Reducing Transportation Costs and Inventory Shrinkage in the Washington State Tree Fruit Industry

by

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ABSTRACT

Perishability and stock-outs are two sources of inventory inefficiency in the Washington State tree fruit industry. This thesis measures the size of these inefficiencies in terms of dollars per box, and describes five solutions, four qualitative and one quantitative, that seek to address them. To establish the magnitude of the inefficiencies, I regress various fruit characteristics on a set of sales data, thereby ascertaining the relationship between a fruit's price and its age. I find that the industry loses 5% to 12% of potential revenue due to perishability and propose four qualitative policies designed to reduce these losses. Next, I develop an operational management tool in the form of a mixed-integer optimization model which can be used to make optimal sourcing decisions during stock-out events. I find that the potential savings from improved sourcing decisions are between $0.01 and 0.02 per box. These results confirm that the costs and foregone revenue associated with inventory management are significant and merit the tree fruit industry's attention.

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ACKNOWLEDGEMENTS

I grew up in the heart of apple and pear country in Wenatchee, WA and have always been deeply fond of my hometown, as well as the role that agriculture, as the primary source of income, plays for many in the area. My goal in writing this thesis is to improve the efficiency of the tree fruit supply chain so that firms in Washington State will remain prosperous.

I would like to thank Dr. Chris Caplice for accepting me into the MLOG program and teaching me the linear programming, inventory theory and multiple regression techniques that made this thesis possible. I also relied heavily on the data provided by so many firms in the Washington State tree fruit industry, especially Stemilt, Domex, Dovex, and McDougall & Sons, as well as the expertise of many individuals, including my father Dale and my brothers Alan and Kyle, and various other industry experts.

I save most of my thanks and love for Allison Rone Foreman, my wonderfully brilliant, beautiful, and caring fiancée. I dedicate this, and anything I may write in the future, to you.

-James S. Foreman

May 8th, 2009

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1 INVENTORY MANAGEMENT IN WASHINGTON STATE

Washington State is the heart of the US tree fruit industry. Annually it produces half the apples, pears and cherries grown in the nation. The majority of production comes from the eastern side of the state, a region endowed with an ideal growing climate. Eastern winds from the Pacific Ocean collide with the Cascade Mountain range to create an orographic effect, producing a desert-like climate that limits the presence of harmful insects and plant diseases. Snow accumulates at high elevations to provide an abundant supply of irrigation water throughout the season. In addition to these climatic advantages, Washington State has developed the physical infrastructure, intellectual capital, and technology necessary to be one of the premier tree fruit growing regions in the world.

In order to capitalize on these advantages, those involved in the industry must continually seek out new revenue streams and eliminate sources of inefficiency. Public and private tree fruit organizations historically focused their energy on researching and implementing polices that reduced production costs per box, as well as promoting sales through advertising and new product introductions. Inventory management, on the other hand, remained a relatively untapped area of cost savings and potential profit. In recent years, as energy prices began to soar and firms started seeking ways to reduce their fuel consumption, the tree fruit industry was reminded that alternate sources of cost savings and profit existed. In keeping with this momentum, this thesis describes two specific sources of inventory inefficiency in the Washington State tree fruit industry, shrinkage of finished goods inventory and transportation costs associated with a stock-out event. It estimates the impact of these inefficiencies on profits in terms of dollars per box, and proposes several ways to reduce those impacts.

1.1 Scope and Overview of this Document's Structure

This first chapter will give an overview of the firms in the Washington State tree fruit industry and describe the physical process of how fruit moves through the supply chain. In the second chapter I review the relevant literature and discuss other sources used in my research. In the third chapter I quantify the relationship between the price of fruit and its age. I begin by introducing what I call the *Big pile, Small pile problem*, and move on to describe the regression method used to model it. After describing the results of the model, I estimate the current costs associated with inventory shrinkage in the industry. I then introduce four inventory management policies designed to reduce inventory inefficiencies by increasing the visibility of production and demand and reducing ordering complexity.

In the fourth chapter, I develop an optimization tool designed to improve sourcing decisions made by sales managers in the event of a stock-out. I begin by introducing what I call the *Sourcing Problem* faced by sales managers and describing the mixed-integer linear program (MILP) I used to model it. I then provide estimates of potential savings in terms of dollars per box and describe the practical steps a firm can take to implement a MILP tool into their daily operations. In the fifth chapter I summarize the challenges faced by firms in the Washington State tree fruit industry and propose eight recommendations to reduce inventory inefficiencies; I also discuss additional research that may lead to cost savings in the tree fruit industry.

1.2 Washington State Tree Fruit Supply Chain

Each year, $2 billion worth of apples, pears, and cherries, some 125 to 150 million boxes, move through the Washington State tree fruit supply chain — starting from growers and moving to packers, marketers, distributors, retailers, and ending at consumers. This process has taken place for the last 120 years, during which time significant vertical integration has taken place at all levels of the supply chain. Today, every possible combination of grower, packer, marketer, distributor, and retailer exists. Although the extent to which a firm is vertically integrated significantly changes its overall strategy, the role and responsibility at each echelon of the supply chain remains the same.

Figure 1.1 depicts the physical flow of fruit through the tree fruit supply chain in Washington State. It is a directional diagram where the arrows represent the physical flow of fruit from the grower on the left to the consumer on the right. The process begins when growers harvest fruit and transport it to a raw material (RM) storage unit on a flatbed trailer. Fruit remains in these storage units until needed to fill a current or expected order, at which time it is moved to the packing facility. Fruit enters the packing facility as RM in bins; it exits as finished goods (FG) inventory in boxes. During the packing process, fruit of lesser quality is consolidated and sold to processing facilities for 5 to 20% of the price of whole fresh fruit in order to be converted into slices, canned fruit, or juice. When inventory exits the packing facility, the FG boxes already sold are loaded onto a refrigerated truck owned by either a third party logistics provider (3PL) or a retailer; the unsold boxes are returned to storage. The process ends when you, the consumer, purchase whole fresh fruit or other fruit products from a retailer.

