PERISHABLE FOOD WASTE REDUCTION THROUGH TECHNOLOGICAL IMPLEMENTATION AT THE RETAIL LEVEL OF THE FOOD SUPPLY CHAIN

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ABSTRACT

Perishable Food Waste Reduction Through Technological Implementation at the Retail Level of the Food Supply Chain

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Food waste has become a disaster of global proportion that the world can no longer turn a blind eye to. This paper aims to reduce food waste at the retail level of the food supply chain by recommending and quantifying the effects of current technology that can be implemented in traditional supermarkets. This research recommends that retailers implement electronic shelf labels in stores and employ dynamic pricing of perishable products, leading to reduction of food waste. No prior research had considered the primary goal of reducing food waste while preserving retailer profit through technological implementation. This paper quantifies the effects of implementing this technology and provides economic justification of the required investment through the calculation of profitability metrics and discussion of environmental regulations retailers will soon have to abide by. Our results indicate, even in the most conservative of scenarios, that the payback period for full implementation of electronic shelf labels will be less than or slightly over one year and the return on investment is high in all situations discussed. Sensitivity analyses of labor costs, revenue, and profitability ratios are illustrated to provide a full breadth of these results.

Keywords: Dynamic pricing, food waste, food supply chain, electronic shelf label

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I. Introduction

Today we see the direct and indirect impact that unsustainable business and consumer practices have had on our planet over the last century. Forests are burning for weeks on end, icebergs are melting, temperatures are fluctuating unnaturally all over the world, and so much more. While social media is helping to bring about awareness campaigns and calls to action, consumers seem to think that the blame lands solely on large corporations and call on them to pursue more ethical and sustainable business practices. However, this is not enough. Efforts to protect our planet need to become widespread and individualized. In developed countries, 40% of food waste actually occurs at the retail and consumer level (Food and Drug Administration [FDA], n.d.). This means that perfectly edible food is thrown away by producers, retail grocery stores, and consumers. The Food and Agriculture Organization of the United Nations (FAO) estimates that about one-third of edible food specifically made for human consumption ends up being lost or wasted (Gustavsson et al., 2011).

One must wonder why anyone would waste perfectly edible food? There are many cases that lead to edible food being sent to landfill. Cosmetic flaws contribute vastly to food waste. Produce that has visible imperfections such as bruises or are "oddly" shaped are discarded by producers and retailers who do not believe they are up to quality specifications. Even if this produce is displayed in grocery stores, much is often neglected and never purchased by consumers who interpret cosmetic flaws as a sign of poor quality. Although there are efforts to rescue food that is considered "ugly" such as Imperfect Foods and Misfit Produce, much of this food supply that cannot be repurposed or diverted ends up being landfilled by retailers. Another common reason is due to confusion over food product date labels. Consumers mistakenly interpret these dates as exact, leading them to throw away any products that are approaching or have surpassed the printed date. Further, puzzling phrases are often used when describing these dates. You may see “freeze by,” “sell by,” and even “best by” which is understandably perplexing to consumers afraid of contracting illness from eating expired food. Nevertheless, confusion over food product dating is no excuse for the amount of food wasted each year. Almost 15% of U.S. households were food insecure at a point in time in 2011. This number is sure to have risen especially in the wake of the COVID-19 pandemic. It is estimated that even reallocating just 30% of all food waste in the U.S. could feed every American suffering from food insecurity (Leib & Gunders, 2013).

II. Problem Description

An estimated one-third of all food made for human consumption is lost or wasted globally. Consequently, food waste is a serious problem in both developed and developing countries. The majority of food wasted in developing countries stems from the early to mid-stages in the food supply chain (FSC). This could be due to financial, technical, and managerial limitations for storage and harvesting combined with complicated infrastructure and climate conditions. Conversely, the majority of food waste in developed countries is generated at the consumer level. This is likely due to consumer behavior combined with a lack of communication between manufacturers, retailers, and the general public. Consumers in developed countries tend to have a careless attitude about overstocking food products because they can afford to waste food unlike many consumers in lower-income countries. This could be due to the fact that many stakeholders in the FSC see food waste as an essential part of business, not an inefficiency that can and needs to be improved. This mindset and other contributors to global food wastage can be seen in the Ishikawa diagram of Figure 1.

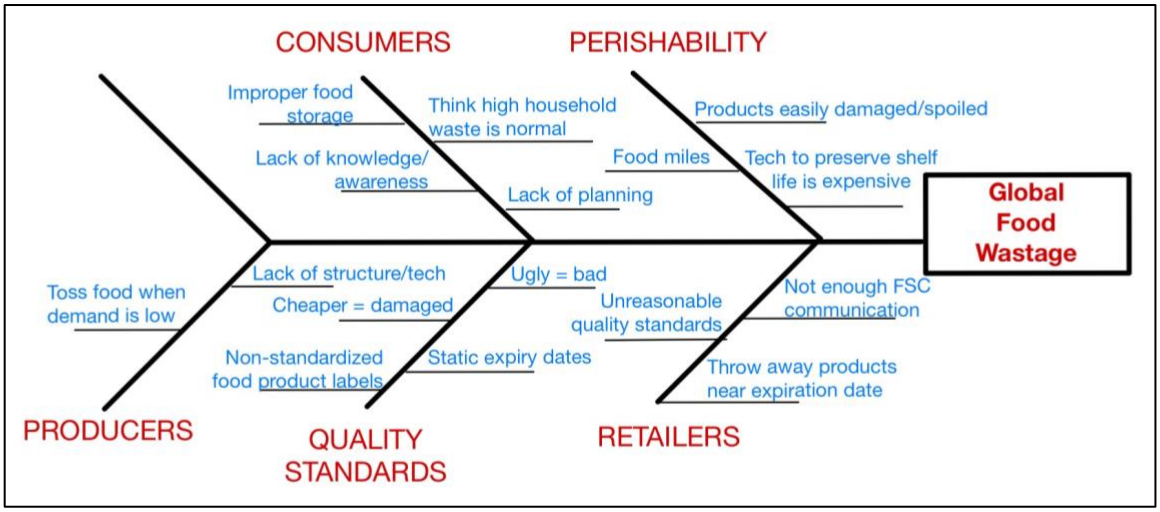

Figure 1: Ishikawa Diagram of Global Food Wastage

Food waste that is not diverted to composting ends up being combusted or landfilled. With 2,000 active landfills, the United States of America (USA) is still set to run out of space in landfills within the next 18 years while the amount of solid waste being produced is rising (McCarthy, 2018). Landfills are extremely detrimental to the environment and contribute heavily to climate change. Food waste in landfills contributes to 18% of the total methane emissions in the USA, one of the most common greenhouse gases that cause global warming (United States Environmental Protection Agency [EPA], 2016). An approximation of the direct impacts of food waste on the environment can be seen in Figure 2.

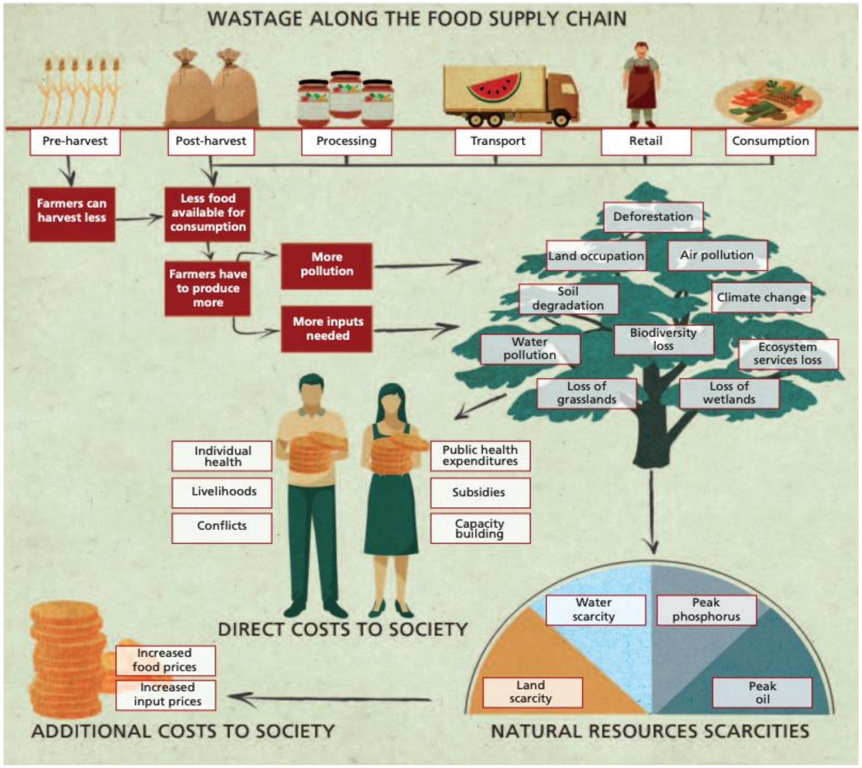

Figure 2: Approximation of Direct Impacts of Food Wastage (FAO, 2014)

