product (Plastic Tubs and MSWFC) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	Gen1	300	Plastic	Gen1	300	-131.40	4.0156	232	-32.72	<.0001
Metal	Gen1	300	Plastic	Gen2	300	-133.80	4.0156	232	-33.32	<.0001
Metal	Gen1	300	Plastic	Gen1	600	29.0000	4.0156	232	7.22	<.0001
Metal	Gen1	300	Plastic	Gen2	600	32.9667	4.0156	232	8.21	<.0001
Metal	Gen2	300	Plastic	Gen2	300	-135.30	4.0156	232	-33.69	<.0001
Metal	Gen2	300	Plastic	Gen1	600	27.5000	4.0156	232	6.85	<.0001
Metal	Gen2	300	Plastic	Gen2	600	31.4667	4.0156	232	7.84	<.0001
Metal	Gen2	300	Plastic	Gen1	300	-132.90	4.0156	232	-33.10	<.0001
Metal	Gen1	600	Plastic	Gen1	300	-190.40	4.0156	232	-47.41	<.0001
Metal	Gen1	600	Plastic	Gen2	300	-192.80	4.0156	232	-48.01	<.0001
Metal	Gen1	600	Plastic	Gen1	600	-30.0000	4.0156	232	-7.47	<.0001
Metal	Gen1	600	Plastic	Gen2	600	-26.0333	4.0156	232	-6.48	<.0001
Metal	Gen2	600	Plastic	Gen1	300	-195.37	4.0156	232	-48.65	<.0001

Table 27 (cont'd)

Metal	Gen2	600	Plastic	Gen2	300	-197.77	4.0156	232	-49.25	<.0001
Metal	Gen2	600	Plastic	Gen1	600	-34.967	4.0156	232	-8.71	<.0001
Metal	Gen2	600	Plastic	Gen2	600	-31.00	4.0156	232	-7.72	<.0001

The following results refer specifically to each row of results in Table 27.

- Row 1. Comparing the case of MSWFC with a Gen 1 tag moving at 300 fpm versus the case of plastic tubs with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 300 fpm averaging 131.4 more tag reads per trial.
- Row 2. Comparing the case of MSWFC with a Gen 1 tag moving at 300 fpm versus the case of plastic tubs with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 300 fpm averaging 133.8 more tag reads per trial.
- Row 3. Comparing the case of MSWFC with a Gen 1 tag moving at 300 fpm versus the case of plastic tubs with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 1 tag moving at 300 fpm averaging 29 more tag reads per trial.
- Row 4. Comparing the case of MSWFC with a Gen 1 tag moving at 300 fpm versus the case of plastic tubs with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 1 tag moving at 300 fpm averaging 33 more tag reads per trial.
- Row 5. Comparing the case of MSWFC with a Gen 2 tag moving at 300 fpm versus the case of plastic tubs with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 300 fpm averaging 135.3 more tag reads per trial.

- Row 6. Comparing the case of MSWFC with a Gen 2 tag moving at 300 fpm versus the case of plastic tubs with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 2 tag moving at 300 fpm averaging 27.5 more tag reads per trial.
- Row 7. Comparing the case of MSWFC with a Gen 2 tag moving at 300 fpm versus the case of plastic tubs with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of MSWFC with a Gen 2 tag moving at 300 fpm averaging 31.5 more tag reads per trial.
- Row 8. Comparing the case of MSWFC with a Gen 2 tag moving at 300 fpm versus the case of plastic tubs with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 300 fpm averaging 132.9 more tag reads per trial.
- Row 9. Comparing the case of MSWFC with a Gen 1 tag moving at 600 fpm versus the case of plastic tubs with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 300 fpm averaging 190.4 more tag reads per trial.
- Row 10. Comparing the case of MSWFC with a Gen 1 tag moving at 600 fpm versus the case of Plastic Tubs with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 300 fpm averaging 192.8 more tag reads per trial.

- Row 11. Comparing the case of MSWFC with a Gen 1 tag moving at 600 fpm versus the case of plastic tubs with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 600 fpm averaging 30 more tag reads per trial.
- Row 12. Comparing the case of MSWFC with a Gen 1 tag moving at 600 fpm versus the case of plastic tubs with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 600 fpm averaging 26 more tag reads per trial.
- Row 13. Comparing the case of MSWFC with a Gen 2 tag moving at 600 fpm versus the case of plastic tubs with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 300 fpm averaging 195.4 more tag reads per trial.
- Row 14. Comparing the case of MSWFC with a Gen 2 tag moving at 600 fpm versus the case of plastic tubs with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 300 fpm averaging 197.8 more tag reads per trial.
- Row 15. Comparing the case of MSWFC with a Gen 2 tag moving at 600 fpm versus the case of plastic tubs with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 600 fpm averaging 35 more tag reads per trial.
- Row 16. Comparing the case of MSWFC with a Gen 2 tag moving at 600 fpm versus the case of plastic tubs with a Gen 2 tag moving at 600 fpm, there was a

significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 600 fpm averaging 31 more tag reads per trial.

Plastic-Plastic Interactions

Table 28 shows the statistical analysis output of the three-way interaction between the case of plastic tubs, a tag, and a conveyor speed.

Table 28: Difference In Average Number of Tag Reads Per Trial Between Product (Plastic Tubs) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Plastic	Gen1	300	Plastic	Gen2	300	-2.4000	4.0156	232	-0.60	0.5506
Plastic	Gen1	300	Plastic	Gen1	600	160.40	4.0156	232	39.94	<.0001
Plastic	Gen1	300	Plastic	Gen2	600	164.37	4.0156	232	40.93	<.0001
Plastic	Gen2	300	Plastic	Gen1	600	162.80	4.0156	232	40.54	<.0001
Plastic	Gen2	300	Plastic	Gen2	600	166.77	4.0156	232	41.53	<.0001
Plastic	Gen1	600	Plastic	Gen2	600	3.9667	4.0156	232	0.99	0.3243

The following results refer specifically to each row of results in Table 28.

- Row 1. Comparing the case of plastic tubs with a Gen 1 tag moving at 300 fpm versus the case of plastic tubs with a Gen 2 tag moving at 300 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 300 fpm averaging 2.4 more tag reads per trial.
- Row 2. Comparing the case of plastic tubs with a Gen 1 tag moving at 300 fpm versus the case of plastic tubs with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 300 fpm averaging 160.4 more tag reads per trial.
- Row 3. Comparing the case of plastic tubs with a Gen 1 tag moving at 300 fpm versus the case of plastic tubs with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 300 fpm averaging 164.4 more tag reads per trial.
- Row 4. Comparing the case of plastic tubs with a Gen 2 tag moving at 300 fpm versus the case of plastic tubs with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 300 fpm averaging 162.8 more tag reads per trial.
- Row 5. Comparing the case of plastic tubs with a Gen 2 tag moving at 300 fpm versus the case of plastic tubs with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 2 tag moving at 300 fpm averaging 166.7 more tag reads per trial.

- Row 6. Comparing the case of plastic tubs with a Gen 1 tag moving at 600 fpm versus the case of plastic tubs with a Gen 2 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of plastic tubs with a Gen 1 tag moving at 600 fpm averaging 4 more tag reads per trial.

Package Shape Effect Results

Aluminum Cans:

In Trial 1, the case traveled on the conveyor at 300 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 3,015 instances in which the tag was detected. On average there were 100.5 tag reads per trial with a standard deviation of 13.5.

In Trial 2, the case traveled on the conveyor at 600 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 1,235 instances in which the tag was detected. On average there were 41.2 tag reads per trial with a standard deviation of 11.7.

In Trial 3, the case traveled on the conveyor at 300 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 4,601 instances in which the tag was detected. On average there were 153.4 tag reads per trial with a standard deviation of 12.61.

In Trial 4, the case traveled on the conveyor at 600 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 1,273 instances in which the tag was detected. On average there were 42.4 tag reads per trial with a standard deviation of 15.8.

Aluminum Bottles:

In Trial 1, the case traveled on the conveyor at 300 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 2,719 instances in which the tag was detected. On average there were 90.6 tag reads per trial with a standard deviation of 17.3.

In Trial 2, the case traveled on the conveyor at 600 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 1,319 instances in which the tag was detected. On average there were 44 tag reads per trial with a standard deviation of 14.9.

In Trial 3, the case traveled on the conveyor at 300 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 3,166 instances in which the tag was detected. On average there were 105.5 tag reads per trial with a standard deviation of 13.4.

In Trial 4, the case traveled on the conveyor at 600 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 1102 instances in which the tag was detected. On average there were 36.7 tag reads per trial with a standard deviation of 12.7.

Aluminum Tins:

In Trial 1, the case traveled on the conveyor at 300 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 36 instances in which the tag was detected. On average there were 1.2 tag reads per trial with a standard deviation of 1.9.

In Trial 2, the case traveled on the conveyor at 600 fpm equipped with a Gen 1 tag. Over the 30 trials, there were 13 instances in which the tag was detected. On average there were 0.43 tag reads per trial with a standard deviation of 1.2.

In Trial 3, the case traveled on the conveyor at 300 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 1,324 instances in which the tag was detected. On average there were 44.1 tag reads per trial with a standard deviation of 9.1.

In Trial 4, the case traveled on the conveyor at 600 fpm equipped with a Gen 2 tag. Over the 30 trials, there were 112 instances in which the tag was detected. On average there were 3.7 tag reads per trial with a standard deviation of 2.3.

Statistical Analysis of the Package Shape Effect Test

Table 29 depicts the results from testing the fixed effects involved in testing the product effect on tag readability.

Table 29: Tests of Fixed Effects for Product Shape Effect

Type III Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Product	2	348	1230.39	<.0001
Speed	1	348	1901.54	<.0001
Tag	1	348	207.68	<.0001
Product*Speed	2	348	224.12	<.0001
Product*Tag	2	348	33.00	<.0001
Speed*Tag	1	348	228.69	<.0001
Product*Speed*Tag	2	348	11.72	<.0001

The following results refer specifically to each row of results in Table 29.

Row 1. Statistical analysis output concluded that package shape (bottles, cans, tins) had a significant effect on the average number of tag reads per trial.

Row 2. Statistical analysis output concluded that speed (300 fpm or 600 fpm) had a significant effect on the average number of tag reads per trial.

Row 3. Statistical analysis output concluded that tag type (Gen 1 or Gen 2) had a significant effect on the average number of tag reads per trial.

Row 4. Statistical analysis output concluded that product by speed had a significant effect on the average number of tag reads per trial.

Row 5. Statistical analysis output concluded that product by tag had a significant interaction effect on the average number of tag reads per trial.

Row 6. Statistical analysis output concluded that speed by tag had significant interaction effect on the average number of tag reads per trial.

Row 7. Statistical analysis output concluded that product by speed by tag had a significant interaction effect on the average number of tag reads per trial.

Table 30 shows the statistical analysis output of the average number of tag reads per trial by product.

Table 30: Average Number of Tag Reads Per Trial by Product Type

Product Least Squares Means					
Product	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	69.2167	1.0820	348	63.97	<.0001
Can	84.3667	1.0820	348	77.97	<.0001
Tin	12.3750	1.0820	348	11.44	<.0001

The following results refer specifically to each row of results in Table 30.

- Row 1. The case of bottles, averaged 69.2 tag reads per trial,

- Row 2. The case of cans averaged 84.4 tag reads per trial
- Row 3. The case of tins averaged 12.4 tag reads per trial.

Table 31 shows the statistical analysis output of the comparison of the average number of reads per trial by product.

Table 31: Difference Average Number of Reads Per Trial by Product Type

Differences of Product Least Squares Means						
Product	**_Product**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	**Can**	-15.1500	1.5302	348	-9.90	<.0001
Bottle	**Tin**	56.8417	1.5302	348	37.15	<.0001
Can	**Tin**	71.9917	1.5302	348	47.05	<.0001

The following results refer specifically to each row of results in Table 31.

- Row 1. Comparing the case of bottles versus the case of cans, there was a significant statistical difference in the number of tag reads, with the cans averaging 15.2 more tag reads per trial.
- Row 2. Comparing the case of bottles versus the case of tins, there was a significant statistical difference in the number of tag reads, with the bottles averaging 56.8 more tag reads per trial.
- Row 3. Comparing the case of cans versus the case of tins, there was a significant statistical difference in the number of tag reads, with the cans averaging 72 more tag reads per trial.