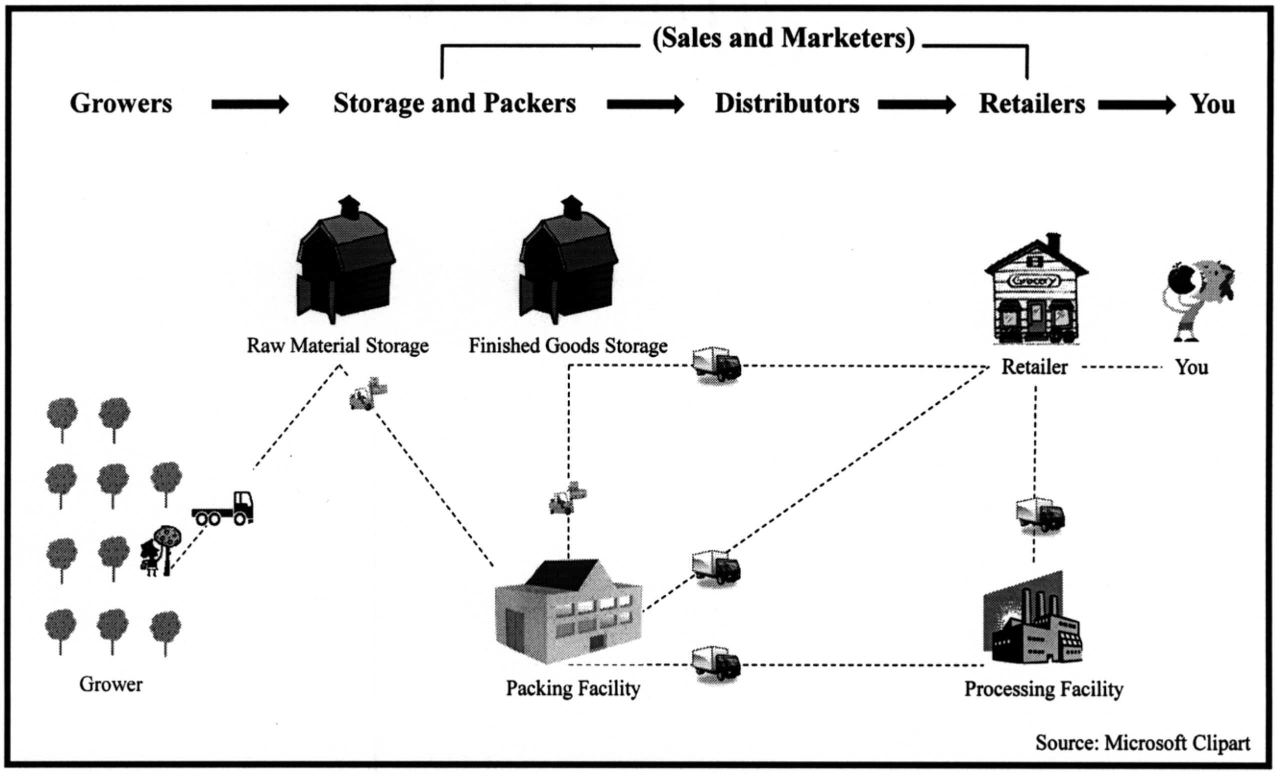


FIGURE 1.1 THE PHYSICAL FLOW OF FRUIT IN THE WASHINGTON STATE TREE FRUIT INDUSTRY

The following four subsections describe the physical flow of inventory and the major transportation and inventory decisions made by growers, storage and packing personnel, sales and marketing personnel, and retailers and consumers. I do not address decisions made by distributors; they are focused on the execution, not the planning, of transportation and inventory management. The scope of this document does not lend itself to addressing each of the transportation and inventory decisions faced by firms in the tree fruit supply chain. Most of the intellectually interesting and financially significant inventory decisions are made by managers in the storage and packing and sales and marketing functions. The decision-making tools and policy recommendations made in this document primarily apply to firms that operate in either or both of these functions.

1.2.1 Inventory and Transportation Decisions Made by Growers

Apples, pears, and cherries are hand-picked from June through October and consolidated by variety into wooden or plastic bins weighing up to 1,000 lbs. When fruit is in a bin, it contains many sizes and grades and is at a raw material (RM) state of inventory. After being filled with freshly picked fruit, bins are fork lifted onto a flatbed trailer and driven to a nearby storage shed within 8 to12 hours in order to limit damage to the fruit. Most growers use their own equipment to transport fruit; this limits costs and reduces the time that fruit spends outside. Some growers, however, pay sheds to transport fruit while others receive free hauling. After making myriad decisions during the twelve months it takes to grow fruit, growers make relatively few inventory and transportation decisions once the crop is 'in the barn.' This creates an interesting dynamic between growers and packing and sales organizations because growers own the inventory until it is received by retailers, yet they bear the risks associated with shrinkage and quality issues during the storage, packing, and sales process, the duration of which lies outside of their immediate control.

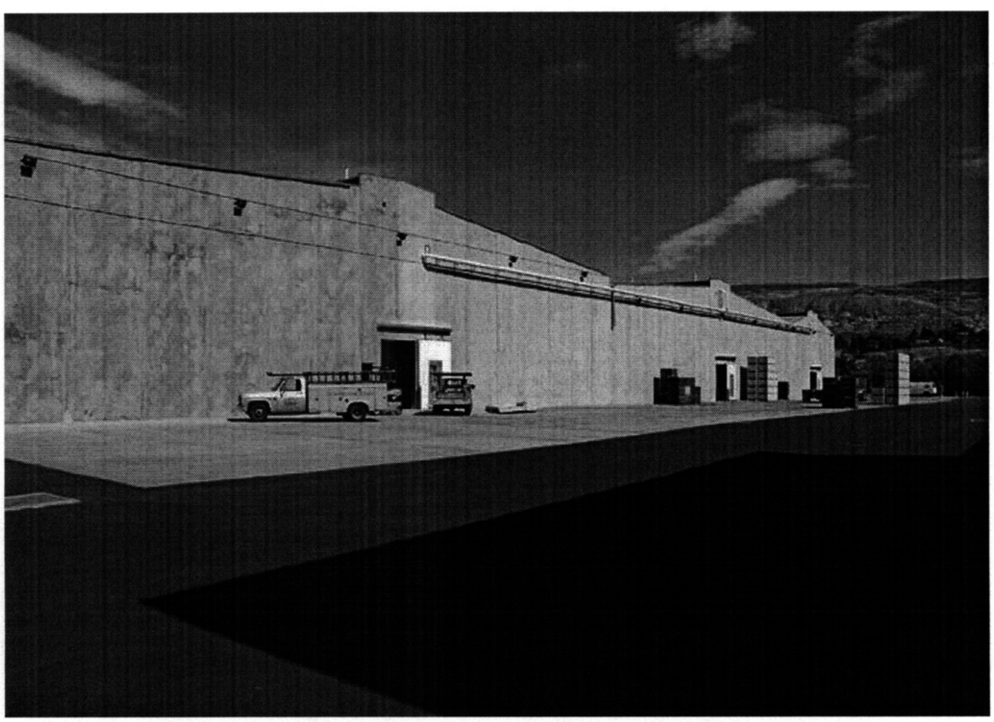
Managers of growing operations face one major inventory decision prior to the execution of harvesting and transporting fruit to the storage unit: when to pick their fruit. If fruit is left on the tree for a few extra days, it will become much larger and will likely receive higher returns; however, this also results in poorer long-term storability. To correctly time the decision of when to harvest, managers must have a good idea of the storability of their fruit and the date on which they expect it to be sold. Some packers facilitate this decision by offering different seasonal inventory 'pools.' Pools offered typically include early, regular storage, controlled atmosphere (CA) storage, midterm CA, and long term CA, also called the gamblers pool. Some managers attempt to predict the pool that will generate the highest return and then make the decision of when to pick the fruit based on when it will ultimately be sold. However, this exemplifies the inefficiency that results when a manager tries to optimize his or her operations without considering the effect of the decision on the entire tree fruit supply chain. In the short run, the optimal decision for the grower is to err on the side of having larger fruit; in the long run, however, this will result in a consistently lower quality product and a degradation of the Washington State tree fruit brand.