Food waste also indirectly impacts the environment, society, and livelihoods as well. The FAO estimates the carbon footprint of global food waste to be 3.3 Gigatons, making food waste the 3rd top emitter of CO_2 following the USA and China (FAO, 2013). Global food wastage also amounts to about 250 km^3 of water usage per year, which is approximately three times the volume of Lake Geneva. Solely uneaten food occupies 1.4 billion hectares of land, which is closely represented as 30% of the entire world’s arable land. Wildlife is also negatively impacted. Food waste incurs biodiversity loss due to monocropping and expansion of land used for agriculture for food that does not even get eaten. The full landscape of indirect impacts from food waste can be seen in Figure 3 below.

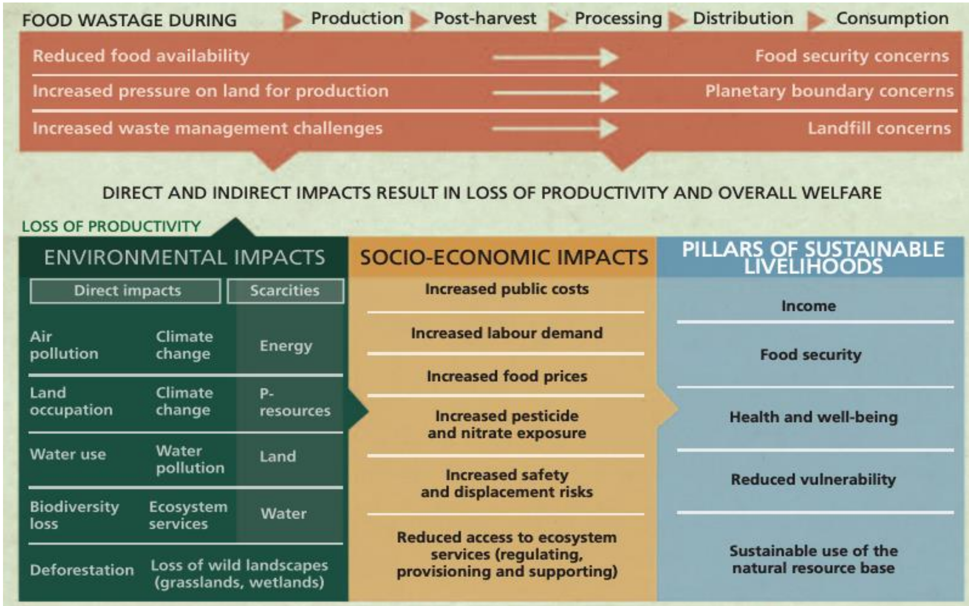

Figure 3: Full Landscape of the Indirect Impacts of Food Wastage on the Environment, Society, and Livelihoods (FAO, 2014)

The economic costs associated with global food waste are estimated to amount to about $1 trillion each year, not including indirect costs (FAO, 2014). In the USA alone, food waste amounts to about $41.9 billion per year from supermarkets, restaurants, and convenience stores combined (Weber et al., 2011). Large food retailers such as Walmart, Kroger, and Albertsons have such large market power in the USA and access to funding to try changing traditional business practices to reduce food waste, as suggested by the Harvard Business Review (Kor et al., 2017). It is clear in the direct and indirect impacts of food waste that we as a human species are on borrowed time. There is no time to lose in regards to making real, tangible changes in every sector of the FSC.

III. Literature Review

Remaining Shelf Life

The first area of literature relevant to this study is the remaining shelf life (RSL). RSL refers to the estimated duration that a product has until spoilage. RSL can be improved with proper handling procedures and technology. The idea of implementing Dynamic Expiry Dates (DEDs) instead of currently used Fixed Expiry Dates (FEDs) was explored by researchers who found that DEDs could decrease opportunity losses from stockouts and food loss by almost 80% (Tromp et al., 2012). DEDs would reflect a more accurate RSL than FEDs. By determining the RSL of a product by some percentage of its original quality value, retailers can use this information to employ dynamic pricing and discount these products in order to entice customers to purchase them rather than let these goods potentially spoil and go to waste. This methodology is tested by La Scalia, et al. (2019). These researchers found that First Expiring First Out (FEFO) techniques are best used when RSL is known in order to make monitoring technology investments cost effective and feasible for warehouse management (La Scalia et al., 2019). Other research looks into different freshness-keeping efforts that can be employed to extend shelf life. Freshness-keeping efforts can range from periodically spraying vegetables with water to refrigerating certain products in closed containers versus open. Increasing RSL even by one day can reduce waste by 42.8% in some cases (Broekmeulen & van Donselaar, 2016). However, Zhang and Wang found that freshness-keeping efforts are only appropriate to use in the case of moderate inventory level (Zhang & Wang, 2020). This shows that when inventory level is too high or too low, there is no effective use of implementing these extra efforts which would lead to unnecessary costs. One study discusses the benefit of using dynamic pricing in extending shelf life, but also brings up a very concerning point. There are cases where retailers may be enticed to dispose of goods rather than salvage them with a discounted price in order to offset any loss due to disposal costs (Li et al., 2012). This could be due to the fact that many businesses believe food waste to be a necessary part of the retail business model. Executives and managers see certain waste levels as a sign that a store is managing quality control and consumer demand well, keeping shelves fully stocked, and turning product quickly (Gunders, 2012). Unfortunately, this mindset perpetuates the inefficiency of food wastage and lost revenue in the retail business model. This study intends to reduce food waste first and foremost, and then maximize retailer profits. This objective will become important as the food wastage problem continues to rise in the coming years and policies requiring businesses to offset waste get ratified.

Food Product Dating

Consumers everywhere are accustomed to following food product labels religiously and toss food approaching or past the labeled date on the product packaging in the garbage or compost. In fact, over one-third of consumers always discard food close to or past the date on the label, and 84% do so at least occasionally. A study conducted in the United Kingdom found that 20% of consumer waste occurs because of date label confusion (Leib et al., 2016). However, the term “expiration date” itself is a misnomer. The dates printed on food packaging were meant to serve as an estimation for when the product is of best quality. The Food Safety and Inspection Service (FSIS) refers to these dates as “food product dating” and explicitly states that these are meant for food quality, not safety. It was found that one-third of consumers incorrectly think that food date labels are regulated by the government (Leib et al., 2016). Unfortunately, there are currently no federal policies or laws in place requiring any product to be labeled with an expiration date except for infant formula. Food product labels are merely recommended. If a manufacturer chooses to voluntarily provide this information, then the date label must follow the format of a month and day along with a phrase explaining the meaning of the date, such as “Best by August 10” (FSIS, 2019). This gives manufacturers the sole power to dictate the date label information provided on products. Commonly used phrases such as “Sell-By” and “Use-By” tend to confuse retailers and consumers of the safety of the product, and understandably so. The FSIS recommends manufacturers to use “Best if used by” to stress that the information is based on product quality, not safety (FSIS, 2019). While consumers may argue that they follow these labels explicitly for their safety, improper storage of a perishable, such as dairy milk, can lead the container of milk to expire far before the printed date. Although it was noted in the 1970’s when open product dating was first introduced that FEDs could not ensure the microbiological safety of food, supermarkets still voluntarily adopted the practice due to customer demand for transparency of food freshness and quality (Leib & Gunders, 2013).