Table 32 shows statistical analysis output concluded that conveyor speed had a significant effect on the average number of tag reads per trial, with 300 fpm averaging 54.5 more tag reads per trial than 600 fpm.

Table 32: Average Number of Tag Reads Per Trial and Difference Between Means by Conveyor Speed

Speed Least Squares Means					
Speed	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
300	82.5611	0.8835	348	93.45	<.0001
600	28.0778	0.8835	348	31.78	<.0001
MD	54.4833	1.2494	348	43.61	<.0001

Table 33 shows statistical analysis output concluded that tag type had a significant effect on the average number of tag reads per trial, with Gen 2 averaging 18 more tag reads per trial than Gen 1.

Table 33: Average Number of Tag Reads Per Trial and Difference Between Means by Tag Type

Tag Least Squares Means					
Tag	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	46.3167	0.8835	348	52.43	<.0001
Gen2	64.3222	0.8835	348	72.81	<.0001
MD	-18.0056	1.2494	348	-14.41	<.0001

Table 34 shows the statistical analysis output of the interaction between the product and a conveyor speed.

Table 34: Average Number of Tag Reads Per Trial, Product by Speed

Product*Speed Least Squares Means						
Product	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	**300**	98.0833	1.5302	348	64.10	<.0001
Bottle	**600**	40.3500	1.5302	348	26.37	<.0001
Can	**300**	126.93	1.5302	348	82.95	<.0001
Can	**600**	41.8000	1.5302	348	27.32	<.0001
Tin	**300**	22.6667	1.5302	348	14.81	<.0001
Tin	**600**	2.0833	1.5302	348	1.36	0.1743

The following results refer specifically to each row of results in Table 34.

- Row 1. The case of bottles moving at 300 fpm averaged 98.1 reads per trial,
- Row 2. The case of bottles moving at 600 fpm averaged 40.4 reads per trial
- Row 3. The case of cans moving at 300 fpm averaged 126.9 reads per trial,
- Row 4. The case of cans moving at 600 fpm averaged 41.8 reads per trial
- Row 5. The case of tins moving at 300 fpm averaged 22.7 reads per trial
- Row 6. The case of tins moving at 600 fpm averaged 2.1 reads per trial, this **was not** a statistically significant amount.

Table 35 shows the statistical analysis output of the interaction between the two way interaction between the three products and the two speeds.

Table 35: Difference in Average Number of Tag Reads Per Trial Between Product by Speed

Differences of Product*Speed Least Squares Means								
Product	Speed	_Product	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	300	Bottle	600	57.7333	2.1641	348	26.68	<.0001
Bottle	300	Can	300	-28.8500	2.1641	348	-13.33	<.0001
Bottle	300	Can	600	56.2833	2.1641	348	26.01	<.0001
Bottle	300	Tin	300	75.4167	2.1641	348	34.85	<.0001
Bottle	300	Tin	600	96.0000	2.1641	348	44.36	<.0001
Bottle	600	Can	300	-86.5833	2.1641	348	-40.01	<.0001
Bottle	600	Can	600	-1.4500	2.1641	348	-0.67	0.5033
Bottle	600	Tin	300	17.6833	2.1641	348	8.17	<.0001
Bottle	600	Tin	600	38.2667	2.1641	348	17.68	<.0001
Can	300	Can	600	85.1333	2.1641	348	39.34	<.0001
Can	300	Tin	300	104.27	2.1641	348	48.18	<.0001
Can	300	Tin	600	124.85	2.1641	348	57.69	<.0001
Can	600	Tin	300	19.1333	2.1641	348	8.84	<.0001
Can	600	Tin	600	39.7167	2.1641	348	18.35	<.0001

Table 35 (cont'd)

Tin	**300**	**Tin**	**600**	20.5833	2.1641	348	9.51	<.0001

The following results refer specifically to each row of results in Table 35.

- Row 1. Comparing the case of bottles moving at 300 fpm versus the case of bottles moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles at 300 fpm averaging 57.7 more tag reads per trial.
- Row 2. Comparing the case of bottles moving at 300 fpm versus the case of cans moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans at 300 fpm averaging 28.9 more tag reads per trial.
- Row 3. Comparing the case of bottles moving at 300 fpm versus the case of cans moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles at 300 fpm averaging 56.3 more tag reads per trial.
- Row 4. Comparing the case of bottles moving at 300 fpm versus the case of tins moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles at 300 fpm averaging 75.4 more tag reads per trial.
- Row 5. Comparing the case of bottles moving at 300 fpm versus the case of tins moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles at 300 fpm averaging 96 more tag reads per trial.
- Row 6. Comparing the case of bottles moving at 600 fpm versus the case of cans moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans at 300 fpm averaging 86.6 more tag reads per trial.

- Row 7. Comparing the case of bottles moving at 600 fpm versus the case of cans moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of cans at 600 fpm averaging 1.5 more tag reads per trial.
- Row 8. Comparing the case of bottles moving at 600 fpm versus the case of tins moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles at 600 fpm averaging 17.7 more tag reads per trial.
- Row 9. Comparing the case of bottles moving at 600 fpm versus the case of tins moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles at 600 fpm averaging 38.3 more tag reads per trial.
- Row 10. Comparing the case of cans moving at 300 fpm versus the case of cans moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans at 300 fpm averaging 85.1 more tag reads per trial.
- Row 11. Comparing the case of cans moving at 300 fpm versus the case of tins moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans at 300 fpm averaging 104.3 more tag reads per trial.
- Row 12. Comparing the case of cans moving at 300 fpm versus the case of tins moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans at 300 fpm averaging 124.9 more tag reads per trial.

- Row 13. Comparing the case of cans moving at 600 fpm versus the case of tins moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans at 600 fpm averaging 19.1 more tag reads per trial.
- Row 14. Comparing the case of cans moving at 600 fpm versus the case of tins moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans at 600 fpm averaging 39.7 more tag reads per trial.
- Row15. Comparing the case of tins moving at 300 fpm versus the case of tins moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of tins at 300 fpm averaging 20.6 more tag reads per trial.

Table 36 shows the statistical analysis output of the interaction between product and tag type.

Table 36: Average Number of Tag Reads Per Trial, Product by Tag Generation

Product*Tag Least Squares Means						
Product	**Tag**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	**Gen1**	67.3000	1.5302	348	43.98	<.0001
Bottle	**Gen2**	71.1333	1.5302	348	46.49	<.0001
Can	**Gen1**	70.8333	1.5302	348	46.29	<.0001
Can	**Gen2**	97.9000	1.5302	348	63.98	<.0001
Tin	**Gen1**	0.8167	1.5302	348	0.53	0.5939
Tin	**Gen2**	23.9333	1.5302	348	15.64	<.0001

The following results refer specifically to each row of results in Table 36.

- Row 1. The case of bottles with a Gen 1 tag averaged 67.3 reads per trial.
- Row 2. The case of bottles with a Gen 2 tag averaged 71.3 reads per trial.
- Row 3. The case of cans with a Gen 1 tag averaged 70.8 reads per trial.
- Row 4. The case of cans with a Gen 2 tag averaged 97.9 reads per trial.
- Row 5. The case of tins with a Gen 1 tag averaged 0.8 reads per trial; this **was not** a statistically significant amount.
- Row 6. The case of tins with a Gen 2 tag averaged 23.9 reads per trial.

Table 37 shows the statistical analysis output of the two way interaction between the product and tag type.

Table 37: Difference In Average Number of Tag Reads Per Trial Between Product by Tag Type

Differences of Product*Tag Least Squares Means								
Product	Tag	_Product	_Tag	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen1	Bottle	Gen2	-3.8333	2.1641	348	-1.77	0.0774
Bottle	Gen1	Can	Gen1	-3.5333	2.1641	348	-1.63	0.1034
Bottle	Gen1	Can	Gen2	-30.6000	2.1641	348	-14.14	<.0001
Bottle	Gen1	Tin	Gen1	66.4833	2.1641	348	30.72	<.0001
Bottle	Gen1	Tin	Gen2	43.3667	2.1641	348	20.04	<.0001
Bottle	Gen2	Can	Gen1	0.3000	2.1641	348	0.14	0.8898
Bottle	Gen2	Can	Gen2	-26.7667	2.1641	348	-12.37	<.0001
Bottle	Gen2	Tin	Gen1	70.3167	2.1641	348	32.49	<.0001
Bottle	Gen2	Tin	Gen2	47.2000	2.1641	348	21.81	<.0001
Can	Gen1	Can	Gen2	-27.0667	2.1641	348	-12.51	<.0001
Can	Gen1	Tin	Gen1	70.0167	2.1641	348	32.35	<.0001
Can	Gen1	Tin	Gen2	46.9000	2.1641	348	21.67	<.0001
Can	Gen2	Tin	Gen1	97.0833	2.1641	348	44.86	<.0001
Can	Gen2	Tin	Gen2	73.9667	2.1641	348	34.18	<.0001
Tin	Gen1	Tin	Gen2	-23.1167	2.1641	348	-10.68	<.0001

The following results refer specifically to each row of results in Table 37.

- Row 1. Comparing the case of bottles with a Gen 1 tag versus the case of bottles with a Gen 2 tag, there **was not** a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag averaging 3.8 more tag reads per trial.

- Row 2. Comparing the case of bottles with a Gen 1 tag versus the case of cans with a Gen 1 tag, there **was not** a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag averaging 3.5 more tag reads per trial.
- Row 3. Comparing the case of bottles with a Gen 1 tag versus the case of cans with a Gen 2 tag, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag averaging 30.6 more tag reads per trial.
- Row 4. Comparing the case of bottles with a Gen 1 tag versus the case of tins with a Gen 1 tag, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag averaging 66.5 more tag reads per trial.
- Row 5. Comparing the case of bottles with a Gen 1 tag versus the case of tins with a Gen 2 tag, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag averaging 43.4 more tag reads per trial.
- Row 6. Comparing the case of bottles with a Gen 2 tag versus the case of cans with a Gen 1 tag, there **was not** significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag averaging 0.3 more tag reads per trial.
- Row 7. Comparing the case of bottles with a Gen 2 tag versus the case of cans with a Gen 2 tag, there was a significant statistical difference in the number of tag

reads, with the case of cans with a Gen 2 tag averaging 26.8 more tag reads per trial.

- Row 8. Comparing the case of bottles with a Gen 2 tag versus the case of tins with a Gen 1 tag, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag averaging 70.3 more tag reads per trial.
- Row 9. Comparing the case of bottles with a Gen 2 tag versus the case of tins with a Gen 2 tag, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag averaging 47.2 more tag reads per trial.
- Row 10. Comparing the case of cans with a Gen 1 tag versus the case of cans with a Gen 2 tag, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag averaging 27.1 more tag reads per trial.
- Row 11. Comparing the case of cans with a Gen 1 tag versus the case of tins with a Gen 1 tag, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag averaging 70 more tag reads per trial.
- Row 12. Comparing the case of cans with a Gen 1 tag versus the case of tins with a Gen 2 tag, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag averaging 46.9 more tag reads per trial.

- Row 13. Comparing the case of cans with a Gen 2 tag versus the case of tins with a Gen 1 tag, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag averaging 97.1 more tag reads per trial.
- Row 14. Comparing the case of cans with a Gen 2 tag versus the case of tins with a Gen 2 tag, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag averaging 74 more tag reads per trial.
- Row 15. Comparing the case of tins with a Gen 1 tag versus the case of tins with a Gen 2 tag, there was a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag averaging 23.1 more tag reads per trial.

Table 38 shows the statistical analysis output of the interaction between product and tag type.

Table 38: Average Number of Tag Reads Per Trial, Product by Tag Generation

Speed*Tag Least Squares Means						
Tag	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	64.1111	1.2494	348	51.31	<.0001
Gen2	**300**	101.01	1.2494	348	80.85	<.0001
Gen1	**600**	28.5222	1.2494	348	22.83	<.0001
Gen2	**600**	27.6333	1.2494	348	22.12	<.0001

The following results refer specifically to each row of results in Table 38.

- Row 1. A case with a Gen 1 tag moving 300 fpm averaged 64.1 reads per trial,

- Row 2. A case with a Gen 2 tag moving 300 fpm averaged 101 reads per trial, a statistically significant amount.
- Row 3. A case with a Gen 1 tag moving 600 fpm averaged 28.5 reads per trial, a statistically significant amount.
- Row 4. A case with a Gen 2 tag moving 600 fpm averaged 27.6 reads per trial, a statistically significant amount.