The incentives of growers and packing sheds are not aligned with respect to the decision of when to pick fruit. Growers, as mentioned above, try to find the optimal balance between higher returns from a larger size and lower returns from higher shrinkage. Packers, on the other hand, if allowed to make the decision, would err on the side of fruit with longer storability because poor quality fruit increases their labor costs and the time they spend managing inventory, thus lowering their efficiency metrics. It comes as no surprise that packing firms employ field-man, or agricultural consultants, who provide guidance on when to begin the harvest, in an effort to counteract the incentives that growers have to harvest at a sub-optimal time from an inventory perspective.

1.2.2 Inventory and Transportation Decisions Made by Packers

Receiving and Storage Processes

When a truck arrives at a storage location, it is quickly offloaded by a team of forklifts and, if necessary, reloaded with empty bins and sent on its way. Depending on the commodity and variety, bins may be soaked in cool water (hydro-cooling) or drenched in a fungicide mixture before being placed into a storage unit. Two types of storage exist, Cold Storage (CS), where the temperature is controlled, and Controlled Atmosphere (CA), where both temperature and oxygen levels are controlled in order to prolong the shelf life of fruit. Large storage operations have upwards of twenty CS and CA units, which are multi-story concrete buildings composed of individual rooms ranging in capacity from 600 to 2,500 bins.



Source: www.dovex.com

Figure 1.2 A Cold Storage or Controlled Atmosphere Unit

One major inventory decision is made during the receiving process: which bins should be placed into which storage units. Usually, fruit expected to be sold within three months is put into CS, whereas fruit that is scheduled to be sold after three months is put into CA. CS units can easily be opened and closed, but CA units remain locked until their contents are needed for packing. In general, higher-quality fruit is placed into long term CA storage because it will be in better condition after many months in storage than lower-quality fruit. In order to decide where to store incoming bins, storage managers look at the historical quality of the fruit provided by each grower, by each orchard, and of each variety, as well as data gathered during the random sampling of fruits from each load. These random samplings involve multiple tests, including: firmness (in pounds), brix (the sugar-to-water mass ratio of a liquid), starch iodine, water core, and core temperatures. Additionally, storage managers take notes on the average size and color of the fruit, where applicable, to help them make future inventory decisions. Storage managers balance this information with the unique capacity constraints of their infrastructure as well as their predicted sales plan to determine which bins to place into which storage units.

THE PACKING PROCESS

Nearly all storage sheds are physically located near a packing shed, a large building filled with automated equipment designed to wash, wax, sort, scan, and package fruit. Packing sheds sort the raw material from the bins according to a number of characteristics and package them in a variety of bags and boxes. The majority of this process is automated, with the exception of some sorting and the final packaging. While being run through the automated packing line, the fruit is at a work-in-progress (WIP) state of inventory; when it comes off the conveyor belt it is at a finished goods (FG) state of inventory. After being packaged, FG inventory are either loaded directly onto an outgoing refrigerated truck or placed back into a CS unit. Most FG boxes, with the exception of some pear varieties and golden delicious apples, are not placed into CA units because they will only be in storage for a few weeks and it is not cost effective to seal a CA room for such a short period of time. A standard unit of FG inventory is 44 pounds for a box of pears, 42 pounds for a box of apples, and 20 pounds for a box of cherries while a standard 53-foot truck has a capacity of 1,000 packed boxes of apples or pears. A typical packing shed can process 200 bins of fruit per day and produce 4,000 boxes of FG inventory.

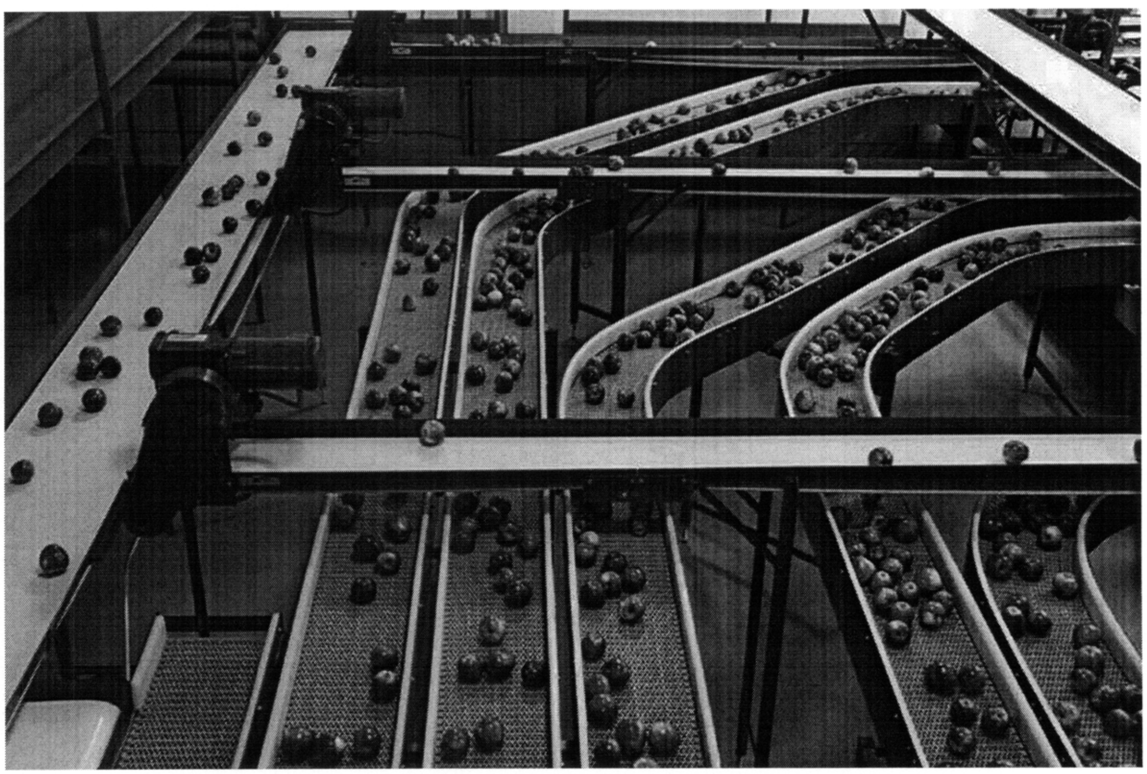


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FIGURE 1.3 APPLES BEING AUTOMATICALLY SORTED DURING THE PACKING PROCESS

Managers of the packing process face the single biggest inventory decision in the entire tree fruit supply chain: which stock keeping units (SKUs) should be produced each day. This is an extremely complex decision because future demand is unknown, production has a lead-time of 6 to 24 hours, fruit condition and RM inventory levels by SKU are imprecisely known, and FG inventory are in a constant state of physiological decay, which reduces retail value by the day. In order to make this decision, packing managers meet with their sales and marketing teams to establish a packing plan for the upcoming two to four weeks.