Food Waste Reduction

Another pivotal portion of literature to note is research centering around a main objective of reducing food waste. While there are many avenues to pursue in reducing global food wastage, the first we will delve into is unreasonable supermarket expectations. In the USA, a majority of supermarkets and popular grocery stores are actually owned and operated by the same few companies. This leads to a concentration of power among supermarkets, leading to them demanding detrimental practices, such as overproduction and cosmetic perfection of farmers. Overproduction has become a normalized expectation of farmers with supermarket contracts. Supermarkets demand that their producers always have enough supply to avoid stockouts in-store, yet if demand happens takes a plunge, farmers are expected to absorb the cost and waste associated with this surplus (Feedback, 2018). In fact, Feeding America estimates more than 6 billion pounds of fresh produce goes unharvested or unsold each year (Gunders, 2012). Distributors and retailers also have the ability to cancel or alter orders due to incorrectly forecasting demand (Feedback, 2018). These last-minute changes make it even more difficult for farmers to find alternative uses for unused product before spoilage. If left in their fields or on their land, farmers often can repurpose unused produce by turning it into compost or animal feed. However, if orders have already been packaged or transported, farmers lose out on the cost of harvest, packaging, shipping, and then the product itself, as many are unable to find rushed alternative avenues of revenue such as bargain stores, farmers markets, etc. As for cosmetic standards, retailers often instill additional produce standards to the United States Department of Agriculture's (USDA) initial guidelines, refusing to purchase or receive produce that does not meet their specifications. This leads to farmers having to train their workers to selectively harvest, leaving any produce that does not meet minimum quality specifications behind in order to minimize labor costs (Gunders, 2012). Contract farming, although more profitable, reaps more food waste than independent farming. Contract farmers must adhere to any unreasonable demands their retailers present as mentioned earlier. Some farmers forecast to have as much as 15% of their produce rejected. Dsouza found that even reducing the rejection rate to just 5% can significantly reduce food waste in contract farming (Dsouza, 2020). Accurately forecasting demand is another way for retailers and producers to reduce food waste. Proper forecasting can lead to appropriate planning and purchasing. Because the idea of overflowing displays is so popular to many retailers, it is common to inaccurately forecast demand, leading to continuous overstock. However, Stop and Shop conducted an analysis into using less-full displays and found that spoilage was reduced and customer satisfaction was actually increased, disproving the idea of "full to the brim" displays (Gunders, 2012). By accurately forecasting customer demand for perishables, retailers can not only reduce the risk and occurrence of overstock, but also increase revenue. One study found that by differentiating products that are slow versus fast-moving and attributing appropriate forecasted demand for each item can actually reduce waste up to 12% (Broekmeulen & van Donselaar, 2016).

Perishability Management Technologies

The next realm of literature to consider is potential technological investments for improving inventory management and tracking of perishables. The use of RFID (radio-frequency identification) and TTI (time-temperature indicator) technology is becoming more common in supply chain practices and is currently being researched in order to use in storage and management of perishable goods. One study looked into the value of information (VOI) that TTI technology can provide to retail grocery stores and the FSC. TTI can provide historical information that decreases spoilage, increases product availability, and increases service levels as a product flows through the FSC (Ketzenberg et al., 2015). Another study found that TTIs also increase the efficiency of price differentiation strategy in terms of raising expected profits when enabling dynamic pricing dependent on RSL of products (Herbon et al., 2014). Similarly, one study concluded that when employing dynamic pricing and demand dependent on quality level of inventory, implementing better inventory holding technologies can efficiently increase profits and lower negative impact of deterioration (Rabbani et al., 2016). Another technology to consider when using dynamic pricing is electronic shelf labels (ESLs). ESLs are miniature electronic devices used to replace standard paper tags displaying product costs in retail stores. ESLs have been implemented in many industries with retail storefronts, but have yet to make a widespread introduction to traditional supermarkets in the USA. ESLs can display product information relative to price, country of origin, reviews and even barcodes for further consumer interaction. The opportunity that ESLs present to grocery stores are instantaneous price adjustments, flexibility of pricing strategies, and robust price correctness. Boden et al. (2020) note that ESLs can ensure price consistency between online and offline channels, consistently and clearly present product information, and improve the appearance of product displays. One study found that ESLs also positively influence store image and do not affect consumers' price fairness perception, something that retailers fear when contemplating the use of ESLs (Garaus et al., 2016). With the combined used of dynamic pricing and ESL technology, retailers can reduce costs associated with manual price tagging, often referred to as menu costs, which one study found to cost .7% of annual store revenue when a store changes an average of 15.66% of product prices per week (Levy et al., 1997). This research is important to show that in many cases, implementation of enhanced technology for managing and storing perishables can lead to an increase in overall profits despite requiring a large initial investment.

Dynamic Pricing

Dynamic pricing can be described as the adjustment of the price of goods sold due to varying factors. Common examples of dynamic pricing are seasonal sales at clothing stores, bundled deals of electronic products, and even fluctuating prices on websites such as Amazon. Dynamic pricing can follow different schedules, such as a one-time adjustment policy or regular, bi-weekly adjustments. Depending on the different factors being considered in each scenario, one-time adjustments and multi-period adjustments could both prove to be beneficial to the retailer. Clearly, manually adjusting prices in-store would require more planning and possibly an increase in labor to reflect new prices on products. When considering the managerial and labor costs associated with adjusting prices in-store, a one-time adjustment is most optimal. However, it was found that adjusting the price of the product in the middle of its shelf life was always preferred (Chen et al., 2017) Conversely, Chung and Li (2013) found that multi-period pricing actually brings higher profits and reduces waste when demand is either accurately forecasted or overestimated. The schedule of price adjusting may have to reflect the values of each individual retailer. Plainly, a retailer who values reducing food waste and the costs associated overall, may prefer an increase in labor costs and dealing with unknown demand with more frequent amendments to prices if that means less food will spoil due to not being purchased. Unforeseen demand can be detrimental to retailers and the food supply chain, as evidently seen in the case of the COVID-19 pandemic. For this reason, many researchers have chosen to proceed with their studies by assuming stochastic demand to model a more authentic scenario. In the case of assumed stochastic demand, one study found that optimal selling price is deterministic in the case of non-instantaneous deteriorating items with shortages and surplus permitted, allowing managers to adjust strategy and pricing immediately to warrant maximum profit (Luo et al., 2020). While dynamic pricing of perishable goods has been found to be more profitable than static pricing in most scenarios (Li et al., 2014), there are cases found in research where dynamic pricing does not always reap higher total profit for retailers. Customer behavior can be detrimental to revenue with dynamic pricing in cases of stochastic demand. Because customers are human and behave unexpectedly, their choices can be hard to forecast and model. It is innate human nature to act “greedy” and purchase products with only one’s satisfaction in mind. Customers are likely to choose produce that looks “prettier” and assume that it is higher quality, the same way that customers may choose to buy a gallon of milk with a later expiration date over another, believing they will reap greater satisfaction from a longer RSL. Consumer strategy can therefore cause variation in demand due to delayed purchasing. However, this can be combatted with the threatening of stock outs or unexpected pricing (Su et al., 2008). One study considered factoring in consumers’ price fairness perception to foster a relationship between the consumer and retailer but would require the sacrifice of retailer revenue in order to achieve an optimal markdown policy and mutually beneficial relationship in the long-run (Wang et al., 2016). Adenso-Díaz et al. (2017) studied scenarios in which customer behavior and low values of price elasticity actually ended up in a decrease of revenue from the use of dynamic pricing, but also found that nearly all cases of dynamic pricing reduce total product. This presents the possibility of retailers having to compromise profits in order to reduce food waste. However, retailers could still reap non-financial incentives such as improved customer satisfaction, social responsibility image, and reputation, to name a few. In cases where demand can be accurately forecasted, Chung and Li found that multi-period dynamic pricing strategies are more profitable to retailers than static pricing strategies and more effective in reducing waste from unsold stock. A particularly interesting note from this study shows that the more dynamic pricing approaches are, the more customers become aware of RSL conditions in planning their consumption (Chung & Li, 2013). Enhanced consumer awareness of shelf-life conditions has been studied to significantly reduce food waste overall at the retail and post-consumer stages of the food supply chain.