Table 39 shows the statistical analysis output of the two way interaction between the tag type and speed

Table 39: Difference In Average Number of Tag Reads Per Trial Between Tag Type by Speed

Differences of Speed*Tag Least Squares Means								
Tag	**Speed**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	**Gen2**	**300**	-36.9000	1.7670	348	-20.88	<.0001
Gen1	**300**	**Gen1**	**600**	35.5889	1.7670	348	20.14	<.0001
Gen1	**300**	**Gen2**	**600**	36.4778	1.7670	348	20.64	<.0001
Gen2	**300**	**Gen1**	**600**	72.4889	1.7670	348	41.02	<.0001
Gen2	**300**	**Gen2**	**600**	73.3778	1.7670	348	41.53	<.0001
Gen1	**600**	**Gen2**	**600**	0.8889	1.7670	348	0.50	0.6152

The following results refer specifically to each row of results in Table 39.

- Row 1. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 36.9 more tag reads per trial.

- Row 2. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 1 tag at 300 fpm averaging 35.6 more tag reads per trial.
- Row 3. Comparing the Gen 1 tag moving at 300 fpm versus the Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 1 tag at 300 fpm averaging 36.5 more tag reads per trial.
- Row 4. Comparing the Gen 2 tag moving at 300 fpm versus the Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 72.5 more tag reads per trial.
- Row 5. Comparing the Gen 2 tag moving at 300 fpm versus the Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the Gen 2 tag at 300 fpm averaging 73.4 more tag reads per trial.
- Row 6. Comparing the Gen 1 tag moving at 600 fpm versus the Gen 2 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the Gen 1 tag at 600 fpm averaging only 0.9 more tag reads per trial.

Table 40 shows the statistical analysis output of the interaction between the product, tag type, and conveyor speed.

Table 40: Average Number of Tag Reads Per Trial, Product by Tag Generation by Speed

Product*Speed*Tag Least Squares Means							
Product	**Tag**	**Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	**Gen1**	**300**	90.6333	2.1641	348	41.88	<.0001
Bottle	**Gen2**	**300**	105.53	2.1641	348	48.77	<.0001
Bottle	**Gen1**	**600**	43.9667	2.1641	348	20.32	<.0001
Bottle	**Gen2**	**600**	36.7333	2.1641	348	16.97	<.0001
Can	**Gen1**	**300**	100.50	2.1641	348	46.44	<.0001
Can	**Gen2**	**300**	153.37	2.1641	348	70.87	<.0001
Can	**Gen1**	**600**	41.1667	2.1641	348	19.02	<.0001
Can	**Gen2**	**600**	42.4333	2.1641	348	19.61	<.0001
Tin	**Gen1**	**300**	1.2000	2.1641	348	0.55	0.5796
Tin	**Gen2**	**300**	44.1333	2.1641	348	20.39	<.0001
Tin	**Gen1**	**600**	0.4333	2.1641	348	0.20	0.8414
Tin	**Gen2**	**600**	3.7333	2.1641	348	1.73	0.0854

The following results refer specifically to each row of results in Table 40.

- Row 1. The case of bottles with a Gen 1 tag moving 300 fpm averaged 90.6 tag reads per trial.
- Row 2. The case of bottles with a Gen 2 tag moving 300 fpm averaged 105.5 tag reads per trial.
- Row 3. The case of bottles with a Gen 1 tag moving 600 fpm averaged 44 tag reads per trial.

- Row 4. The case of bottles with a Gen 2 tag moving 600 fpm averaged 36.7 tag reads per trial.
- Row 5. The case of cans with a Gen 1 tag moving 300 fpm averaged 100.5 tag reads per trial.
- Row 6. The case of cans with a Gen 2 tag moving 300 fpm averaged 153.4 tag reads per trial.
- Row 7. The case of cans with a Gen 1 tag moving 600 fpm averaged 41.2 tag reads per trial.
- Row 8. The case of cans with a Gen 2 tag moving 600 fpm averaged 42.4 tag reads per trial.
- Row 9. The case of tins with a Gen 1 tag moving 300 fpm averaged 1.2 tag reads per trial, this **was not** a statistically significant amount.
- Row 10. The case of tins with a Gen 2 tag moving 300 fpm averaged 44.1 tag reads per trial.
- Row 11. The case of tins with a Gen 1 tag moving 600 fpm averaged 0.43 tag reads per trial, this **was not** a statistically significant amount.
- Row 12. The case of tins with a Gen 2 tag moving 600 fpm averaged 3.7 tag reads per trial.

Bottle-Bottle Interaction

Table 41 shows the statistical analysis output of the three-way interaction between the case of bottles, tag type, and conveyor speed.

Table 41: Difference in Average Number of Tag Reads Per Trial Between Product (Bottles) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	**Tag**	**Speed**	**_Product**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	**Gen1**	**300**	**Bottle**	**Gen2**	**300**	-14.9000	3.0605	348	-4.87	<.0001
Bottle	**Gen1**	**300**	**Bottle**	**Gen1**	**600**	46.6667	3.0605	348	15.25	<.0001
Bottle	**Gen1**	**300**	**Bottle**	**Gen2**	**600**	53.9000	3.0605	348	17.61	<.0001
Bottle	**Gen2**	**300**	**Bottle**	**Gen1**	**600**	61.5667	3.0605	348	20.12	<.0001
Bottle	**Gen2**	**300**	**Bottle**	**Gen2**	**600**	68.8000	3.0605	348	22.48	<.0001
Bottle	**Gen1**	**600**	**Bottle**	**Gen2**	**600**	7.2333	3.0605	348	2.36	0.0187

The following results refer specifically to each row of results in Table 41.

- Row 1. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of bottles with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 14.9 more tag reads per trial.
- Row 2. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of bottles with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 46.7 more tag reads per trial.
- Row 3. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of bottles with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 53.9 more tag reads per trial.
- Row 4. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of bottles with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 61.6 more tag reads per trial.
- Row 5. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of bottles with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 68.8 more tag reads per trial.
- Row 6. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of bottles with a Gen 2 tag moving at 600 fpm, there **was not** a

significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 600 fpm averaging 7.2 more tag reads per trial.

Can-Can Interaction

Table 42 shows the statistical analysis output of the three-way interaction between the case of cans, tag type, and conveyor speed.

Table 42: Difference in Average Number of Tag Reads Per Trial Between Product (Cans) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Can	Gen1	300	Can	Gen2	300	-52.8667	3.0605	348	-17.27	<.0001
Can	Gen1	300	Can	Gen1	600	59.3333	3.0605	348	19.39	<.0001
Can	Gen1	300	Can	Gen2	600	58.0667	3.0605	348	18.97	<.0001
Can	Gen2	300	Can	Gen1	600	112.20	3.0605	348	36.66	<.0001
Can	Gen2	300	Can	Gen2	600	110.93	3.0605	348	36.25	<.0001
Can	Gen1	600	Can	Gen2	600	-1.2667	3.0605	348	-0.41	0.6792

The following results refer specifically to each row of results in Table 42.

- Row 1. Comparing the case of cans with a Gen 1 tag moving at 300 fpm versus the case of cans with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 52.9 more tag reads per trial.
- Row 2. Comparing the case of cans with a Gen 1 tag moving at 300 fpm versus the case of cans with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 59.3 more tag reads per trial.
- Row 3. Comparing the case of cans with a Gen 1 tag moving at 300 fpm versus the case of cans with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 58.1 more tag reads per trial.
- Row 4. Comparing the case of cans with a Gen 2 tag moving at 300 fpm versus the case of cans with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 112.2 more tag reads per trial.
- Row 5. Comparing the case of cans with a Gen 2 tag moving at 300 fpm versus the case of cans with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 110.9 more tag reads per trial.
- Row 6. Comparing the case of cans with a Gen 1 tag moving at 600 fpm versus the case of cans with a Gen 2 tag moving at 600 fpm, there **was not** a significant

statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 600 fpm averaging 1.30 more tag reads per trial.

Tin-Tin Interaction

Table 43 shows the statistical analysis output of the three-way interaction between the case of tins, tag type, and conveyor speed.

Table 43: Difference in Average Number of Tag Reads Per Trial Between Product (Tins) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Tin	Gen1	300	Tin	Gen2	300	-42.9333	3.0605	348	-14.03	<.0001
Tin	Gen1	300	Tin	Gen1	600	0.7667	3.0605	348	0.25	0.8023
Tin	Gen1	300	Tin	Gen2	600	-2.5333	3.0605	348	-0.83	0.4084
Tin	Gen2	300	Tin	Gen1	600	43.7000	3.0605	348	14.28	<.0001
Tin	Gen2	300	Tin	Gen2	600	40.4000	3.0605	348	13.20	<.0001
Tin	Gen1	600	Tin	Gen2	600	-3.3000	3.0605	348	-1.08	0.2817

The following results refer specifically to each row of results in Table 43.

- Row 1. Comparing the case of tins with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 300 fpm averaging 42.9 more tag reads per trial.
- Row 2. Comparing the case of tins with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of tins with a Gen 1 tag moving at 300 fpm averaging 0.7 more tag reads per trial.
- Row 3. Comparing the case of tins with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 600 fpm averaging 2.5 more tag reads per trial.
- Row 4. Comparing the case of tins with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 300 fpm averaging 43.7 more tag reads per trial.
- Row 5. Comparing the case of tins with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 300 fpm averaging 40.4 more tag reads per trial.
- Row 6. Comparing the case of tins with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there **was not** a significant

statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 600 fpm averaging 3.3 more tag reads per trial.

Bottle-Can Interactions

Table 44 shows the statistical analysis output of the three-way interaction between the bottles and cans, tag type, and conveyor speed.

Table 44: Difference in Average Number of Tag Reads Per Trial Between Two Products (Bottles and Cans) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	**Tag**	**Speed**	**_Product**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	Gen1	300	Can	Gen1	300	-9.8667	3.0605	348	-3.22	0.0014
Bottle	Gen1	300	Can	Gen2	300	-62.7333	3.0605	348	-20.50	<.0001
Bottle	Gen1	300	Can	Gen1	600	49.4667	3.0605	348	16.16	<.0001
Bottle	Gen1	300	Can	Gen2	600	48.2000	3.0605	348	15.75	<.0001
Bottle	Gen2	300	Can	Gen2	300	-47.8333	3.0605	348	-15.63	<.0001
Bottle	Gen2	300	Can	Gen1	600	64.3667	3.0605	348	21.03	<.0001
Bottle	Gen2	300	Can	Gen2	600	63.1000	3.0605	348	20.62	<.0001
Bottle	Gen2	300	Can	Gen1	300	5.0333	3.0605	348	1.64	0.1009
Bottle	Gen1	600	Can	Gen1	300	-56.5333	3.0605	348	-18.47	<.0001
Bottle	Gen1	600	Can	Gen2	300	-109.40	3.0605	348	-35.75	<.0001
Bottle	Gen1	600	Can	Gen1	600	2.8000	3.0605	348	0.91	0.3609
Bottle	Gen1	600	Can	Gen2	600	1.5333	3.0605	348	0.50	0.6167
Bottle	Gen2	600	Can	Gen1	300	-63.7667	3.0605	348	-20.84	<.0001
Bottle	Gen2	600	Can	Gen2	300	-116.63	3.0605	348	-38.11	<.0001

Table 44 (cont'd)

Bottle	Gen2	600	Can	Gen1	600	-4.4333	3.0605	348	-1.45	0.1484
Bottle	Gen2	600	Can	Gen2	600	-5.7000	3.0605	348	-1.86	0.0634

The following results refer specifically to each row of results in Table 44.

- Row 1. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of cans with a Gen 1 tag moving at 300 fpm, there a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 9.9 more tag reads per trial.
- Row 2. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of cans with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 62.7 more tag reads per trial.
- Row 3. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of cans with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 49.5 more tag reads per trial.
- Row 4. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of cans with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 48.2 more tag reads per trial.
- Row 5. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of cans with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 47.8 more tag reads per trial.
- Row 6. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of cans with a Gen 1 tag moving at 600 fpm, there was a significant

statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 64.4 more tag reads per trial.

- Row 7. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of cans with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 63.1 more tag reads per trial.
- Row 8. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of cans with a Gen 1 tag moving at 300 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 5 more tag reads per trial.
- Row 9. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of cans with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 56.5 more tag reads per trial.
- Row 10. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of cans with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 109.4 more tag reads per trial.
- Row 11. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of cans with a Gen 1 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 600 fpm averaging 2.8 more tag reads per trial.