1.2.3 Inventory and Transportation Decisions Made by Sales and Marketing

Sales and marketing firms rarely take physical control of inventory in the tree fruit supply chain but rather act as brokers for one or more packing sheds. They have visibility of current FG inventory levels at each of the packing sheds they represent and are responsibility for maximizing returns to the packing sheds, and ultimately to growers. Such firms consist of a staff of salespersons who make phone calls to retailers and coordinate logistics with 3PLs or the retailers' logistics department. For consistency's sake, in this document I refer to all employees of a sales organization as "sales managers." Although they do not see the inventory or bear any of the operational risk associated with shrinkage, sales managers are in charge of making three financially significant inventory and transportation decisions on a daily basis.

The first decision is whether to accept an incoming order. The compensation schemes of sales managers, usually a commission based on the actual free-on-board (FOB) selling price paid by the retailer, has a huge impact on this decision. The second and most difficult decision made by sales managers is the price at which they sell fruit. Chapter 3 addresses this issue by establishing a relationship between fruit price and nine other characteristics; it develops a pricing model with respect to the age of fruit that can be used by sales managers to make optimal pricing decisions under rapidly changing conditions.

After an incoming order has been accepted and a price has been set, the third decision a sales manager must make is from where to source the order. Chapter 4 addresses this decision, analyzing how to optimize the sourcing of FG inventory during stock-out events while minimizing labor, transportation and inventory costs. Aside from making these three operational decisions, sales managers have the ability to establish inventory management policies; I outline several of these strategies, which are designed to reduce inventory shrinkage, in Chapter 3.

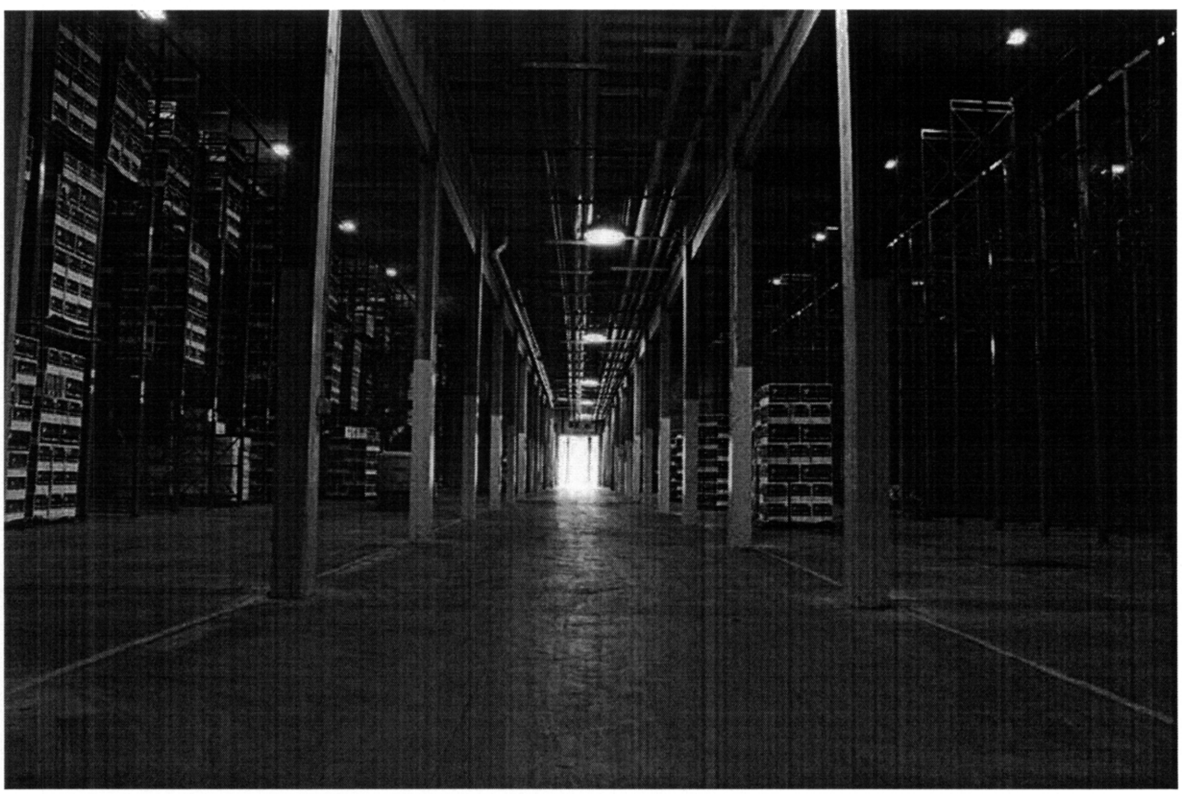

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FIGURE 1.4 FG BOXES STACKED ON PALLETS INSIDE A COLD STORAGE FACILITY

1.2.4 Inventory and Transportation Decisions Made by Retailers and Consumers

After a sale is made, the fruit is picked up by a 3PL or a truck from the retailer's internal fleet. FG inventory is then moved via truck, rail, ship, or air to retailers all over the world. I use the term "retailer" throughout this document to represent any firm that buys fruit directly from a sales and marketing organization. In reality this includes wholesalers, distributors and traditional retailers, which use a fulfillment or sourcing department to establish contact and place orders with tree fruit sales managers. Currently the bulk of these transactions take place on the phone and the majority of retailers require their supplier to have electronic data interface (EDI) capabilities. Large retailers may setup longer contracts or reoccurring purchases with sales organizations to limit transaction costs and reduce administrative complexity. In these situations, retailers may provide point-of-sale (POS) data to the sales organizations, which can use the data to forecast consumer demand and to better understand current market conditions. A select number of large retailers have set up vendor managed inventory (VMI) programs with sales organizations in order to reduce the risk of carrying inventory and also to utilize sales managers' expertise of customer demand. Ultimately, retailers make purchasing decisions based on their forecasted consumer demand as well as their estimate of a sales organizations' ability to compete on price, quality, product selection, and reliability of service.