Past research has found that dynamic pricing reduces food waste in most, if not all, scenarios regardless of what happens to retailer revenue and especially in the case of having excess stock or greater stock than average consumer demand (Chung & Li, 2013; Adenso- Díaz et al., 2017; Chung, 2019). As this is our principal objective, we will proceed with the solution of implementing dynamic pricing. Chung does mention that employing dynamic pricing strategies will in turn increase labor costs (Chung, 2019). Chen et al. provide the situation of comparing dynamic pricing to fixed pricing when considering “menu costs,” or the labor costs to make these adjustments. They found that when these costs are small to moderate, employing dynamic pricing is optimal, but when these costs are high, firms should proceed with fixed pricing for optimal revenue performance. This information is key in providing a justification for implementing dynamic pricing practices. Because all of these studies focused on maximizing retailer revenue, there is a gap in research finding the optimal balance of reducing food waste while not having to sacrifice retailer profit. This thesis aims to bridge the gap by implementing dynamic pricing strategies and technological innovations to minimize food waste and preserve retailer profit.

IV. Solution Directions

Available Technological Innovations

In order to economically justify investing in technological advancements to reduce food waste, we will be primarily targeting reducing labor costs associated with price adjusting. Every retail store employs a range of different positions that complete different tasks. In this thesis we will be focusing on stockers, individuals hired to manually stock, price, inspect, and adjust moving product throughout the store as needed. This specific position is built on tediously manual labor. Most of the tasks assigned to stockers are extremely time-consuming, and likely involve unnecessary movement and waiting. These inefficiencies can be eliminated with technological advancements that already exist and are being used in the retail industry today. The first technology to discuss is RFID. RFID solutions can already be found throughout supply chains in many industries such as healthcare, clothing, manufacturing, and even food. Transparency and traceability are two things consumers are rapidly demanding in purchasing products. Consumers want to know where their food is coming from, how it was made, where the ingredients came from, and how long it will last. This information can all be tracked automatically and provided to consumers with ease. Avery Dennison specifically has a suite of RFID solutions catered to the FSC called the Avery Dennison® Freshmarx® Cloud. This ecosystem of RFID solutions provides each stage of the FSC with technology that can be implemented to maximize transparency and traceability and reduce labor costs and inefficiencies, as pictured in Figure 5 below.

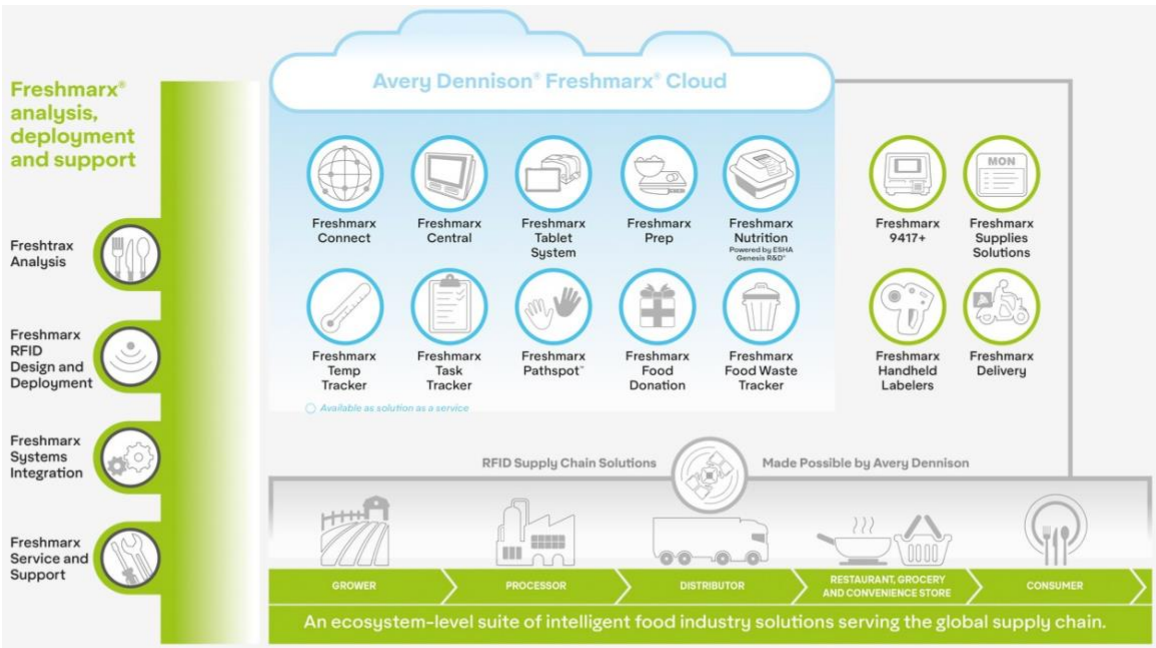

Figure 4: Avery Dennison® Freshmarx® Cloud of RFID Solutions (Avery Dennison Corporation, n.d.)

The next technology is the Produce Connect Mobile Application (PCMA). The PCMA is an application that uses artificial intelligence to determine the quality grade of produce shipments based on USDA official guidelines. The app documents quality as it travels through the supply chain, reduces the occurrence of disputes between producers and retailers and estimates RSL with up to 70% accuracy. Once the RSL is determined, this information can accompany the produce to the retailer and help reduce waste at the retail and consumer level. The PCMA is also critical in reducing costs, waste, and time associated with produce disputes of quality standards. The current process many retailers and producers must endure is demonstrated in Figure 6.

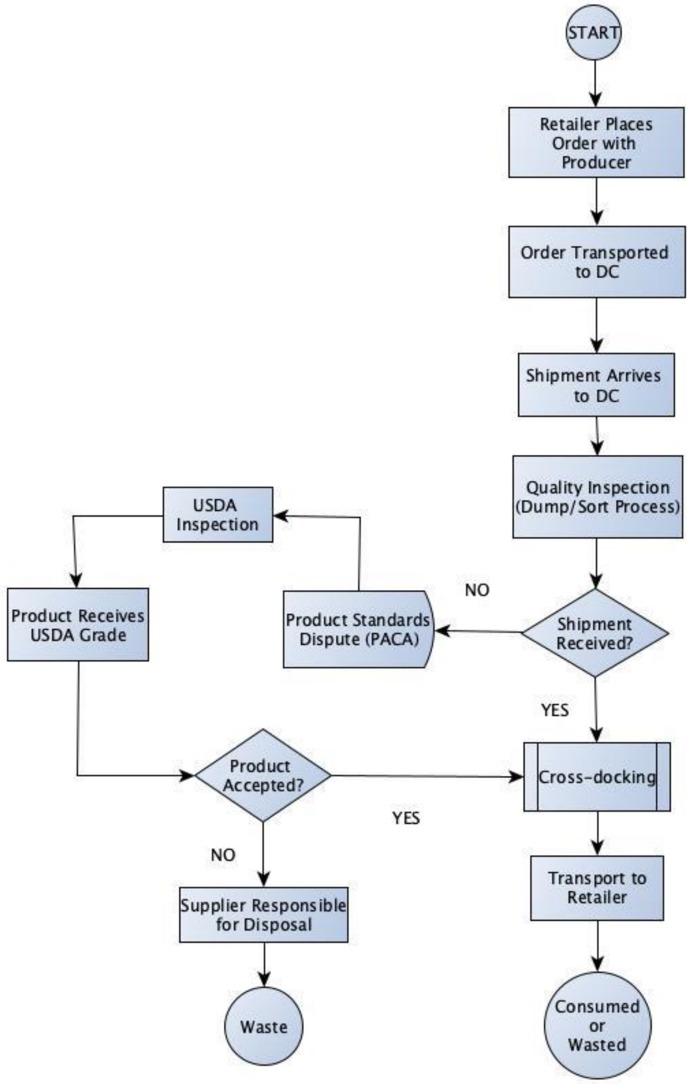

Figure 5: Current Produce Standards Dispute Process Between Producers and Retailers

The last technological solution is utilizing ESLs and dynamic pricing. As discussed in Section III, dynamic pricing is an effective strategy that is proficient at reducing waste at the retail level but is difficult to implement due to time-consuming and expensive manual labor costs. ESLs eliminate the need for manual labor to tag and adjust prices. Figure 6 and 7 below show common examples of what ESLs look like in retail grocery stores.

Figure 6: ESL Shelf Labels Used in Supermarkets (Opticon Vietnam, 2015)

Figure 7: ESL Examples with Barcodes and QR Codes (Opticon Vietnam, 2015)

These two solutions combined can introduce dynamic pricing strategies while simultaneously reducing manual labor costs to find the optimal relationship between minimizing waste and preserving retailer profit. The costs and benefits to each of these solutions are summarized in Table 1 below.