- Row 12. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of cans with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 600 fpm averaging 1.5 more tag reads per trial.
- Row 13. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of cans with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 63.8 more tag reads per trial.
- Row 14. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of cans with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 116.6 more tag reads per trial.
- Row 15. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of cans with a Gen 1 tag moving at 600 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 600 fpm averaging 4.4 more tag reads per trial.
- Row 16. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of cans with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 600 fpm averaging 5.7 more tag reads per trial.

Bottle-Tin Interactions

Table 45 shows the statistical analysis output of the three-way interaction between the bottles and tins, tag type, and conveyor speed.

Table 45: Difference in Average Number of Tag Reads Per Trial Between Two Products (Bottles and Tins) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen1	300	Tin	Gen1	300	89.4333	3.0605	348	29.22	<.0001
Bottle	Gen1	300	Tin	Gen2	300	46.5000	3.0605	348	15.19	<.0001
Bottle	Gen1	300	Tin	Gen1	600	90.2000	3.0605	348	29.47	<.0001
Bottle	Gen1	300	Tin	Gen2	600	86.9000	3.0605	348	28.39	<.0001
Bottle	Gen2	300	Tin	Gen2	300	61.4000	3.0605	348	20.06	<.0001
Bottle	Gen2	300	Tin	Gen1	600	105.10	3.0605	348	34.34	<.0001
Bottle	Gen2	300	Tin	Gen2	600	101.80	3.0605	348	33.26	<.0001
Bottle	Gen2	300	Tin	Gen1	300	104.33	3.0605	348	34.09	<.0001
Bottle	Gen1	600	Tin	Gen1	300	42.7667	3.0605	348	13.97	<.0001
Bottle	Gen1	600	Tin	Gen2	300	-0.1667	3.0605	348	-0.05	0.9566
Bottle	Gen1	600	Tin	Gen1	600	43.5333	3.0605	348	14.22	<.0001
Bottle	Gen1	600	Tin	Gen2	600	40.2333	3.0605	348	13.15	<.0001
Bottle	Gen2	600	Tin	Gen1	300	35.5333	3.0605	348	11.61	<.0001
Bottle	Gen2	600	Tin	Gen2	300	-7.4000	3.0605	348	-2.42	0.0161

Table 45 (cont'd)

Bottle	Gen2	600	Tin	Gen1	600	36.3000	3.0605	348	11.86	<.0001
Bottle	Gen2	600	Tin	Gen2	600	33.0000	3.0605	348	10.78	<.0001

The following results refer specifically to each row of results in Table 45.

- Row 1. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 89.4 more tag reads per trial.
- Row 2. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 46.5 more tag reads per trial.
- Row 3. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 90.2 more tag reads per trial.
- Row 4. Comparing the case of bottles with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 300 fpm averaging 86.9 more tag reads per trial.
- Row 5. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 61.4 more tag reads per trial.
- Row 6. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant

statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 105.1 more tag reads per trial.

- Row 7. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 101.8 more tag reads per trial.
- Row 8. Comparing the case of bottles with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 300 fpm averaging 104.3 more tag reads per trial.
- Row 9. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 600 fpm averaging 42.8 more tag reads per trial.
- Row 10. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 300 fpm averaging 0.2 more tag reads per trial.
- Row 11. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 600 fpm averaging 43.5 more tag reads per trial.

- Row 12. Comparing the case of bottles with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 1 tag moving at 600 fpm averaging 40.2 more tag reads per trial.
- Row 13. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 600 fpm averaging 35.5 more tag reads per trial.
- Row 14. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 300 fpm averaging 7.4 more tag reads per trial.
- Row 15. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 600 fpm averaging 36.3 more tag reads per trial.
- Row 16. Comparing the case of bottles with a Gen 2 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of bottles with a Gen 2 tag moving at 600 fpm averaging 33 more tag reads per trial.

Can-Tin Interactions

Table 46 shows the statistical analysis output of the three-way interaction between the cans and tins, tag type, and conveyor speed.

Table 46: Difference in Average Number of Tag Reads Per Trial Between Two Products (Cans and Tins) by Tag Generation by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Can	Gen1	300	Tin	Gen1	300	99.3000	3.0605	348	32.45	<.0001
Can	Gen1	300	Tin	Gen2	300	56.3667	3.0605	348	18.42	<.0001
Can	Gen1	300	Tin	Gen1	600	100.07	3.0605	348	32.70	<.0001
Can	Gen1	300	Tin	Gen2	600	96.7667	3.0605	348	31.62	<.0001
Can	Gen2	300	Tin	Gen2	300	109.23	3.0605	348	35.69	<.0001
Can	Gen2	300	Tin	Gen1	600	152.93	3.0605	348	49.97	<.0001
Can	Gen2	300	Tin	Gen2	600	149.63	3.0605	348	48.89	<.0001
Can	Gen2	300	Tin	Gen1	300	152.17	3.0605	348	49.72	<.0001
Can	Gen1	600	Tin	Gen1	300	39.9667	3.0605	348	13.06	<.0001
Can	Gen1	600	Tin	Gen2	300	-2.9667	3.0605	348	-0.97	0.3330
Can	Gen1	600	Tin	Gen1	600	40.7333	3.0605	348	13.31	<.0001
Can	Gen1	600	Tin	Gen2	600	37.4333	3.0605	348	12.23	<.0001
Can	Gen2	600	Tin	Gen1	300	41.2333	3.0605	348	13.47	<.0001
Can	Gen2	600	Tin	Gen2	300	-1.7000	3.0605	348	-0.56	0.5789

Table 46 (cont'd)

Can	Gen2	600	Tin	Gen1	600	42.0000	3.0605	348	13.72	<.0001
Can	Gen2	600	Tin	Gen2	600	38.7000	3.0605	348	12.65	<.0001

The following results refer specifically to each row of results in Table 46.

- Row 1. Comparing the case of cans with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 99.3 more tag reads per trial.
- Row 2. Comparing the case of cans with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 56.4 more tag reads per trial.
- Row 3. Comparing the case of cans with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 100.7 more tag reads per trial.
- Row 4. Comparing the case of cans with a Gen 1 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 300 fpm averaging 96.8 more tag reads per trial.
- Row 5. Comparing the case of cans with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 109.2 more tag reads per trial.
- Row 6. Comparing the case of cans with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant

statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 152.9 more tag reads per trial.

- Row 7. Comparing the case of cans with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 149.6 more tag reads per trial.
- Row 8. Comparing the case of cans with a Gen 2 tag moving at 300 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 300 fpm averaging 152.2 more tag reads per trial.
- Row 9. Comparing the case of cans with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 600 fpm averaging 40 more tag reads per trial.
- Row 10. Comparing the case of cans with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 300 fpm averaging 3 more tag reads per trial.
- Row 11. Comparing the case of cans with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 600 fpm averaging 40.7 more tag reads per trial.

- Row 12. Comparing the case of cans with a Gen 1 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 1 tag moving at 600 fpm averaging 37.4 more tag reads per trial.
- Row13. Comparing the case of cans with a Gen 2 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 300 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 600 fpm averaging 41.2 more tag reads per trial.
- Row14. Comparing the case of cans with a Gen 2 tag moving at 600 fpm versus the case of tins with a Gen 2 tag moving at 300 fpm, there **was not** a significant statistical difference in the number of tag reads, with the case of tins with a Gen 2 tag moving at 300 fpm averaging 1.7 more tag reads per trial.
- Row 15. Comparing the case of cans with a Gen 2 tag moving at 600 fpm versus the case of tins with a Gen 1 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 600 fpm averaging 42 more tag reads per trial.
- Row 16. Comparing the case of cans with a Gen 2 tag moving at 600 fpm versus the case of Tins with a Gen 2 tag moving at 600 fpm, there was a significant statistical difference in the number of tag reads, with the case of cans with a Gen 2 tag moving at 600 fpm averaging 38.7 more tag reads per trial.

CHAPTER 5 – CONCLUSIONS AND RECOMMENDATIONS

The results of the testing described in the previous chapter show that conveyor speed had a significant impact on the average number of tag reads per trial for RFID transponders on packages. Additionally, product type, package type, and package shape all had a significant impact on the average number of tag reads per trial for RFID transponders on packages moving on a conveyor. The results also show that the tag type, had a significant effect on the average number of tag reads per trial for product type (ketchup and motor oil), and package shape (cans, bottles, and tins), but did not have a significant impact on average number of tag reads per trial for RFID transponders that were placed on the package effect products (plastic tubs and metalized spiral wound fiberboard containers (MSWFC)). The hypotheses outlined at the start of this research were evaluated and determined to be true or false. The outcomes of this evaluation are listed below. Additionally, the effect of the variable in both two-way and three-interactions are also discussed and concluded

Hypothesis 1. Conveyor speed will not have an influence on the average amount of tag reads per trial for RFID transponders.

This hypothesis was rejected. In the product effect, package effect, and package shape effect tests, conveyor speed had a significant effect on the percent readability of transponders. The average amount of tag reads per trial with the conveyor operating at 300 feet per minute (fpm) was always significantly greater than the average amount of tag reads per trial with the conveyor operating at 600 fpm **(Table 47)**.

Table 47: Average Advantage in Tag Reads at 300 fpm Over 600 fpm

Average Advantage in Tag Reads at 300 fpm Over 600 fpm, Speed Least Squares Means					
Effect Test	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Mean Difference (MD) between 300fpm -600 fpm (Product Effect)	-109.17	2.4358	232	44.82	<.0001
MD between 300 fpm- 600 fpm (Package Effect)	-112.16	2.0078	232	55.86	<.0001
MD between 300 fpm-600 fpm (Package Shape Effect)	-54.4833	1.2494	348	43.61	<.0001

In all two-way and three-way interactions involving conveyor speed, speed had a significant effect on the average number of tag reads per trial, acting as the dominant variable in the interactions for the product effect products, the package effect products, and the product shape effect products (not involving tins).

The Effect of Conveyor Speed on the Product Effect Test, Ketchup and Motor Oil

Two-Way Interactions

Product by Speed

In studying Table 6, which shows the difference in the average number of tag reads per trial between product by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 48, Row 1 and 2).**
- When **product and speed** were the two variables, speed was the dominant variable, making either product average more tag reads per trial when moving at 300 fpm compared to the product moving at 600 fpm **(Table 48, Row 3 and 4).**

Table 48: Product-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed Least Squares Means								
Product	Speed	_Product	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	300	Ketchup	600	74.6167	3.4447	232	21.66	<.0001
Oil	300	Oil	600	143.72	3.4447	232	41.72	<.0001
Ketchup	300	Oil	600	44.5000	3.4447	232	12.92	<.0001
Ketchup	600	Oil	300	-173.83	3.4447	232	-50.46	<.0001

Tag Type by Speed

In studying Table 10, which shows the difference in the average number of tag reads per trial between tag type by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 49, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 49, Row 3 and 4)**.

Table 49: Tag Type-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Speed*Tag Least Squares Means								
Tag	Speed	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Gen1	300	Gen1	600	90.1667	3.4447	232	26.18	<.0001
Gen2	300	Gen2	600	128.17	3.4447	232	37.21	<.0001
Gen1	300	Gen2	600	100.38	3.4447	232	29.14	<.0001
Gen2	300	Gen1	600	117.95	3.4447	232	34.24	<.0001

Three-Way Interactions

Ketchup-Ketchup Interactions

In studying Table 12, which shows the difference in the average number of tag reads per trial between product (ketchup) by tag type by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 50, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 50, Row 3 and 4)**.

Table 50: Ketchup-Ketchup Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	300	Ketchup	Gen1	600	55.6333	4.8715	232	11.42	<.0001
Ketchup	Gen2	300	Ketchup	Gen2	600	93.6000	4.8715	232	19.21	<.0001
Ketchup	Gen1	300	Ketchup	Gen2	600	61.7333	4.8715	232	12.67	<.0001
Ketchup	Gen2	300	Ketchup	Gen1	600	87.5000	4.8715	232	17.96	<.0001

Ketchup-Motor Oil Interactions

In studying Table 13, which shows the difference in the average number of tag reads per trial between product (ketchup and motor oil) by tag type by speed, some overall conclusions can be formed.