1.3 Tree Fruit Industry Overview Using Porter's Five Forces Model

This section steps back from the daily decisions made by firms in the tree fruit industry in order to analyze power dynamics across the supply chain; certain echelons, and even individual firms, have the power to drive change while others are merely participants. Economic theory suggests that competition will drive profits for all firms within a given industry to a risk-adjusted constant; however this is not observed in practice because some firms possess more power than others. Professor Michael Porter, of Harvard Business School, developed a framework in 1979 to assess the sources of power within an industry. Called the "Five Forces" model, it remains a popular tool to analyze competitive forces and predict the relative profitability of firms in an industry. With the sales organization as a point of reference, retailers are 'first tier buyers,' consumers are 'second tier buyers,' packers are 'first first tier suppliers,' and growers are 'second tier suppliers.' The following sub-sections address each of the "Five Forces" shown in Figure 1.5. Using this framework to analyze the tree fruit industry clarifies the sources of power for growers, packers, sales and marketers, distributors, retailers, and consumers.

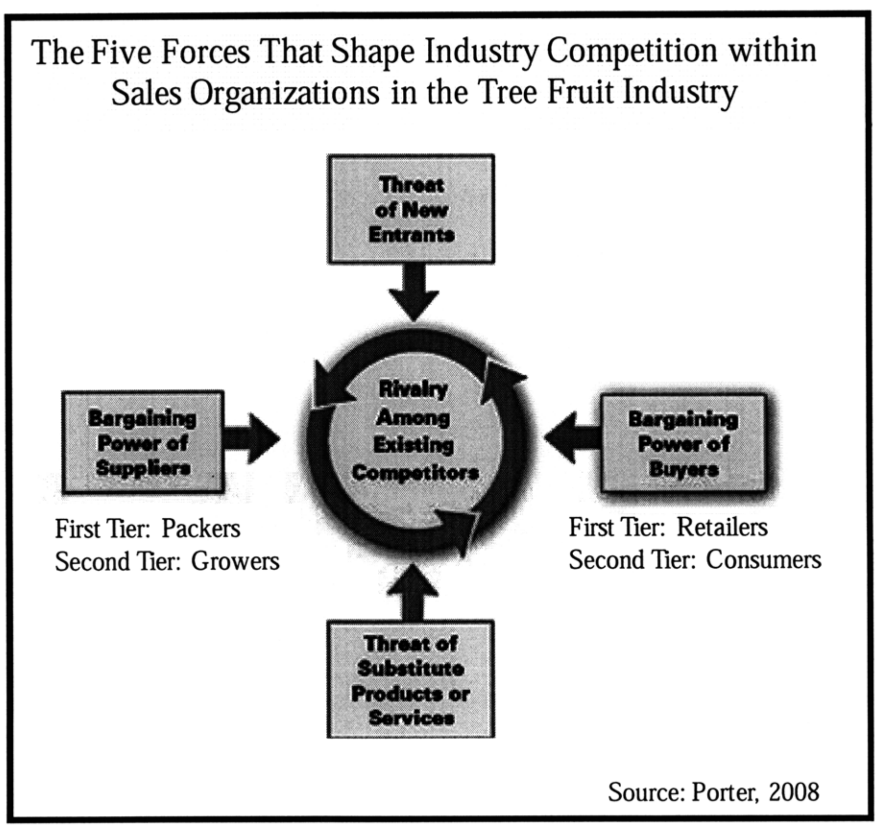


FIGURE 1.5 MICHAEL PORTER'S FIVE FORCES FRAMEWORK

FORCE #1: SECOND-TIER SUPPLIER POWER (GROWERS)

Apples were first sold commercially in Washington State as early as 1889. Today more than 225,000 acres of apples, pears and cherries are planted statewide. The majority of this acreage comes from the nine counties highlighted in Figure 1.6. When citing the source of fruit industry insiders do not reference growing counties, but rather one of three growing regions: North Wenatchee (Okanogan, Chelan, Douglas), Yakima Valley (Kittitas, Yakima, Benton), and the Columbia Basin (Grant, Adams, Franklin).