Technological Solution	Applicable Stages of the FSC	Benefits	Costs
Radio Frequency Identification (RFID)	✓ Post-Harvest Processing ✓ Packaging Warehouse ✓ Cold Storage Warehouse ✓ Distribution Center ✓ Retail Grocery Store	- automated data capture - improved data accuracy and quality - improved inventory management - reduced need for line-of-sight scanning - larger capacity of data storage than barcodes	- cost of investment - long integration process - employee training required - requires robust infrastructure
Produce Connect Mobile Application (PCMA)	Post-Harvest Processing Packaging Warehouse Cold Storage Warehouse ✓ Distribution Center ✓ Retail Grocery Store	- predict RSL with 70% accuracy - reduce occurrence of product disputes between producers and retailers - avoid involvement from USDA representatives - know the grade of produce instantly	- cost of investment - employee training required
Electronic Shelf Labels (ESLs)	Post-Harvest Processing Packaging Warehouse Cold Storage Warehouse Distribution Center ✓ Retail Grocery Store	- reduce labor costs associated with tagging and adjusting prices - eliminates costs of paper tags - reduced time to adjust prices - improves appearance of shelving	- cost of investment - employee training required - ESL lifespan ranges 5 to 15 years - dynamic pricing strategies still need to be strategized

Table 1: Summary of Associated Costs and Benefits of Recommended Technological Solutions

V. Solution Evaluation

Retailer Profit

While revenue is an extremely important aspect of overall retailer performance, retailer profit is what truly drives a company to make important decisions. Retailer profit encompasses revenue along with a considerable amount of costs. Purchasing includes the costs for purchasing, ordering, and transporting product. Inventory costs consist of all costs associated with controlling, handling, storing, and stocking inventory in store. Labor costs are all costs associated with manual labor tasks such as price adjustments, culling, and more. Overhead operating expenses include costs associated with running the retail store such as insurance, rent, utilities, and the like. Disposal costs are charges for disposing of product, whether spoiled or expired. Let P be retailer profit, which is calculated as revenue, R, minus the purchasing costs, PC, inventory holding costs, HC, labor costs, LC, operating expenses, OC, and disposal costs, DC. Therefore, we have the calculation for retailer profit to be:

$$P = R - (PC + HC + LC + OC + DC). \qquad (1)$$

Economic Analysis of Retailer Labor Costs

Because we are not considering the possibility of increasing retailer revenue, although it is extremely likely, we will focus on the reduction of costs, specifically LC. The LC that we will be discussing are manual tasks associated with product price adjustments that are inefficient and costly to the firm. Levy et al. (1997) found that traditional supermarkets in the USA spend an average of .7% of annual store revenue on menu costs, or the LC that we are focusing on in this thesis. Following suit, we will use this percentage in our calculations. Since this study was conducted in 1997, there are of course many changes that have occurred over the last two decades that we will be neglecting for simplicity. We will not be considering technology that firms may have implemented to speed up the LC being discussed. Nor will we consider the effects of inflation in order to justify not acknowledging the consideration mentioned prior. Levy et al. (1997) also note that the hourly wage of grocery workers in the stores they studied was between $14 to $20, which has not changed much to the average salary of these workers today. We will be calculating the average annual LC of adjusting prices for 5 of the top 10 supermarket chains in the USA based on the highest-grossing revenue. Of these top 10 chains, Walmart, Aldi, and Meijer were removed for not following the traditional supermarket format that we are investigating. HEB Grocery Co and Ahold Delhaze were also removed as outliers. We will be taking the reported annual revenue for each corporation and dividing it by the number of reported stores in the corporation to get the average annual store revenue seen in line 3 of Table 2. The percentage of revenue is the .7% found in the study by Levy et al. (1997) in line 4. The LC per store for each supermarket chain is calculated as the estimated revenue per store multiplied by the percentage of revenue spent on the LC in question, which can be seen in the last line of Table 5 below.

	Kroger	Albertson's	Publix	Wakefern	Whole Foods
Corporation Revenue*	$ 132,498,000,000	$ 69,690,400,000	$ 44,900,000,000	$ 18,300,000,000	$ 15,724,000,000
Number of Stores*	2,759	2,323	1,236	354	500
Revenue per Store	$ 49,000,000	$ 31,000,000	$ 37,000,000	$ 52,000,000	$ 32,000,000
Percentage of Revenue	0.7%	0.7%	0.7%	0.7%	0.7%
Cost per Store	$ 343,000	$ 217,000	$ 259,000	$ 364,000	$ 224,000
				Grand Mean	$ 281,400

Table 2: Calculation of Average Annual Costs Per Store Associated with LC

*Corporation revenue and number of stores for supermarket chains were web scraped from publicly available sources (FoodIndustry, 2019; Redman, 2020; Publix, 2021; Financial The Kroger Co, n.d.; Financial Alberstons Companies Inc., n.d.).
**All values provided in the table above reflect average annual numbers and are rounded to the nearest thousand to reflect that they are estimations and not exact.

The grand average cost of labor per store for price adjusting comes to a grand mean of $281,400 which we will refer to as the calculated *LC* moving forward. These costs will in turn become potential labor savings with the implementation of ESLs and dynamic pricing which we will discuss further in the next subsection. It is important to note that the findings used by Levy et al. (1997) to calculate the numbers in Table 2 are based on the assumption that traditional supermarkets change an average of 15.66% of total product prices in store each week. It is important to note that this number is based on the operations of supermarkets in the 1990's. Due to the vast evolution of the grocery industry and supermarkets over the past two decades, it is fair to assume that this is an underestimate of the percentage of products that undergo weekly price adjustments in supermarkets today. We come to this conclusion for two reasons: intense competition has developed directly from rival supermarkets and indirectly from the introduction of nonconventional supermarkets, discount stores, and supercenters that force traditional supermarkets to evolve to provide the best products at the lowest prices with the most enjoyable shopping experience; the digitization of grocery shopping has exponentially increased due to online giants such as Amazon and the COVID-19 pandemic.

Economic Analysis of ESL Implementation

The ESL global market is estimated to be worth $400 million and projected to grow by 15% annually until 2022 (Boden et al., 2020). For this reason, there are many competing companies selling ESLs constantly improving their technology to remain competitive in the market as more retailers begin investing into it. ESLs are estimated to cost between $6 to $8 depending on size, type, and capabilities (SOLUM, n.d.). The number of total ESLs needed will depend on how many stock keeping units (SKUs), or single products, are sold in a store. Additionally, gateways will need to be purchased to accompany ESLs, as a single gateway can update anywhere from 1,000 to 3,000 ESLs. The example is given for a 1,000 m^2 store having an average of 10,000 SKUs and requiring between 3 to 4 gateways in the entire store (SOLUM, n.d.). We will be using this information as a conversion factor for calculating the total initial cost of investment for ESLs for the top supermarkets in the USA based on their average traditional supermarket square footage. Because supermarkets can carry an average of 15,000 to 60,000 SKUs in a single store, we will be conducting a sensitivity analysis based on four cases: (1) high estimate of SKUs or 60,000; (2) median estimate of SKUs or 37,500; (3) low estimate of SKUs or 15,000; and (4) 10,000 SKUs per 1,000 m^2. We will need to convert m^2 to ft^2 to calculate the number of SKUs per store for Case 4, so we note that there are 1,000 m^2 per 10,763.9 ft^2. Therefore, the equation for calculating number of SKUs for Case 4 is as follows:

$$\# SKUs = (10000\ SKUs/1000m^2)\ (1m^2/10.764ft^2)\ (average\ ft^2\ per\ store) \qquad (2)$$

The initial cost of ESL investment including the sensitivity analysis of all four cases mentioned are broken down in Table 3. The number of SKUs per case are depicted in lines 5 through 8.