- When the **product and speed** were the two variables, speed was the dominant variable, providing more average reads per trial for the product moving at 300 fpm compared to the product moving at 600 fpm **(Table 51, Row 1-4)**.
- When **product, tag, and speed** were all variables, speed was the dominant variable, providing more average reads per trial for the product and tag moving at 300 fpm, compared to the product and tag moving at 600 fpm **(Table 51, Row 5-8)**.

Table 51: Ketchup-Motor Oil Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	300	Oil	Gen1	600	21.4000	4.8715	232	4.39	<.0001
Ketchup	Gen1	600	Oil	Gen1	300	-158.93	4.8715	232	-32.63	<.0001
Ketchup	Gen2	300	Oil	Gen2	600	67.6000	4.8715	232	13.88	<.0001
Ketchup	Gen2	600	Oil	Gen2	300	-188.73	4.8715	232	-38.74	<.0001
Ketchup	Gen1	300	Oil	Gen2	600	35.7333	4.8715	232	7.34	<.0001
Ketchup	Gen1	600	Oil	Gen2	300	-182.63	4.8715	232	-37.49	<.0001
Ketchup	Gen2	600	Oil	Gen1	300	-165.03	4.8715	232	-33.88	<.0001
Ketchup	Gen2	300	Oil	Gen1	600	53.2667	4.8715	232	10.93	<.0001

Motor Oil-Motor Oil Interactions

In studying Table 14, which shows the difference in the average number of tag reads per trial between product (motor oil) by tag type by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 52, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 52, Row 3 and 4)**.

Table 52: Motor Oil-Motor Oil Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Oil	Gen1	300	Oil	Gen1	600	124.70	4.8715	232	25.60	<.0001
Oil	Gen2	300	Oil	Gen2	600	162.73	4.8715	232	33.41	<.0001
Oil	Gen1	300	Oil	Gen2	600	139.03	4.8715	232	28.54	<.0001
Oil	Gen2	300	Oil	Gen1	600	148.40	4.8715	232	30.46	<.0001

The Effect of Conveyor Speed on the Package Effect Test, Chips in Plastic Tubs and Chips in MSWFC:

Two-Way Interactions

Product by Speed

In studying Table 20, which shows the difference in the average number of tag reads per trial between product by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 53, Row 1 and 2)**.
- When **product and speed** were the two variables, speed was the dominant variable, making either product average more tag reads per trial when moving at 300 fpm compared to the product moving at 600 fpm **(Table 53, Row 3 and 4)**.

Table 53: Product-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed Least Squares Means								
Product	Speed	_Product	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	300	Metal	600	60.7333	2.8395	232	21.39	<.0001
Plastic	300	Plastic	600	163.58	2.8395	232	57.61	<.0001
Metal	300	Plastic	600	30.2333	2.8395	232	10.65	<.0001
Metal	600	Plastic	300	-194.08	2.8395	232	-68.35	<.0001

Tag Type by Speed

In studying Table 24, which shows the difference in the average number of tag reads per trial between tag type by speed, some overall conclusion can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 54, Row 1 and 2).**
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 54, Row 1 and 2).**

Table 54: Tag Type-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Speed*Tag Least Squares Means								
Tag	Speed	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Gen1	300	Gen1	600	109.70	2.8395	232	38.63	<.0001
Gen2	300	Gen2	600	114.62	2.8395	232	40.37	<.0001
Gen1	300	Gen2	600	114.17	2.8395	232	40.21	<.0001
Gen2	300	Gen1	600	110.15	2.8395	232	38.79	<.0001

Three-Way Interactions

MSWFC-MSWFC Interactions

In studying Table 26, which shows the difference in the average number of tag reads per trial between product (MSWFC) by tag type by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 55, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 55, Row 3 and 4)**.

Table 55: MSWFC-MSWFC Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	**Tag**	**Speed**	**_Product**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**Gen1**	**300**	**Metal**	**Gen1**	**600**	59.0000	4.0156	232	14.69	<.0001
Metal	**Gen2**	**300**	**Metal**	**Gen2**	**600**	62.4667	4.0156	232	15.56	<.0001
Metal	**Gen1**	**300**	**Metal**	**Gen2**	**600**	63.9667	4.0156	232	15.93	<.0001
Metal	**Gen2**	**300**	**Metal**	**Gen1**	**600**	57.5000	4.0156	232	14.32	<.0001

MSWFC-Plastic Tub Interactions

In studying Table 27, which shows the difference in the average number of tag reads per trial between product (plastic tubs and MSWFC) by tag type by speed, some overall conclusions can be formed.

- When the **product and speed** were the two variables, speed was the dominant variable, providing more average reads per trial for the product moving at 300 fpm compared to the product moving at 600 fpm **(Table 56, Row 1-4)**.
- When **product, tag, and speed** were all variables, speed was the dominant variable, providing more average reads per trial for the products and tags moving at 300 fpm compared to the products and tags moving at 600 fpm **(Table 56, Row 5-8)**.

Table 56: MSWFC-Plastic Tubs Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	Gen1	300	Plastic	Gen1	600	29.0000	4.0156	232	7.22	<.0001
Metal	Gen1	600	Plastic	Gen1	300	-190.40	4.0156	232	-47.41	<.0001
Metal	Gen2	300	Plastic	Gen2	600	31.4667	4.0156	232	7.84	<.0001
Metal	Gen2	600	Plastic	Gen2	300	-197.77	4.0156	232	-49.25	<.0001
Metal	Gen1	300	Plastic	Gen2	600	32.9667	4.0156	232	8.21	<.0001
Metal	Gen1	600	Plastic	Gen2	300	-192.80	4.0156	232	-48.01	<.0001
Metal	Gen2	600	Plastic	Gen1	300	-195.37	4.0156	232	-48.65	<.0001
Metal	Gen2	300	Plastic	Gen1	600	27.5000	4.0156	232	6.85	<.0001

Plastic Tub-Plastic Tub Interactions

In studying Table 28, which shows the difference in the average number of tag reads per trial between product (plastic tubs) by tag generation by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 57, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 57, Row 3 and 4)**.

Table 57: Plastic Tubs-Plastic Tubs Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Plastic	Gen1	300	Plastic	Gen1	600	160.40	4.0156	232	39.94	<.0001
Plastic	Gen2	300	Plastic	Gen2	600	166.77	4.0156	232	41.53	<.0001
Plastic	Gen1	300	Plastic	Gen2	600	164.37	4.0156	232	40.93	<.0001
Plastic	Gen2	300	Plastic	Gen1	600	162.80	4.0156	232	40.54	<.0001

The Effect of Conveyor Speed on the Package Shape Effect Test, Metal Bottles, Metal Cans, and Metal Tins

Two-Way Interactions

Product by Speed

In studying Table 35, which shows the difference in the average number of tag reads per trial between product by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 58, Row 1-3)**.
- When **product and speed** were the two variables, speed was the dominant variable between only bottles and cans. The product moving at 300 fpm always averaged more tag reads per trial than the product moving at 600 fpm **(Table 58, Row 4-9)**.

Table 58: Product-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed Least Squares Means								
Product	Speed	_Product	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	300	Bottle	600	57.7333	2.1641	348	26.68	<.0001
Can	300	Can	600	85.1333	2.1641	348	39.34	<.0001
Tin	300	Tin	600	20.5833	2.1641	348	9.51	<.0001
Bottle	300	Can	600	56.2833	2.1641	348	26.01	<.0001
Bottle	600	Can	300	-86.5833	2.1641	348	-40.01	<.0001
Bottle	300	Tin	600	96.0000	2.1641	348	44.36	<.0001
Bottle	600	Tin	300	17.6833	2.1641	348	8.17	<.0001
Can	300	Tin	600	124.85	2.1641	348	57.69	<.0001
Can	600	Tin	300	19.1333	2.1641	348	8.84	<.0001

Tag Type by Speed

In studying Table 39, which shows the difference in the average number of tag reads per trial between tag type by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 59, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 59, Row 3 and 4)**.

Table 59: Tag Type-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Speed*Tag Least Squares Means								
Tag	**Speed**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	**Gen1**	**600**	35.5889	1.7670	348	20.14	<.0001
Gen2	**300**	**Gen2**	**600**	73.3778	1.7670	348	41.53	<.0001
Gen1	**300**	**Gen2**	**600**	36.4778	1.7670	348	20.64	<.0001
Gen2	**300**	**Gen1**	**600**	72.4889	1.7670	348	41.02	<.0001

Three-Way Interaction

Bottle-Bottle Interaction

In studying Table 41, which shows the difference in the average number of tag reads per trial between product (bottles) by tag type by speed, some overall conclusion can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 60, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 60, Row 3 and 4)**.

Can-Can Interaction

In studying Table 42, which shows the difference in the average number of tag reads per trial between product (cans) by tag type by speed, some overall conclusions can be formed.

- When **speed** was the only variable, 300 fpm always averaged more tag reads per trial than 600 fpm **(Table 61, Row 1 and 2)**.
- When **speed and tag type** were the two variables, speed was the dominant variable, making either generation of tag average more tag reads per trial when traveling at 300 fpm versus 600 fpm **(Table 61, Row 3 and 4)**.

Table 60: Bottle-Bottle Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen1	300	Bottle	Gen1	600	46.6667	3.0605	348	15.25	<.0001
Bottle	Gen2	300	Bottle	Gen2	600	68.8000	3.0605	348	22.48	<.0001
Bottle	Gen1	300	Bottle	Gen2	600	53.9000	3.0605	348	17.61	<.0001
Bottle	Gen2	300	Bottle	Gen1	600	61.5667	3.0605	348	20.12	<.0001

Table 61: Can-Can Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Can	Gen1	300	Can	Gen1	600	59.3333	3.0605	348	19.39	<.0001
Can	Gen2	300	Can	Gen2	600	110.93	3.0605	348	36.25	<.0001
Can	Gen1	300	Can	Gen2	600	58.0667	3.0605	348	18.97	<.0001
Can	Gen2	300	Can	Gen1	600	112.20	3.0605	348	36.66	<.0001

Tin-Tin Interaction

In studying Table 43, which shows the difference in the average number of tag reads per trial between product (tins) by tag type by speed, some overall conclusions can be formed.

- When **speed** was the only variable:
  - With the case of tins traveling 300 fpm and the case of tins traveling 600 fpm equipped with a Gen 1 tag, there was no statistical difference in the average number of tag reads per trial **(Table 62, Row 1)**.
  - With the case of tins traveling 300 fpm and the case of tins traveling 600 fpm equipped with a Gen 2 tag, speed was the dominant variable, with the case of tins moving at 300 fpm averaging 40.4 more tag reads per trial. **(Table 62, Row 2)**.

- When **speed and tag type** were the two variables:
  - With the case of tins with a Gen 1 tag was moving 300 fpm, there **was not** a significant statistical difference in the average number of tag reads per trial compared to the case of tins with a Gen 2 tag moving 600 fpm **(Table 62, Row 3)**.
  - The case of tins with a Gen 2 tag moving 300 fpm, averaged more tag reads per trial than the case of tins with a Gen 1 tag moving 600 fpm.
    - Since the dominant tag type and dominant speed prevailed in this particular scenario, it is difficult to say that speed or tag type was the dominant variable in this three-way interaction **(Table 62, Row 4)**

Table 62: Tin-Tin Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Tin	Gen1	300	Tin	Gen1	600	0.7667	3.0605	348	0.25	0.8023
Tin	Gen2	300	Tin	Gen2	600	40.4000	3.0605	348	13.20	<.0001
Tin	Gen1	300	Tin	Gen2	600	-2.5333	3.0605	348	-0.83	0.4084
Tin	Gen2	300	Tin	Gen1	600	43.7000	3.0605	348	14.28	<.0001

Bottle-Can Interactions

In studying Table 44, which shows the difference in the average number of tag reads per trial between two products (bottles and cans) by tag generation by speed, some overall conclusions can be formed.

- When **product and speed** were the two variables, speed was the dominant variable, providing more average reads per trial for the product moving at 300 fpm compared to the product moving at 600 fpm **(Table 63, Row 1-4)**.
- When **product, tag, and speed** were all variables, speed was the dominant variable, providing more average reads per trial for the product and tag moving at 300 fpm compared to the products and tags moving at 600 fpm **(Table 63, Row 5-8)**.