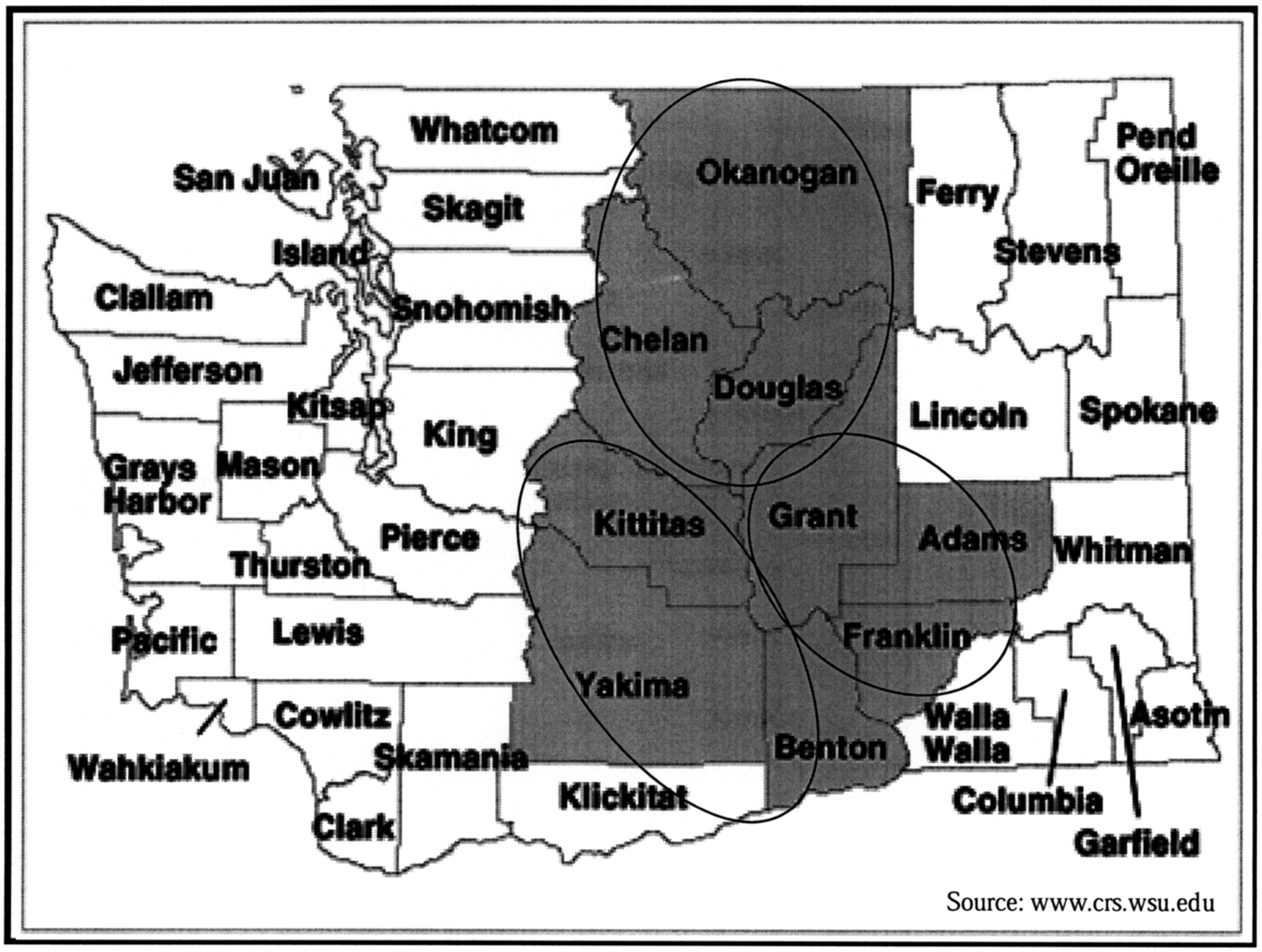


FIGURE 1.6 NINE MAJOR WASHINGTON STATE FRUIT PRODUCING COUNTIES

From the perspective of a sales and marketing organization, the second-tier supply base is made up of some 5,000 growers in Washington State. As one measure of the level of supplier power, the "Five Forces" model uses a concentration metric, which is defined as the combined market share of the some number of firms in an industry. For example, if the largest four firms in an industry have a combined market share of 25%, the concentration rate would be shown as $C^4 = 25\%$. According to the annual ranking published in 'American/Western Fruit Grower,' the largest grower in the US in terms of acreage is Evans Fruit Farm, which owns 7,300, or 3.1% of the acres planted in Washington State. The same article lists the top four growers as Evans Fruit, Stemilt Growers, Gebbers Farms, and Broetje Orchards, which own a combined 11.5% of the acreage in Washington State. As second-tier suppliers, growers have a concentration rate of $C^1 = 3.1\%$ and $C^4 = 11.5\%$; these low values suggest that growers are numerous and lack concentrated power. To be considered a "highly concentrated" industry, the largest four firms need to have at least 50% of the market share, or $C^4 = 50\%$.

While the number of growers has declined steadily over the past fifty years, the supply base has not consolidated to the point that growers have enough volume to influence packers or sales organizations. Growers tend to be weak because they are numerous, lack product differentiation, and pose little threat of vertical integration to their buyers. Few growers have the capital to threaten vertical integration, for one; moreover, packing sheds face low switching costs when changing from one grower to another. Core competencies of growers include the execution of growing fruit and managing labor, but most have little experience in storage, logistics, international trade, sales, or marketing functions. The primary way that growers can increase their power within the industry is to increase their production volume, grow higher value or higher quality products, or vertically integrate into the packing or sales echelon.

Force #1: First-Tier Supplier Power (Packers)

The first-tier supply base is much more powerful than the grower base, and includes 100 to 200 storage and packing sheds located as far north as Canada and as far south as Oregon. A dogma in the tree fruit industry is that if you want to make money, you need to own a packing shed — they provide consistent returns in years in which there is bad weather, overproduction, or a recession. As a result, the ideal vision for most packing sheds is to own enough acreage to fill their sheds during low-volume years, while relying on outside growers to provide the balance of their volume, thus guaranteeing profits while lowering their risk profile. This model has attracted those involved in the tree fruit industry as well as the bankers responsible for financing agricultural operations, most of whom prefer lending to businesses that own physical infrastructure.

The tendency of bankers to offer more favorable financing to storage and packing sheds than growers has been a key factor in the evolution of the tree fruit supply chain. During prolonged periods of low prices, underperforming growers lose financing and go out of business; during the ensuing recovery other large growers or storage and packing sheds receive funding to buy them out, a process which encourages grower consolidation. The financial bias toward packing storage sheds has also arguably led to overcapacity in packing lines. According to the Washington State Apple Commission, storage capacity in 1997 was 181 million boxes, of which 121 million, or 67%, were CA. At current production levels of 125 to 150 million boxes per year, capacity appears excessive, but because many storage units, especially CA, are old and outdated, new capacity continues to be built. In years when the crop is small, packing overcapacity results in a shift of some power that has historically resided with packers to growers. Growers can exercise this power by requesting free hauling from the orchard to the storage sheds or by requiring a minimum per bin return.

Based on the volume of packed boxes, the concentration rate of the largest packing shed in Washington State, C^1, is 14% while C^4 = 25%. First-tier suppliers are more powerful than growers because they are more concentrated and have a credible threat of backward integration by reestablishing an internal sales department; even though this would be a difficult and expensive proposition, it remains a possibility. The keys to success in the packing industry include maintaining economies of scale, continually upgrading infra-structure and information technology (IT) systems, and coordinating packing plans with sales plans of the sales and marketing department.

FORCE #2: FIRST AND SECOND-TIER BUYER POWER (RETAILERS AND CONSUMERS)

Hundreds of firms buy fruit by the box, but only a handful consistently buy fruit by the truckload. These large retailers have tremendous power in dictating price, as well as packaging, quality standards and new product configurations. The volume purchased by each retailer varies across sales organizations, but C^4 is in the range of 25-40%. The largest retailers are powerful because they have bargaining leverage based on large order volumes, they control valuable POS data about purchasing trends, and they provide access to the only major marketplace for fresh fruit. Fruit sales organization are unlikely to invest in a brick and mortar fruit retail outlets; thus, unless alternative direct-to-consumer sales channels are developed there is little threat of vertical integration into the retail business.

The aggregate tastes of consumers represent the most powerful force in the tree fruit industry. For example, those involved in the production of apples will not soon forget how quickly consumers changed their preferences away from the red delicious apple variety in the late 1990's. Learning from this painful change in consumer tastes, the industry has kept in more touch with concerns of their ultimate customer, the individual. Despite millions of dollars spent on promoting Washington State apples, consumption of fresh apples per person in the US has hovered around 18 pounds per year per person for decades, though the total (fresh and processed) consumption has been on the rise over the past twenty years (Xia 1999). Key leaders in the tree fruit industry continually try to increase the demand of Washington tree fruit; while there is little consensus on the most effective way to do so, these same leaders agree on at least one source of difficulty in expanding sales; substitute products.