	Kroger	Albertson's	Publix	Wakefern	Whole Foods
Square Footage*	57,000	46,000	45,000	75,000	40,000
Gateways Needed	21	17	17	28	15
Cost of Gateways	$ 6,355	$ 5,128	$ 5,017	$ 8,361	$ 4,459
Management Cost**	$ 500	$ 500	$ 500	$ 500	$ 500
Case 1: # SKUs	60,000	60,000	60,000	60,000	60,000
Case 2: # SKUs	37,500	37,500	37,500	37,500	37,500
Case 3: # SKUs	15,000	15,000	15,000	15,000	15,000
Case 4: # SKUs	52,955	42,735	41,806	69,677	37,161
Case 1	$ 487,000	$ 486,000	$ 486,000	$ 489,000	$ 485,000
Case 2	$ 307,000	$ 306,000	$ 306,000	$ 309,000	$ 305,000
Case 3	$ 127,000	$ 126,000	$ 126,000	$ 129,000	$ 125,000
Case 4	$ 431,000	$ 348,000	$ 340,000	$ 567,000	$ 303,000
Average Total Cost	$ 338,000	$ 316,500	$ 314,500	$ 373,500	$ 304,500
				Grand Mean	$ 329,400

Table 3: ESL Initial Investment Breakdown with Sensitivity Analysis

*Square footage for each store is the average square footage reported for each supermarket chain. (Ceballos, 2015; Schram, 2017; Radice, 2019; Coppola, 2020; Kroger, n.d.)
**The management cost is defined as the cost for maintenance and software necessary to manage ESLs in the store based on the estimate given by SOLUM (SOLUM, n.d.). While it is not explicitly stated that this is a general one-time fee, we will address this oddity further in the estimation of ongoing costs.
***All cost calculations in this table have been rounded to the nearest thousand for each case to signify that these numbers are in fact estimates.

For every 1 SKU there will need to be 1 ESL. The costs in Table 3 are based on the highest estimated cost of $8 per ESL and needing 4 gateways per 1,000 m^2 or 10,764 ft^2 in a single store. This provides a more conservative and accurate evaluation of costs associated with the initial investment. The grand mean cost of implementation amongst the highest-grossing revenue grocery chains is $329,400 which is graphed in Figure 7.

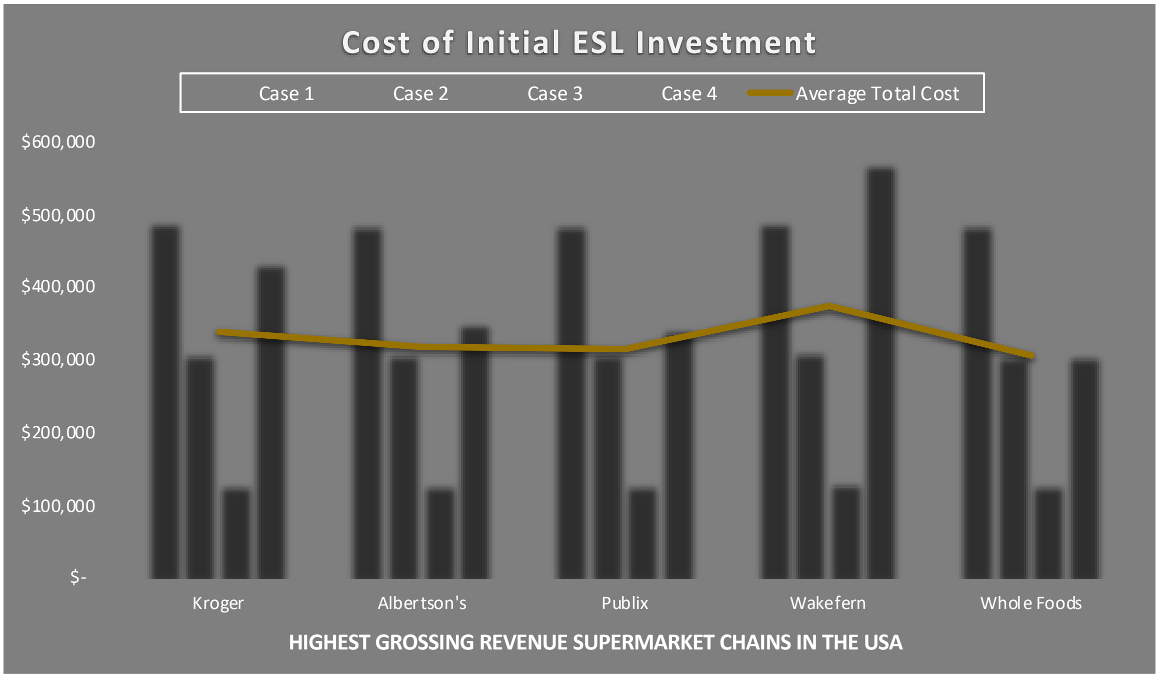

Figure 8: Sensitivity Analysis of Cost of Initial ESL Investment

Economic Analysis of Profitability Ratios

To provide economic justification for retailers to make the investment discussed, net present value (NPV), return on investment (ROI), and payback period (PBP) will be calculated to quantify the profitability of implementation. The bulk of the cost of full implementation of ESLs will be in the initial investment. However, there are likely to be ongoing annual costs (*OAC*) associated with software, maintenance, repairs, troubleshooting, and more in the following years. Because there is a significant lack of information on this subject, we will make the assumption that *OAC* will amount to an additional 15% of initial investment each year, or $42,210. There will also be costs to replace ESLs. Let this cost be *CR*, for cost of replacement. The battery life for ESLs are estimated to range anywhere from 5-15 years depending on the type of ESL, frequency of price adjustment, and which company they are purchased from (Displaydata, 2019;

Pricer, 2020). To quantify ESL replacement, we will conduct a sensitivity analysis of battery life based on these four cases: (1) high estimate of battery life; (2) median estimate of battery life; (3) low estimate of battery life; and (4) lowest estimate of battery life. The number of years for each case will be 12.5, 10, 7.5, and 5 years respectively. These years will also determine the deterioration rate that we will add to the *OAC*. The deterioration rate is the percentage of ESLs expected to require replacement each year. The deterioration rate (*DR*) for each case is calculated as follows:

$$DR = 1 / (\text{estimated battery lifespan}) \tag{3}$$

For example, Case 1 estimates a battery lifespan of 12.5 years which makes the DR for Case 1 equal to 8%. We will use *DR* to calculate *CR*. The calculation for costs of replacing ESLs based on *DR* each year is as follows:

$$CR = (DR)(60{,}000\ SKUs)(\$8) \tag{4}$$

We use the highest estimate of 60,000 SKUs and $8 per ESL to be as conservative as possible with our estimates. For example, the CR for years 1 through 20 for Case 1 will be equal to $38,400. Therefore, the annual costs of implementation for each case, or cash outflows C_{OUT}, will be calculated as follows:

$$C_{OUT} = OAC + CR \tag{5}$$

This will allow us to calculate the estimated total ESL implementation cost per year for each case, which will, in turn, be used to calculate NPV, ROI, and PBP for each scenario. Calculating costs and profitability ratios of four different cases allows retailers to see a broader picture of potential costs for a range of situations if they choose to implement ESLs into their store.

	ESL Implementation Cost				Labor Savings				
	CASH OUTFLOW				CASH INFLOW	NET CASH FLOW			
	Case 1	Case 2	Case 3	Case 4	All Cases	Case 1	Case 2	Case 3	Case 4
DR	8%	10%	13%	20%					
0	$329,400	$329,400	$329,400	$329,400	$0	($329,400)	($329,400)	($329,400)	($329,400)
1	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
2	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
3	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
4	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
5	$88,000	$98,000	$114,000	$475,000	$281,400	$193,400	$183,400	$167,400	($193,600)
6	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
7	$88,000	$98,000	$443,000	$146,000	$281,400	$193,400	$183,400	($161,600)	$135,400
8	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
9	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
10	$88,000	$427,000	$114,000	$475,000	$281,400	$193,400	($145,600)	$167,400	($193,600)
11	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
12	$418,000	$98,000	$114,000	$146,000	$281,400	($136,600)	$183,400	$167,400	$135,400
13	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
14	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
15	$88,000	$98,000	$443,000	$475,000	$281,400	$193,400	$183,400	($161,600)	($193,600)
16	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
17	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
18	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
19	$88,000	$98,000	$114,000	$146,000	$281,400	$193,400	$183,400	$167,400	$135,400
20	$88,000	$427,000	$114,000	$475,000	$281,400	$193,400	($145,600)	$167,400	($193,600)