Table 63: Bottle-Can Three-Way Interaction, Difference in Number of Tag Reads Caused by Speed

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen1	300	Can	Gen1	600	49.4667	3.0605	348	16.16	<.0001
Bottle	Gen1	600	Can	Gen1	300	-56.5333	3.0605	348	-18.47	<.0001
Bottle	Gen2	300	Can	Gen2	600	63.1000	3.0605	348	20.62	<.0001
Bottle	Gen2	600	Can	Gen2	300	-116.63	3.0605	348	-38.11	<.0001
Bottle	Gen1	300	Can	Gen2	600	48.2000	3.0605	348	15.75	<.0001
Bottle	Gen1	600	Can	Gen2	300	-109.40	3.0605	348	-35.75	<.0001
Bottle	Gen2	300	Can	Gen1	600	64.3667	3.0605	348	21.03	<.0001
Bottle	Gen2	600	Can	Gen1	300	-63.7667	3.0605	348	-20.84	<.0001

Bottle-Tin Interactions and Can-Tin Interaction

In both bottle-tin and can-tin interactions, product type, not speed, was not the dominant variable. This is discussed in more detail in the bottle-tin and can-tin sections under the package shape effect section within the discussion of hypotheses 4.

Hypothesis 2. Product will not have an influence on the average amount of tag reads per trial for RFID transponders on packages moving on a conveyor.

This hypothesis was rejected. The case of motor oil averaged 64.7 more tag reads per trial than the case of ketchup **(Table 64)**.

Table 64: Average Number of Tag Reads Per Trial and Difference Between Means, by Product Type

Product Least Squares Means					
Product	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	74.4583	1.7223	232	43.23	<.0001
Oil	139.13	1.7223	232	80.78	<.0001
MD	-64.6667	2.4358	232	-26.55	<.0001

Product also had an effect in two-way and three-way interactions. When product was the only variable, motor oil always performed better than ketchup. In two-way and three-way interactions, in which product and tag type were the variables, the dominant variable was product (motor oil), making either generation of tag attached to the case of motor oil average more tag reads per trial.

The Product Effect Test, Ketchup and Motor Oil

Two-Way Interactions

Product by Speed

In studying Table 6, which shows the difference in the average number of tag reads per trial between product by speed, some overall conclusions can be formed.

- When **product** was the only variable, motor oil always averaged more tag reads per trial than ketchup **(Table 65).**

Table 65: Difference in Average Number of Tag Reads Per Trial Between Product by Speed

Differences of Product*Speed Least Squares Means								
Product	Speed	_Product	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	300	Oil	300	-99.2167	3.4447	232	-28.80	<.0001
Ketchup	600	Oil	600	-30.1167	3.4447	232	-8.74	<.0001

Product by Tag Generation

In studying Table 8, which shows the difference in the average number of tag reads per trial between product by tag type, some overall conclusions can be formed.

- When **product** was the only variable, motor oil always averaged more tag reads per trial than ketchup **(Table 66, Row 1 and 2).**
- When **product and tag** type were the two variables, product was the dominant variable, making either generation of tag average more tag reads per trial when on the case of motor oil versus the case of ketchup **(Table 66, Row 3 and 4).**

Table 66: Difference in Average Number of Tag Reads Per Trial Between Product by Tag Generation

Differences of Product*Tag Least Squares Means								
Product	**Tag**	**_Product**	**_Tag**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	**Gen1**	**Oil**	**Gen1**	-68.7667	3.4447	232	-19.96	<.0001
Ketchup	**Gen2**	**Oil**	**Gen2**	-60.5667	3.4447	232	-17.58	<.0001
Ketchup	**Gen1**	**Oil**	**Gen2**	-73.4500	3.4447	232	-21.32	<.0001
Ketchup	**Gen2**	**Oil**	**Gen1**	-55.8833	3.4447	232	-16.22	<.0001

Three-Way Interactions

Ketchup-Motor Oil Interactions

In studying Table 13, which shows the difference in the average number of tag reads per trial between product (ketchup and motor oil) by tag type by speed, some overall conclusions can be formed.

- When the **product** was the only variable (tag type and speed were the same) motor oil always averaged more reads per trial than ketchup **(Table 67)**.
- When the **product and tag type** were the two variables, product was the dominant variable, providing more average reads per trial for either generation of tag attached to the case of motor oil compared to the generation of tag on the case of ketchup **(Table 68)**.

Table 67: Difference in Average Number of Tag Reads Per Trial Between Product (Ketchup and Motor Oil) by Tag Generation (Constant) by Speed (Constant)

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	300	Oil	Gen1	300	-103.30	4.8715	232	-21.20	<.0001
Ketchup	Gen2	300	Oil	Gen2	300	-95.1333	4.8715	232	-19.53	<.0001
Ketchup	Gen1	600	Oil	Gen1	600	-34.2333	4.8715	232	-7.03	<.0001
Ketchup	Gen2	600	Oil	Gen2	600	-26.0000	4.8715	232	-5.34	<.0001

Table 68: Difference in Average Number of Tag Reads Per Trial Between Product (Ketchup and Motor Oil) by Tag Generation by Speed (Constant)

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	300	Oil	Gen2	300	-127.00	4.8715	232	-26.07	<.0001
Ketchup	Gen2	300	Oil	Gen1	300	-71.4333	4.8715	232	-14.66	<.0001
Ketchup	Gen1	600	Oil	Gen2	600	-19.9000	4.8715	232	-4.08	<.0001
Ketchup	Gen2	600	Oil	Gen1	600	-40.3333	4.8715	232	-8.28	<.0001

Hypothesis 3. Packaging materials will not have an influence on the average amount of tag reads per trial for RFID transponders on packages while moving on a conveyor.

This hypothesis was rejected. The case of potato chips in plastic tubs averaged 81.9 more tag reads per trial than the case of potato chips in metalized spiral wound fiberboard containers (MSWFC) **(Table 69)**.

Table 69: Average Number of Tag Reads Per Trial and Difference Between Means, by Product Type

Product	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	60.1833	1.4197	232	42.39	<.0001
Plastic	142.11	1.4197	232	100.09	<.0001
MD	-81.9250	2.0078	232	-40.80	<.0001

Package materials also had an effect in two-way and three-way interactions. When package was the only variable, plastic tubs always performed better than ketchup. In two-way and three-way interactions, in which product and tag type were the variables, the dominant variable was package type (plastic tubs), making either generation of tag attached to the case of plastic tubs average more tag reads per trial.

Evaluation of Package Effect Test, Chips in Plastic Tubs and Chips in MSWFC

Two-Way Interactions

Product by Speed

In studying Table 20, which shows the difference in the average number of tag reads per trial between product by speed, some overall conclusions can be formed.

- When **product** was the only variable, plastic tubs always averaged more tag reads per trial than MSWFC **(Table 70)**.

Table 70: Difference in Average Number of Tag Reads Per Trial Between Product by Speed

Differences of Product*Speed Least Squares Means								
Product	**Speed**	**_Product**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**300**	**Plastic**	**300**	-133.35	2.8395	232	-46.96	<.0001
Metal	**600**	**Plastic**	**600**	-30.5000	2.8395	232	-10.74	<.0001

Product by Tag Type

In studying Table 22, which shows the difference in the average number of tag reads per trial between product by tag type, some overall conclusion can be formed.

- When **product** was the only variable, plastic tubs always averaged more tag reads per trial than MSWFC **(Table 71, Row 1 and 2)**.
- When **product and tag type** were the two variables, package was the dominant variable, making either generation of tag average more tag reads per trial when on the case of plastic tubs versus the case of MSWFC **(Table 71, Row 3 and 4)**.

Table 71: Difference In Average Number of Tag Reads Per Trial Between Product by Tag Type

Differences of Product*Tag Least Squares Means								
Product	**Tag**	**_Product**	**_Tag**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Metal	**Gen1**	**Plastic**	**Gen1**	-80.7000	2.8395	232	-28.42	<.0001
Metal	**Gen2**	**Plastic**	**Gen2**	-83.1500	2.8395	232	-29.28	<.0001
Metal	**Gen1**	**Plastic**	**Gen2**	-79.9167	2.8395	232	-28.14	<.0001
Metal	**Gen2**	**Plastic**	**Gen1**	-83.9333	2.8395	232	-29.56	<.0001

Three-Way Interactions

MSWFC-Plastic Tub Interactions

In studying Table 27, which shows the difference in the average number of tag reads per trial between product (plastic tubs and MSWFC) by tag type by speed, some overall conclusions can be formed.

- When the **product** was the only variable (tag type and speed were the same) plastic tubs always averaged more average reads per trial than MSWFC **(Table 72).**
- When the **product and tag** were the two variables, product was the dominant variable, providing more average reads per trial for either generation of tag attached to the case of plastic tubs compared to the generation of tag on the case of MSWFC **(Table 73)**

Table 72: Difference in Average Number of Tag Reads Per Trial Between Product (Plastic Tubs and MSWFC) by Tag Type (Constant) by Speed (Constant

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	Gen1	300	Plastic	Gen1	300	-131.40	4.0156	232	-32.72	<.0001
Metal	Gen2	300	Plastic	Gen2	300	-135.30	4.0156	232	-33.69	<.0001
Metal	Gen1	600	Plastic	Gen1	600	-30.0000	4.0156	232	-7.47	<.0001
Metal	Gen2	600	Plastic	Gen2	600	-31.0000	4.0156	232	-7.72	<.0001

Table 73: Difference in Average Number of Tag Reads Per Trial Between Product (Plastic Tubs and MSWFC) by Tag Generation by Speed (Constant)

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	Gen1	300	Plastic	Gen2	300	-133.80	4.0156	232	-33.32	<.0001
Metal	Gen2	300	Plastic	Gen1	300	-132.90	4.0156	232	-33.10	<.0001
Metal	Gen1	600	Plastic	Gen2	600	-26.0333	4.0156	232	-6.48	<.0001
Metal	Gen2	600	Plastic	Gen1	600	-34.9667	4.0156	232	-8.71	<.0001

Hypothesis 4. Package shape will not have an influence on the average amount of tag reads per trial for RFID transponders on packages moving on a conveyor.

This hypothesis was rejected. Cans averaged more reads per trial than bottles or tins. Bottles averaged more reads per trial than tins **(Table 74)**.

Table 74: Difference Average Number of Reads Per Trial by Product Type

Differences of Product Least Squares Means						
Product	**_Product**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	**Can**	-15.1500	1.5302	348	-9.90	<.0001
Bottle	**Tin**	56.8417	1.5302	348	37.15	<.0001
Can	**Tin**	71.9917	1.5302	348	47.05	<.0001

In two-way and three-way interactions, product did not always act as the dominant variable.

Cans and Bottles

In two-way interactions in which product was the only variable (speed was held constant), cans averaged more tag reads per trial than bottles at 300 fpm. However at 600 fpm, cans and bottles averaged a statistically similar amount of reads per trial.

In two-way interactions in which product was the only variable (tag type was held constant), when cans and bottles were equipped with a Gen 1 tag, they averaged a statistically similar amount of readers per trial. However, when equipped with a Gen 2 tag, cans averaged more reads per trial than bottles.

In three-way interactions in which product was the only variable (tag type and speed were held constant) cans always averaged more reads per trial than bottles, except on one occasion. When cans with a Gen 1 tag were moving 600 fpm, they performed equal to bottles with a Gen 1 tag moving 600 fpm.

Bottles and Tins

In two-way interactions involving bottles versus tins, bottles always averaged more reads per trial than tins.

In three-way interactions bottles always averaged more tag reads than tins except on two occasions. When product and speed were variables (tag type held constant) tins with a Gen 2 tag moving 300 fpm averaged more tag reads per trial than bottles with a Gen 2 tag moving 600 fpm. When product, tag type and speed were all variables, tins with a Gen 2 tag moving 300 fpm averaged a statistically similar amount to bottles with a Gen 1 tag moving 600 fpm.

Cans and Tins

In two-way interactions involving cans versus tins, cans always averaged more reads per trial than tins.

In three-way interactions cans always averaged more tag reads than tins except on two occasions. When product and speed were variables (tag type held constant) tins with a Gen 2 tag moving 300 fpm averaged a statistically similar amount to cans with a Gen 2 tag moving 600 fpm. When product, tag type and speed were all variables, tins with a Gen 2 tag moving 300 fpm averaged a statistically similar amount to cans with a Gen 1 tag moving 600 fpm.

Evaluation of Package Shape Effect Test, Metal Bottles, Metal Cans and Metal Tins

Two-Way Interactions

Product by Speed

In studying Table 35, which shows the difference in the average number of tag reads per trial between product by speed, some overall conclusions can be formed.