FORCE #3: THREAT OF SUBSTITUTION

The threat of substitution, or retailers purchasing alternative goods to Washington State tree fruit, is low to moderate. Firms in Washington primarily compete against domestic producers in New York and Michigan and countries such as Argentina, Chile, China, France, Italy and New Zealand. Washington State and other domestic producers have competitive advantages in fruit quality, access to customers, technology, and business climate. However, some foreign producers have lower labor costs, and many can quickly adopt new technologies and have been improving their level of fruit quality and safety standards. Retailers can buy some varieties of apples from Chile and New Zealand and some variety of pears from Argentina; however fruit from the Southern Hemisphere is only available during certain months of the year, a fact which lessens whatever substitution effect it might otherwise have.

Retailers can also substitute away from apples, pears and cherries by purchasing bananas, oranges, and other fruit. Still, they will likely never completely shift away from apples and pears because they are staple food items. Cherries are more of a luxury item, only appearing during a short window of 60 to 80 days in the summer months, and are more likely to suffer from substitution effects.

Force #4: Threat of New Entry

The threat of a new entry into the tree fruit sales industry in Washington State is low to moderate. On one hand, all it takes to become a sales broker is a phone and a box of apples. On the other hand, a successful sales organization needs to have access to a wide variety of product and the ability to sell large volumes of fruit. Furthermore, it is not likely that a fruit packing operation would delegate the selling of its fruit to an inexperienced company, or that a retailer would sign a large volume contract with an unproven company; these realities make it difficult to start a sales organization from scratch. Therefore, the threat of a new entry is limited to those firms that have core competencies in agricultural sourcing and sales. The most likely entrant into the sales arena is a current fruit-packing organization that can to move up the value chain to gain more control over their products. The recent trend has been the opposite however, as more packers have outsourced their sales function, resulting in a small number of consolidated sales organizations. Multi-national fruit companies have not been major players in the industry since Dole Fruit Company's attempt to enter the Washington State market twenty years ago.

In 1989, Dole entered the fruit business with the purchase of Wells & Wade and Beebe Orchard Company. Despite its lack of experience in the apple and pear market, it had a reputable brand and utilized the existing relationships that Wells & Wade and Beebe Orchard Company had with buyers to enter the market as grower, packer, and sales organization simultaneously. After 12 unsuccessful years, Dole Northwest, a subsidiary of Dole Fruit, decided to sell off its assets in Washington State in 2001, including two packing warehouses and 1,000 acres of orchard. Unfortunately, its packing managers decided to hasten the process by dumping some of their existing finished goods inventory and selling it as juice apples. Not all of this fruit was company owned, however, and the growers who had given their fruit to Dole to pack and sell were furious with the subpar returns caused by Dole's actions. In a class action suit, the growers eventually settled the case out of court for nearly $2 million.

FORCE #5: COMPETITIVE RIVALRY BETWEEN SALES ORGANIZATIONS

Historically, packing sheds sold their own fruit via an internal sales department. Over the years, many packing sheds have outsourced sales to another packing shed or to an independent sales organization. As a result, the sales echelon is more concentrated and powerful than either growers or packers. The four largest sales organizations in Washington State are Stemilt, Rainier, Chelan Fruit, and Washington Fruit, which each sell 10 to 15 million packed boxes of apples and pears each year. Out of the statewide crop of 100 to 110 million boxes, these four firms have a combined market share of approximately 45%. The top 15 sales organizations sell 75 to 80 million boxes and have approximately 80% market share. While this segment of the tree fruit supply chain has consolidated to a much more significant degree than growers or packers, the level of rivalry remains high. Sales organizations sell FG inventory to each other when stock-outs occur, but they do not openly collaborate to share their demand forecasts or align their sales plan.

To gain competitive advantage, sales organizations have attempted to differentiate themselves based on price, quality, branding, product availability, and customer service. The consolidation of sales organizations has alleviated the price-cutting wars that commonly defined previous decades; however, certain firms with lower operational costs still compete in this way, especially in high volume years. Quality standards are very strict in the industry and generally similar across firms, although investment in new technology as well as excellence in inventory management does separate some sales organizations from others. Most varieties of apples and pears can be sold by anyone, though some organizations own the distribution rights to club varieties such as Pinata, San Rose, or Lady Alice, which gives them an advantage in product availability. Other firms have invested in sliced and bagged apple facilities, pear pre-ripening rooms, organic acreage, and foreign sources of supply in an attempt to integrate other fruits and vegetables into their product offering throughout the entire year. Another approach to product differentiation is through packaging, such as mesh bags, which may help to increase consumer demand. Firms have even sponsored characters from the children's television show "Sesame Street" and Kasey Kahne, a NASCAR driver, in order to gain some sort of competitive advantage.

Table 3.1 provides the concentration rate of the four largest growers, packers, sales organizations and retailers, as well as the estimated number of firms, the critical tasks, and the biggest threats to each echelon in the tree fruit supply chain.

TABLE 1.1 PORTER'S FIVE FORCES IN THE WASHINGTON STATE TREE FRUIT INDUSTRY

	Grower	Packer	Sales Organization	Retailer
C^4: The combined market share of the largest four firms	12%	25%	45%	33%
Estimated # of Firms in Washington State	5,000	100-250	100-250	100s
Critical Tasks	Maximize value through farming practices; risk management; find seasonal labor.	Maintain high quality standards; fill storage and line capacity; cover fixed costs and reduce variable costs.	Match supply and demand; cultivate relationships with key buyers; maximize price per box while maintaining sales velocity.	Attract large customer base; stock shelves; understand consumer buying habits.
Biggest Threats	Over supply of fruit, under supply of labor.	Under supply of fruit, food safety issue.	Under supply, direct-to-consumer channel, loss of key buyer.	Food safety issue, changing consumer tastes, stock-outs.

As demonstrated by the "Five Forces" analysis, the Washington State tree fruit is a very competitive industry at all levels with the exception of growers. Once a firm has established a packing shed or sales organization the threat of substitution and new entry are low, which allows for substantial profits at these echelons. The consolidation of sales organizations has concentrated more power at that level but retailers will always be the most powerful player in this industry, given that they provide the only mass market outlet to consumers. An online market could be established to sell fruit directly to consumers, but this idea is not scalable due to the low value and high transportation cost per box. To be profitable in this industry, firms must decide at a strategic level how they will compete and build a supply chain that is aligned with this schema, while keeping in mind the aggregate and ever-changing tastes of consumers.