Table 4: Sensitivity Analysis of Cash Flows for ESL Investment Over 20 Year Period

Table 4 outlines the cash outflows, inflows, and net flows for each case mentioned prior regarding battery life over the span of 20 years. Initial investment costs shown in Year 0 are the grand mean cost of initial investment of $329,400 determined in the section prior. Years 1 through 20 depict the C_{OUT} calculated for each case as defined in Equation 5. For each respective battery life for each case, we also add the cost of a full reinvestment in ESL implementation in the final year of deterioration. For example, in Case 4 the battery life is estimated to be 5 years, hence the cash outflow for Year 5, 10, 15, and 20 includes a full reinvestment on top of the annual ongoing costs defined in Equation 2. While a full reinvestment is likely not necessary for retailers, our goal is to provide the most conservative estimate to ensure the profitability ratios are generously accounting for any potential unforeseen costs. The cash inflows, C_{In}, for each year will be the potential labor savings we determined earlier of $281,400. Let net cash flow be C_{Net} defined as:

$$C_{Net} = C_{In} - C_{Out} \quad (6)$$

Net cash flows are shown for each case over the 20-year period in the last four columns of Table 4. Any values in red demonstrate a year where the cash outflows outweigh the cash inflows. Cash flow diagrams for each case can be seen below in Figures 9 through 12 to visually represent the net cash flows each year per each case throughout the 20-year period.