- When product was the only variable:
  - Cans averaged more tag reads per trial than bottles when moving at 300 fpm **(Table 75, Row 1)**.
  - Cans did not have a statistically different average number of tag reads per trial than bottles when moving at 600 fpm **(Table 75, Row 2)**.
  - Cans always averaged more tag reads per trial than tins independent of conveyor speed **(Table 75, Row 3 and 4)**.
  - Bottles always averaged more tag reads per trial than tins, independent of conveyor speed **(Table 75, Row 5 and 6)**.

Table 75: Difference in Average Number of Tag Reads Per Trial Between Product by Speed

Differences of Product*Speed Least Squares Means								
Product	**Speed**	**_Product**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Bottle	**300**	**Can**	**300**	-28.8500	2.1641	348	-13.33	<.0001
Bottle	**600**	**Can**	**600**	-1.4500	2.1641	348	-0.67	0.5033
Can	**300**	**Tin**	**300**	104.27	2.1641	348	48.18	<.0001
Can	**600**	**Tin**	**600**	39.7167	2.1641	348	18.35	<.0001
Bottle	**300**	**Tin**	**300**	75.4167	2.1641	348	34.85	<.0001
Bottle	**600**	**Tin**	**600**	38.2667	2.1641	348	17.68	<.0001

Product by Tag Type

In studying Table 37, which shows the difference in the average number of tag reads per trial between product by tag type, some overall conclusions can be formed.

- When the **product** was the only variable:
  - Cans were not statistically different from bottles in the average number of tag reads per trial when each had a Gen 1 tag attached to the case **(Table 76, Row 1).**
  - Cans averaged more tag reads per trial than bottles when each had a Gen 2 tag attached to the case **(Table 76, Row 2).**
  - Both bottles and cans always averaged more tag reads per trial than tins, independent of tag type **(Table 76, Row 3-6).**

Table 76: Difference in Average Number of Tag Reads Per Trial Between Product by Tag Type

Differences of Product*Tag Least Squares Means								
Product	Tag	_Product	_Tag	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen1	Can	Gen1	-3.5333	2.1641	348	-1.63	0.1034
Bottle	Gen2	Can	Gen2	-26.7667	2.1641	348	-12.37	<.0001
Bottle	Gen1	Tin	Gen1	66.4833	2.1641	348	30.72	<.0001
Bottle	Gen2	Tin	Gen2	47.2000	2.1641	348	21.81	<.0001
Can	Gen1	Tin	Gen1	70.0167	2.1641	348	32.35	<.0001
Can	Gen2	Tin	Gen2	73.9667	2.1641	348	34.18	<.0001

Three-Way Interaction

Bottle-Can Interactions

In studying Table 44, which shows the difference in the average number of tag reads per trial between two products (bottles and cans) by tag type by speed, some overall conclusions can be formed.

- When the **product** was the only variable, cans always averaged more tag reads per trial than bottles, except when each product was equipped with a Gen 1 tag moving at 600 fpm, in which the two products were statistically similar in there average amount of tag reads per trial **(Table 77, Row 1).**
- When **product and tag** were the two variables, there was no statistical difference in the average number of tag reads per trial between bottles and cans, except with the case of bottles with a Gen 1 tag moving at 300 fpm compared to the case of cans with a Gen 2 moving at 300 fpm, in which case cans with a Gen 2 tag averaged more tag reads per trial than bottles with a Gen 1 tag **(Table 77, Row 2).**

Table 77: Difference in Average Number of Tag Reads Per Trial Between Product (Bottles and Tins) by Tag Generation by Speed, Where Product Was Not the Dominant Variable

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen1	600	Can	Gen1	600	2.8000	3.0605	348	0.91	0.3609
Bottle	Gen1	300	Can	Gen2	300	-62.7333	3.0605	348	-20.50	<.0001

Bottle-Tin Interactions

In studying Table 45, which shows the difference in the average number of tag reads per trial between two products (bottles and tins) by tag type by speed, some overall conclusions can be formed.

- When the **product** was the only variable (tag type and speed were the same) bottles always averaged more tag reads per trial than tins.
- When the **product and tag** were the two variables, product was the dominant variable, with bottles always averaging more tag reads per trial than tins, regardless of tag type on the case.
- When the **product and speed** were the two variables, product was the dominant variable in 3 of the 4 comparisons, with the bottles always averaging more reads per trial than tins.
  - The exception was when the case of bottles had a Gen 2 tag and was moving at 600 fpm compared to the case of tins with a Gen 2 tag moving 300 fpm, with the latter averaging 7.4 more tag reads per trial **(Table 78, Row 2)**. In this case, speed (300 fpm) was more dominant than product (bottles)
- When **product, tag, and speed** were all variables, product was the dominant variable in 3 of the 4 comparisons, with the bottles always averaging more reads per trial than tins.
  - The exception was when the case of bottles had a Gen 1 tag and was moving at 600 fpm compared to the case of tins with a Gen 2 tag moving 300 fpm, there was not a significant statistical difference in the average number of tag reads **(Table 78, Row 2)**. In this case, the dominant tag (Gen 2) and dominant speed (300 fpm) were more dominant than the dominant product type (bottles).

Table 78: Difference in Average Number of Tag Reads Per Trial Between Product (Bottles and Tins) by Tag Generation by Speed, Where Product Was Not the Dominant Variable

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen2	600	Tin	Gen2	300	-7.4000	3.0605	348	-2.42	0.0161
Bottle	Gen1	600	Tin	Gen2	300	-0.1667	3.0605	348	-0.05	0.9566

Can-Tin Interactions

In studying Table 46, which shows the difference in the average number of tag reads per trial between two products (cans and tins) by tag type by speed, some overall conclusions can be formed.

- When the **product** was the only variable (tag type and speed were the same) cans always averaged more tag reads per trial than tins.
- When the **product and tag** were the two variables, product was the dominant variable, with cans always averaging more tag reads per trial than tins, regardless of tag type on the case.
- When the **product and speed** were the two variables, product was the dominant variable in 3 of the 4 comparisons, with the cans always averaging more reads per trial than tins.
    - The exception was when the case of cans had a Gen 2 tag and was moving at 600 fpm compared to the case of tins with a Gen 2 tag moving 300 fpm, there was not a significant statistical difference in the average number of tag reads per trial **(Table 79, Row 1)**. In this case, speed (300 fpm) was more dominant than product (cans).
- When **product, tag, and speed** were all variables, product was the dominant variable in 3 of the 4 comparisons, with the cans always averaging more reads per trial than tins.
    - The exception was when the case of cans had a Gen 1 tag and was moving at 600 fpm compared to the case of tins with a Gen 2 tag moving 300 fpm, there was not a significant statistical difference in the average number of tag reads per trial **(Table 79, Row 2)**. In this case, the dominant tag (Gen 2) and dominant speed (300 fpm) were more dominant than the dominant product type (cans).

Table 79: Difference in Average Number of Tag Reads Per Trial Between Product (Cans and Tins) by Tag Generation by Speed, Where Product Was Not the Dominant Variable

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Can	Gen2	600	Tin	Gen2	300	-1.7000	3.0605	348	-0.56	0.5789
Can	Gen1	600	Tin	Gen2	300	-2.9667	3.0605	348	-0.97	0.3330

Hypothesis 5. Tag type will not have an influence on the average amount of tag reads per trial for packages moving on a conveyor.

This hypothesis was neither rejected nor failed to be rejected. In the product effect test and the package shape effect test, tag type had a significant effect on the average number of tag reads per trial, therefore rejecting the hypothesis. In the package effect test, tag type did not have a significant effect on the average number of tag reads per trial, therefore failing to reject the hypothesis **(Table 80).**

Table 80: Average Difference Between Number of Tag Reads Per Trail for Gen 1 Tag versus Gen 2 Tag

Average Difference Between Number of Tag Reads Per Trial, Tag Least Square Means					
Effect Test	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
MD Between Gen 1 vs Gen 2 (Product Effect)	-8.7833	2.4358	232	-3.61	0.0004
MD between Gen 1 vs Gen 2 (Package Effect)	2.0083	2.0078	232	1.00	.3182
MD between Gen 1vs Gen 2 (Shape Effect)	-18.0056	1.2594	348	-14.41	<.0001

In both two-way and three-way interactions in which the products (all 7 cases) were moving speed of 300 fpm , the Gen 2 tag either averaged a greater or equal statistical amount of tag reads per trial compared to the Gen 1 tag.

In both two-way and three-way interactions in which the products (6 out of 7 cases) were moving speed of 600 fpm , the Gen 2 tag either averaged a lesser or equal statistical amount of tag reads per trial compared to the Gen 1 tag (except for the case of Tins, Gen 2 averaged more reads per trial statistically).

In two-way interactions involving ketchup, with tag type being the only variable, Gen 2 averaged more reads per trial than Gen 1.

In all two-way interactions involving motor oil, with the tag type being the only variable, Gen 1 averaged more reads per trial than Gen 2.

In all two-way interactions involving MSWFC, with the tag type being the only variable, Gen 1 and Gen 2 averaged an equal amount of reads per trial.

In all two-way interactions involving plastic tubs, with the tag type being the only variable, Gen 1 and Gen 2 averaged an equal amount of reads per trial.

In all two-way interactions involving bottles, with the tag type being the only variable, Gen 1 and Gen 2 averaged an equal amount of reads per trial.

In all two-way interactions involving cans, with the tag type being the only variable, Gen 2 averaged more reads per trial than Gen 1.

In all two-way interactions involving tins, with the tag type being the only variable, Gen 2 averaged more reads per trial than Gen 1.

The Effect of Tag Type in the Product Effect Test

Two Way Interactions

Product by Tag Type, Tag Type Only Variable

In studying Table 8, which shows the difference in the average number of tag reads per trial between product by tag type, some overall conclusions can be formed.

- When **tag type** was the only variable, tag type had a significant effect on the average number of tag reads per trial on the case of ketchup with the Gen 2 tag averaging 12.9 more reads per trial than the Gen 1 tag **(Table 81, Row 1)**.
- In contrast, **tag type** did not have a significant effect on the average number of tag reads per trial for the case of motor oil, making the Gen 1 tag and Gen 2 tag perform as equals **(Table 81, Row 2)**.

Table 81: Product-Tag Type Two-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Tag Least Squares Means								
Product	**Tag**	**_Product**	**_Tag**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Ketchup	**Gen 1**	**Ketchup**	**Gen 2**	-12.8833	3.4447	232	-3.74	0.0002
Oil	**Gen 1**	**Oil**	**Gen 2**	-4.6833	3.4447	232	-1.36	0.1753

Tag Type by Speed, Tag Type Only Variable

In studying Table 10, which shows the difference in the average number of tag reads per trial between tag generation by speed, some overall conclusions can be formed.

- When **tag type** was the only variable, the tag's generation made a difference at 300 fpm, in which the Gen 2 tag averaged 27.8 more reads per trial than the Gen 1 tag **(Table 82, Row 1)**.
- However, at 600 fpm the Gen 1 tag performed better than the Gen 2 tag by an average of 10.22 more reads per trail **(Table 82, Row 2)**.

Table 82: Product-Tag Type Two-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Speed*Tag Least Squares Means								
Tag	**Speed**	**_Tag**	**_Speed**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Gen1	**300**	**Gen2**	**300**	-27.7833	3.4447	232	-8.07	<.0001
Gen1	**600**	**Gen2**	**600**	10.2167	3.4447	232	2.97	0.0033

Three-Way Interactions

Ketchup-Ketchup, Tag Type Only Variable

In studying Table 12, which shows the difference in the average number of tag reads per trial between product (ketchup) by tag type by speed, some overall conclusions can be formed.

- When **tag type** was the only variable, the tag's generation made a difference at 300 fpm, as the Gen 2 tag averaged 31.9 more reads per trial than the Gen 1 tag **(Table 83, Row 1)**.
- However, at 600 fpm there was no statistical difference between the Gen 1 and Gen 2 tag **(Table 83, Row 2)**.

Motor Oil-Motor Oil, Tag Type Only Variable

In studying Table 14, which shows the difference in the average number of tag reads per trial between product (motor oil) by tag generation by speed, some overall conclusions can be formed.

- When **tag type** was the only variable, the tag's generation made a difference at 300 fpm, in which the Gen 2 tag averaged 23.7 more tag reads per trial than Gen 1 tag **(Table 84, Row 1)**.
- However, at 600 fpm the Gen 1 tag averaged 14.3 more tag reads per trial than the Gen 2 tag **(Table 84, Row 2)**.