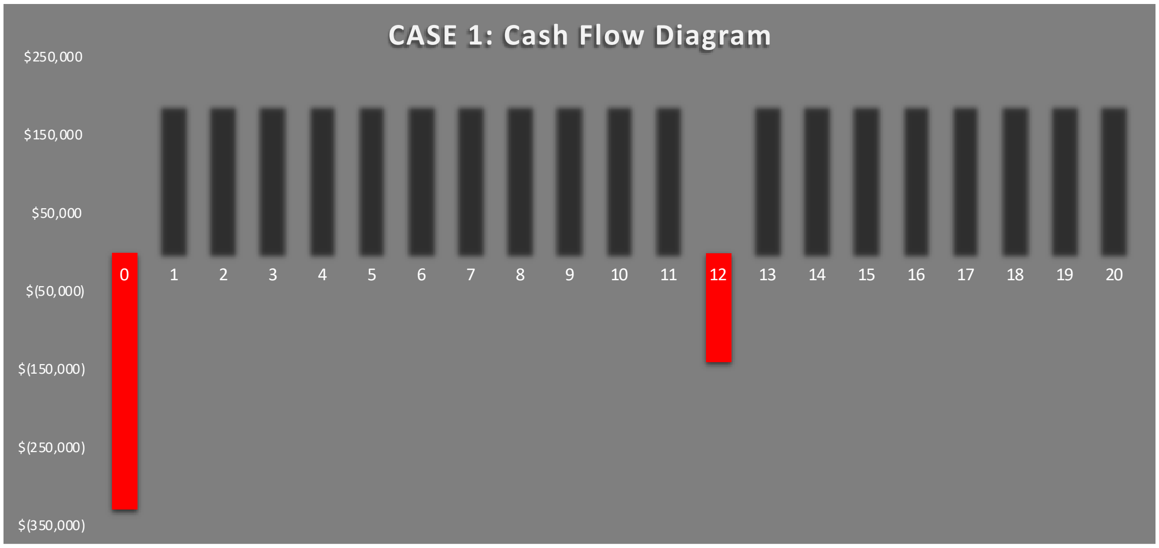

Figure 9: Cash Flow Diagram for Case 1 over the 20-Year Period

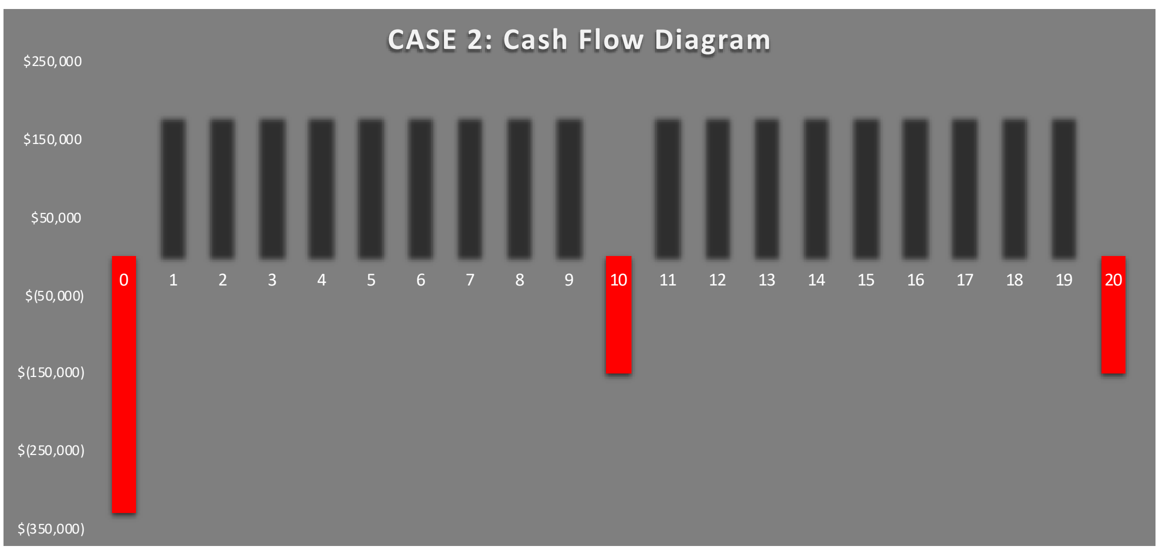

Figure 10: Cash Flow Diagram for Case 2 over the 20-Year Period

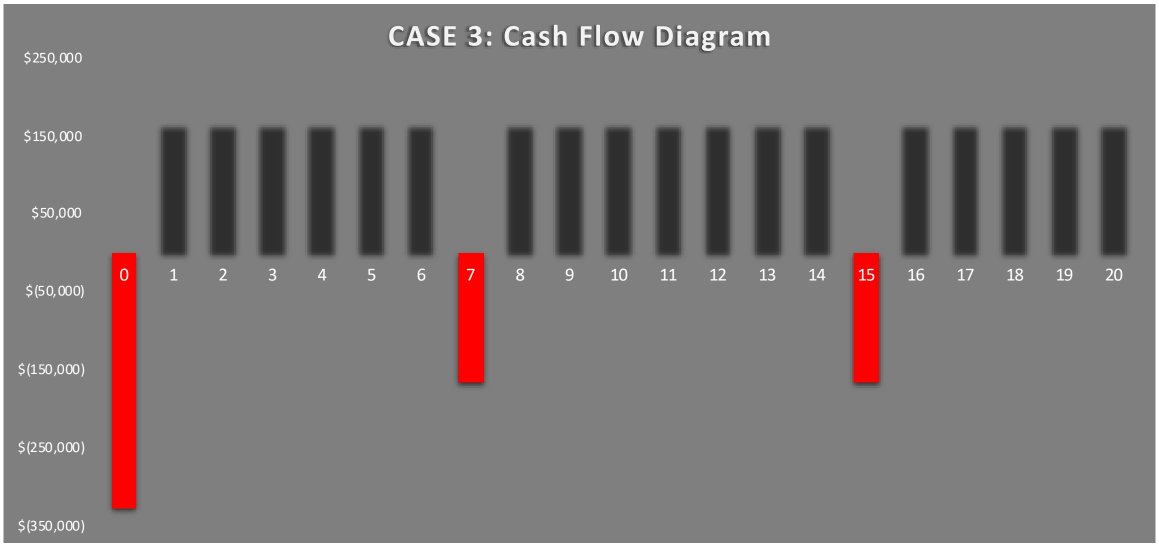

Figure 11: Cash Flow Diagram for Case 3 over the 20-Year Period

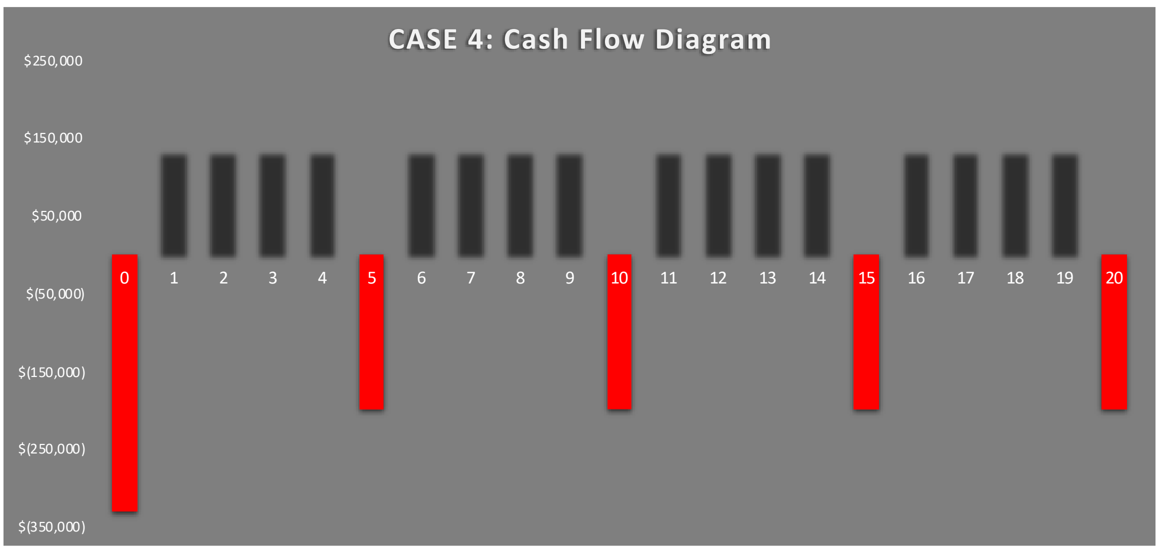

Figure 12: Cash Flow Diagram for Case 4 over the 20-Year Period

Using these calculations, we can carry over the sensitivity analysis into computing NPV, ROI, and PBP. The first profitability metric to determine is NPV. We are using NPV as one of our profitability metrics because NPV considers the time value of money and translates future cash flows into present dollars. Let us define the discount rate as i = 7% for the historical return of the stock market which is 7%. We know our initial investment to be equal to $329,400. Therefore, the equation for NPV is:

$$NPV = \sum_{t=1}^{20} \frac{C_{OUT}}{(1+i)^t} + \$329{,}400 \quad (7)$$

Our next metric is ROI. ROI will represent the net value a retailer will receive from full implementation of ESLs. This equation is defined as:

$$ROI = \frac{\sum C_{IN} - C_{OUT}}{\sum C_{OUT}} \quad (8)$$

While ROI does not factor in the time value of money, the metric is still insightful to retailers in addition to NPV. The last metric is PBP. PBP will give retailers an idea of how long it will take to breakeven on their initial investment. The equation for PBP is defined as follows:

$$PBP = \$329{,}400 / C_{Net} \quad (9)$$

The results for computing the profitability ratios for each case are summarized in Table 5 below.

	Case 1	Case 2	Case 3	Case 4
NPV ($)	$2,231,758	$2,020,075	$1,778,709	$1,157,746
ROI (%)	133%	91%	72%	23%
PBP (years)	1.70	1.80	1.97	2.43

Table 5: Calculation of NPV, ROI, and PBP for Each Scenario Mentioned

The most conservative scenario is Case 4, estimating the shortest battery life and most SKUs on average for a single store. One could argue that Case 4 depicts the worst-case scenario for a retailer upon investing in full ESL implementation. Even so, that retailer would see a PBP of under two and a half years. ROI is high for all cases except for Case 4. However, even in Case 4 the lower ROI still indicates a profitable investment over the 20-year period. The NPV for all cases shows a high positive value which indicates that projected inflows exceed projected outflows, or that the investment is very likely to be profitable.

Environmental Regulation Analysis

As shown in the previous section, converting a store to utilizing ESL technology over standard paper price tags will yield a significant ROI. Looking past an economic standpoint, ESLs will contribute to much more than monetary benefits. First and foremost, ESLs can help to reduce food waste by seamlessly employing dynamic pricing as discussed in the literature review of Section III. Managers can introduce dynamic pricing schedules or even enact one-time price adjustment as last-chance efforts to sell products approaching or nearing the food product date label. Further, ESLs can display key product metrics such as nutritional value, date labels, and even storage techniques, especially when combined with other technologies discussed such as RFID and PCMA. This information can help educate consumers and spread awareness of food waste reduction practices. ESLs also allow for synchronization between online and offline channels. Ensuring customers are seeing the accurate and reliable prices both online and offline can improve customer satisfaction and reduce the phenomenon of "showrooming." Some ESLs even possess sensors capable of detecting additional information, such as temperature, which allow for ease of monitoring refrigeration levels and even studying areas of consumer traffic based on heat signatures. Ultimately it is critical for retailers to consider further benefits of implementing ESLs other than economic reasons due to regulations that are beginning to be enforced all of the country. Certain regulations will legally prevent retailers from sending food waste to landfill. States such as California and Vermont already have policies in place that ban large retailers from disposing of food waste, forcing businesses to either compost, reduce food waste, or find other avenues to divert from landfill. The ban in Vermont has led to an increase of food donations by 20% and the creation of over 900 jobs in Massachusetts for food waste diversion (Schultz, 2017).

VI. Conclusions and Future Recommendations

This paper provides a solution to the problem of reducing food waste at the retail level of the FSC without sacrificing retailer profit by providing recommendations of technological implementation such as RFID, PCMA, and ESLs combined with dynamic pricing. We quantify the prospect of full implementation of ESLs for retail grocery stores belonging to the highest-grossing supermarket chains in the USA. Accompanied by the quantification of investment are sensitivity analyses and profitability metrics to provide full breadth of economic justification for retailers. We find that even in the most conservative of scenarios, PBP is under or slightly over 2 years and that ROI and NPV are significantly high and indicate profitability of investment in all cases. We discuss further benefits and rationalizations for wanting to reduce food waste at the retail level such as improved customer satisfaction, increased consumer knowledge of food waste, synchronization of channels, and access to valuable metrics that can increase understanding of customer demand and behavior. We also consider the need for retailers to reduce food waste due to state regulations that are becoming increasingly standard across the USA. This kind of regulation would ban retailer from disposing of food waste in landfill and require retailers to compost, donate food, or find alternative avenues to divert waste. Upon analyzing the profitability metrics of each conservative case defined, we recommend that retailers invest in a full implementation of ESLs and employ some form of dynamic pricing in their stores. ESLs and dynamic pricing will reduce food waste, preserve profit, increase customer satisfaction, and synchronize retail channels for retailers who spend .7% or more of revenue on manual labor for adjusting paper price tags. We expect the retail grocery industry to step up to the plate and reduce food waste in any way possible on a regular basis. As these practices are adopted and become standard, the technology of ESLs and dynamic pricing will become more common, less expensive, and less prone to malfunction, similar to any other sophisticated technology that becomes popular in industry. It is very likely that ESL software will lead to other benefits such as increase online sales, reduce “showrooming”, provide a better understanding of consumer behavior and perishability.

While we study the reduction of food waste and profitability of ESL implementation and dynamic pricing, this paper has some limitations. First, since a physical experiment was not conducted to gather data, we relied on the data supplied by our sources to be reliable and robust. We primarily used peer-reviewed papers for critical statistics and publicly-available sources for objective data such as corporation revenue and ESL prices. Therefore, our findings are theoretical and should be regarded that way. Second, a specific measure of food waste was not taken due to the lack of physical experimentation. However, much research conducted in years prior have found dynamic pricing to always reduce food waste in any situation when disregarding price adjustment costs (Chung & Li, 2013; Li et al., 2014; Adenso-Diaz et al., 2017; Chen et al., 2017; Chen et al., 2018; Chung, 2019). Now that we have justified the elimination of price adjustments, we assume that dynamic pricing can be seamlessly employed to emphasize reducing food waste.

A future extension of this research would be to physically implement ESLs and dynamic pricing in a grocery store that fits the defined specifications and measure the amount of food waste reduced. This research can also be extended by calculating profitability metrics for firms with less than .7% of revenue spent on manual labor to see if PBP and ROI are still plausible. Lastly, further research can explore the economic benefits and potential food waste reduction of implementation of RFID and PCMA at distribution and retail levels of the FSC.

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