Table 83: Ketchup-Ketchup Three-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Ketchup	Gen1	300	Ketchup	Gen2	300	-31.8667	4.8715	232	-6.54	<.0001
Ketchup	Gen1	600	Ketchup	Gen2	600	6.1000	4.8715	232	1.25	0.2118

Table 84: Motor Oil-Motor Oil Three-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Oil	Gen1	300	Oil	Gen2	300	-23.7000	4.8715	232	-4.87	<.0001
Oil	Gen1	600	Oil	Gen2	600	14.3333	4.8715	232	2.94	0.0036

The Effect of Tag Type in the Package Effect Test

Two Way Interactions

Product by Tag Type, Tag Type Only Variable

In studying Table 22, which shows the difference in the average number of tag reads per trial between product by tag type, some overall conclusion can be formed.

- When **tag type** was the only variable, tag type did not have a significant effect on the average number of reads for either the case of plastic tubs or MSWFC, showing the Gen 1 tag and Gen 2 tag performed statistically similar **(Table 85)**.

Table 85: Product-Tag Type Two-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Tag Least Squares Means								
Product	Tag	_Product	_Tag	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	Gen1	Metal	Gen2	3.2333	2.8395	232	1.14	0.2560
Plastic	Gen1	Plastic	Gen2	0.7833	2.8395	232	0.28	0.7829

Tag Type by Speed, Tag Type Only Variable

In studying Table 24, which shows the difference in the average number of tag reads per trial between tag generation by speed, some overall conclusion can be formed.

- When **tag type** was the only variable, the tag type did not have a significant effect on the average number of reads for either speed of 300 fpm or 600 fpm, showing the Gen 1 tag and the Gen 2 tag performed statistically similar **(Table 86)**.

Table 86: Product-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Speed*Tag Least Squares Means								
Tag	Speed	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Gen1	300	Gen2	300	-0.4500	2.8395	232	-0.16	0.8742
Gen1	600	Gen2	600	4.4667	2.8395	232	1.57	0.1171

Three-Way Interactions

MSWFC-MSWFC, Tag Type Only Variable

In studying Table 26, which shows the difference in the average number of tag reads per trial between product (MSWFC) by tag generation by speed, some overall conclusions can be formed.

- When **tag type** was the only variable, the tag's generation did not matter as there was no statistical difference in the average number of tag reads per trial between the Gen 1 tag and the Gen 2 tag at either 300 fpm or 600 fpm **(Table 87)**.

Plastic Tubs-Plastic Tubs, Tag Type Only Variable

In studying Table 28, which shows the difference in the average number of tag reads per trial between product (plastic tubs) by tag generation by speed, some overall conclusions can be formed.

- When **tag type** was the only variable, the tag's generation did not matter as there was no statistical difference in the average number of tag reads per trial between the Gen 1 tag and the Gen 2 tag at either 300 fpm or 600 fpm **(Table 88)**.

Table 87: MSWFC-MSWFC Three-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Metal	Gen1	300	Metal	Gen2	300	1.5000	4.0156	232	0.37	0.7091
Metal	Gen1	600	Metal	Gen2	600	4.9667	4.0156	232	1.24	0.2174

Table 88: Plastic Tubs-Plastic Tubs Three-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Plastic	Gen1	300	Plastic	Gen2	300	-2.4000	4.0156	232	-0.60	0.5506
Plastic	Gen1	600	Plastic	Gen2	600	3.9667	4.0156	232	0.99	0.3243

The Effect of Tag Type in the Package Shape Effect Test

Two Way Interactions

Product by Tag Type, Tag Type Only Variable

In studying Table 37, which shows the difference in the average number of tag reads per trial between product by tag type, some overall conclusions can be formed.

- When **tag type** was the only variable, Gen 2 averaged more tag reads per trial than Gen 1 for cans and tins **(Table 89, Row 1 and 2)**.
  - The exception arose when the Gen 1 tag on the case of bottles was compared to the Gen 2 tag on the case of bottles, in which their was no statistical difference between the average number of tag reads with the Gen 1 tag versus the Gen 2 tag **(Table 89, Row 3)**.
- When **tag and product** were both variables, product was always the dominant variable (Cans>Bottles>Tins) with one exception.
  - Bottles with a Gen 2 tag and cans with a Gen 1 tag averaged a statistically similar amount of tag reads per trial. This shows a significant advantage for the Gen 2 tag in this situation, with the tag being able to become the dominant variable in the tag by product interaction **(Table 90)**.

Table 89: Product-Tag Type Two-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Tag Least Squares Means								
Product	Tag	_Product	_Tag	Estimate	Standard Error	DF	t Value	Pr > |t|
Can	Gen1	Can	Gen2	-27.0667	2.1641	348	-12.51	<.0001
Tin	Gen1	Tin	Gen2	-23.1167	2.1641	348	-10.68	<.0001
Bottle	Gen1	Bottle	Gen2	-3.8333	2.1641	348	-1.77	0.0774

Table 90: Two-Way Interaction Between Case of Bottles With Gen 2 Tag versus Case of Cans With Gen 1 Tag

Differences of Product*Tag Least Squares Means								
Product	Tag	_Product	_Tag	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen2	Can	Gen1	0.3000	2.1641	348	0.14	0.8898

Tag Type by Speed, Tag Type Only Variable

In studying Table 39, which shows the difference in the average number of tag reads per trial between tag type by speed, some overall conclusions can be formed.

- When tag type was the only variable, the tag's generation made a difference at 300 fpm, in which Gen 2 performed better than Gen 1 **(Table 91, Row 1).**
- However, at 600 fpm the tag 's generation didn't matter as there was no statistical difference between the Gen 1 tag and the Gen 2 tag at 600 fpm **(Table 91, Row 2).**

Table 91: Tag Type-Speed Two-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Speed*Tag Least Squares Means								
Tag	Speed	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Gen1	300	Gen2	300	-36.9000	1.7670	348	-20.88	<.0001
Gen1	600	Gen2	600	0.8889	1.7670	348	0.50	0.6152

Three-Way Interactions

Bottle-Bottle , Tag Type Only Variable

In studying Table 41, which shows the difference in the average number of tag reads per trial between product (bottles) by tag generation by speed, some overall conclusion can be formed

- When tag type was the only variable, the tag's generation made a difference at 300 fpm, in which Gen 2 performed better than Gen 1 **(Table 92, Row 1)**.
- However, at 600 fpm the tag's generation didn't matter as there was no statistical difference between the Gen 1 tag and the Gen 2 tag at 600 fpm **(Table 92, Row 2)**.

Can-Can Interaction, Tag Type Only Variable

In studying Table 42 which shows the difference in the average number of tag reads per trial between product (cans) by tag generation by speed, some overall conclusions can be formed.

- When tag type was the only variable, the tag's Generation made a difference at 300 fpm, in which Gen 2 performed better than Gen 1 **(Table 93, Row 1)**.
- However, at 600 fpm the tag's Generation didn't matter as there was no statistical difference between the Gen 1 tag and the Gen 2 tag at 600 fpm **(Table 93, Row 2)**.

Tin-Tin Interaction, Tag Type Only Variable

In studying Table 43, which shows the difference in the average number of tag reads per trial between product (tins) by tag generation by speed, some overall conclusions can be formed.

- When tag type was the only variable, the tag's generation made a difference at 300 fpm, in which Gen 2 performed better than Gen 1 **(Table 94, Row 1)**.
- However, at 600 fpm the tag's generation didn't matter as there was no statistical difference between the Gen 1 tag and the Gen 2 tag at 600 fpm **(Table 94, Row 2)**.

Table 92: Bottle-Bottle Three-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Bottle	Gen1	300	Bottle	Gen2	300	-14.9000	3.0605	348	-4.87	<.0001
Bottle	Gen1	600	Bottle	Gen2	600	7.2333	3.0605	348	2.36	0.0187

Table 93: Can-Can Three-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Can	Gen1	300	Can	Gen2	300	-52.8667	3.0605	348	-17.27	<.0001
Can	Gen1	600	Can	Gen2	600	-1.2667	3.0605	348	-0.41	0.6792

Table 94: Tin-Tin Three-Way Interaction, Difference in Number of Tag Reads Caused by Tag Type

Differences of Product*Speed*Tag Least Squares Means										
Product	Tag	Speed	_Product	_Tag	_Speed	Estimate	Standard Error	DF	t Value	Pr > |t|
Tin	Gen1	300	Tin	Gen2	300	-42.9333	3.0605	348	-14.03	<.0001
Tin	Gen1	600	Tin	Gen2	600	-3.3000	3.0605	348	-1.08	0.2817

Thoughts and Conclusions

As Dr. Robb Clarke, Associate Professor at Michigan State University, referred to in his article in RFID Product News, "RFID does not work well in all situations and, realistically, only works really well in very controlled environments," due to what Clarke calls, "some inherent complications given the choice of ultra-high frequency (UHF) as a global frequency".[59]

It is apparent that the variables studied in this research (conveyor speed, product type, package type, and package shape) participated in creating complications, upon determining that each variable had an effect on the average number of RFID tag reads per trial. Additionally, tag type, when placed on the case of ketchup, motor oil, metal tins, metal cans, and metal bottles had an effect on the average number of RFID tag reads per trial, but did not effect the average number of tag reads per trial while on the case of potato chips in plastic tubs, and the case of potato chips in MSWFC. Additionally, the documentation of the two-way and three-way interactions that occur between product/package, conveyor speed, and tag type, provide resounding evidence that there is no one fix-all solution for optimal RFID tag performance.

In concentrating on the effect of conveyor speed, when comparing 300 fpm to 600 fpm across all 3 tests, there was an average of almost two times the amount of tag reads per trial at 300 fpm than there was at 600 fpm (91.9 more tag reads per trial at 300 fpm than 600 fpm)

Throughout the entire testing procedure, 6 out of 7 seven products tested were detected in every trial, at each conveyor speed, equipped with either generation of tag. The only product that occasionally went undetected through the portal was the case of metal tins. It is believed that this was due to the fact that there was not one responsive tag location, in either the horizontal or vertical tag orientation, on the case of tins. To possibly improve the readability of the case of tins, previous testing has shown for difficult to read products, the use of a corrugated spacer greatly improved read rates.

It is important to note that in three-way interactions involving all product types, the Gen 2 tag performed greater than or equal to the Gen 1 tag at 300 fpm. Additionally, in three-way interactions involving all product types, the Gen 1 tag performed greater than or equal to the Gen 2 tag when moving at 600 fpm (except for three way interactions involving the case of tins moving at 600 fpm, in which the Gen 2 tag performed better than the Gen 1 tag). The implications of this are clear; companies mandating the use of Gen 2 tags may limit the benefits of the technology (better operation around liquids and metals), when operating conveyors at 600 fpm.

It is also important to note that tag dominance varied by product. The Gen 2 tag outperformed the Gen 1 tag on the case of ketchup, metal cans and metal tins. The Gen 1 tag outperformed the Gen 2 tag on the case of motor oil. The Gen 1 tag performed equal to the Gen 2 tag on the case of metalized spiral wound fiberboard containers, plastic tubs, and metal bottles. In summary, the Gen 2 tag tested provided an advantage, or at least performed equally to Gen 1, for those products or packages which contained high contents of metal or water (metal cans, tins, bottles, and ketchup).

With the knowledge that conveyor speeds have a drastic effect on RFID tag readability, it is crucial that suppliers meeting RFID mandates communicate with their retailers regarding their distribution center and conveyor speed operations. Armed with this information, suppliers can improve product detection at retailer RFID checkpoints, ensuring payment for their product. With retailers having knowledge of the tagged product's location, they are less likely to incur a situation in which a product is out of stock, and through this, retailers are able to increase product sales.

Recommendations for future research involve determining if there is an effect on the average number of reads per trial by both number and antennae location. Previous research performed in this area studied the effect of the number of, and location of, antennae, which was performed using a pallet-load of goods (as compared to the case-loads tested in the conveyor test), placed on a stretch-wrapping machine, all of which was surrounded by an RFID antennae portal. The test, which was performed by Crawforth of Michigan State University, showed that number and location of antennae did have a significant effect on the percent readability of transponders.[22] It would be of benefit to determine if a similar effect occurs with antennae used on conveyor lines, to eliminate unnecessary costs while failing to limit tag readability.

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