2 REVIEW OF LITERATURE AND OTHER SOURCES

While developing my thesis topic, I focused on the fields of operations research, food logistics, and fruit warehousing. I used two operations research tools, multivariate regression analysis and linear programming (LP). Regression techniques are well-developed and widely accepted in the statistical community as tools to conduct statistical analysis. LP is a similarly developed area of research; hundreds of articles have been written on the subject over the past 60 years. Food logistics is a well documented research field; due to changing technology, however, relevant articles date only from the past ten years or so. Fruit and produce warehousing is a fairly specialized field, and optimal inventory policies are different for each type of food, depending on its level of perishability. Cornell University, the University of California at Davis, and Washington State University have specific tree fruit departments and regularly publish journal articles on inventory management. Journals and magazines that have been especially helpful include <u>Food Logistics</u>, <u>Western Fruit Grower</u>, and <u>Good Fruit Grower</u>.

2.1 MULTIVARIATE REGRESSION AND LINEAR PROGRAMMING

Multivariate regression is a technique used to determine the influence of one or many independent variables on a dependant variable. In Chapter 3, I develop a relationship between the price and age of a box of fruit. I use standard multivariate regression techniques to develop the relationship and conduct the calculations using Microsoft Excel and SPSS. I used several academic texts, including: <u>Microsoft Excel Data Analysis and Business Modeling</u>, <u>Spreadsheet Modeling & Decision Analysis</u>, and <u>The Art of Modeling with Spreadsheets</u>.

LP was developed during World War II as an optimization technique designed to reduce costs in military logistics. The first published paper describing LP is George Danzig's 1947 paper on the simplex method. LP is now so commonly used in operations research that certain forms of LP problems have their own name, including network flow, multi-commodity, transportation, transshipment, and assignment problems. The specific problem I address in the fourth chapter is how to source product from multiply nodes in order to be consolidated at a single node, while minimizing transportation costs. This can be formulated using standard linear programming techniques. To ensure I followed these techniques accurately I used several academic texts, including: Spreadsheet Modeling & Decision Analysis, The Art of Modeling with Spreadsheets, SPSS Explained, and The Spreadsheet Solver.

2.2 Industry Newsletters and Other Sources

Fruit growers, packers, and sales and marketers in Washington State acquire data on the sales and production of fruit from several industry newsletters. Furthermore, many organizations have been created to promote the various interests of the tree fruit industry; they often hold conferences, sponsor studies, and publish aggregated industry data for the advancement of general knowledge of all firms in the industry. Some of these organizations include the the Washington State Apple Commission, the Northwest Horticultural Council, the Washington State Growers Clearinghouse, the Washington State Horticultural Association, the Washington State Tree Fruit Research Center, the Washington Valley Traffic Association, the Washington State Fruit Commission, and the Yakima Valley Growers-Shippers Association. During the formulation of the thesis I used data, both published online and in hard copy, from each of these sources; I also interviewed many of the individuals involved in their operation and management.

I conducted twenty informational phone interviews with executives and managers involved in the tree fruit supply chain from August 2008 to April 2009. Although not published in journals, the observations from individuals who have a lifetime of experience are often the best research data available. The most notable interviews I conducted include West Mathison (CEO, Stemilt), Todd George (VP of Logistics, Stemilt), Alan Groff (Foreman Fruit), Tom Riggin (Sales, Chelan Fresh), Robert Kershaw (President, Domex), Brock Remy (Sales, L&M), Doug Ballard (Head of IT, Chelan Fresh), Bryon McDougall (Packing Manager, McDougall & Sons), Mike Hambleton (Sales Manager, CMI), and Gene Louden (Head of Sales, Dovex). These individuals are Chief Executive Officers, Presidents, Vice Presidents, and department heads of the largest growers, packers, and sales organizations in the state. Together they grow, store, and sell the majority of the apples, pears and cherries in Washington and have tremendous influence on the future of the industry. I primarily conducted informational interviews tailored to the expertise of the interviewee. I asked all interviewees, however, for proposed methods to improve profitability throughout the industry and their opinion on the toughest challenges facing the industry in the next ten to twenty years.

3 INVENTORY MANAGEMENT

Fruit is a perishable asset that loses value over time. When it cannot be sold on the whole market or processed into slices, it is pressed into juice or thrown away due to spoilage. These channels generate revenue, but are always less profitable than the whole fresh fruit channel; they are considered forms of inventory shrinkage. Because growers do not selectively pick fruit based on quality, shrinkage during the conversion process of raw material to finished goods inventory is inevitable. Packing sheds use the metric, 'packs per bin' to measure how many FG boxes are produced by each bin. The quantity of raw material (RM) shrinkage can be measured by subtracting the packed volume of these FG boxes from the initial RM volume. Aside from this RM shrinkage, if FG boxes are not sold fast enough, they may need to be repacked due to deteriorating quality or re-lidded due to a change in customer demand; this can be thought of as FG shrinkage. Growers seek to reduce RM shrinkage and increase their packs per bin, but once fruit has been packed into FG boxes it is the packing and sales managers who have the ability to reduce FG shrinkage through effective inventory management. To do this, managers must first understand the relationship between price per box and age of FG inventory.

This chapter has five sections. In the first section I define the inventory problem faced by managers, which I call the *Big Pile, Small Pile* problem. In the second section I describe the regression techniques and variables I used to model the relationship between price per box and the age of inventory. In the third section, I provide the results of the regression and quantify the impact that each of nine variables has on the price of fruit and define the relationship between price and age as an expected price curve over time. In the fourth section I estimate the cost and likelihood of repacking and rejections and subtract those figures from the expected price to find the adjusted relationship between price and age. In the fifth section I conclude by discussing four inventory policies designed to reduce on-hand FG inventory levels, including pre-sorting fruit, demand shaping, vendor managed inventory (VMI), and SKU reduction.

3.1 The Big Pile, Small Pile Problem

"We probably sell fruit at full price until it is 21 days old, then our sales guys start discounting the price."

- Sales Manager

The biggest cause of inventory complexity in the tree fruit industry is the large number of SKUs that must be managed; a typical sales organization offers twenty packaging options, twelve varieties, ten sizes, five grades, and two growing methods. While permutations of all of these attributes are not available, there are upwards of 10,000 SKUs. Typical of a power law distribution, 20% of these SKUs represent 80% of the total packed volume. This can be seen graphically by plotting the packed volume of each SKU, shown as a stylized representation in Figure 3.1. Most retailers prefer product uniformity across their stores, so they purchase SKUs from the *Big pile* first, leaving the *Small Piles*, or the "tails of the manifest." These "tails" are extreme sizes, grades, and varieties with a lower total volume; they are usually sold to smaller retailers and firms that serve niche markets. Sales managers spend most of their time trying to sell these *Small Piles*, and face a tradeoff between reducing prices and risking spoilage as inventory ages. Ultimately, the sales manager must decide how much they will discount fruit based on its age. To effectively make this decision, managers need to know how much value fruit loses over time as well as any additional costs incurred from the handling and processing of aging inventory.

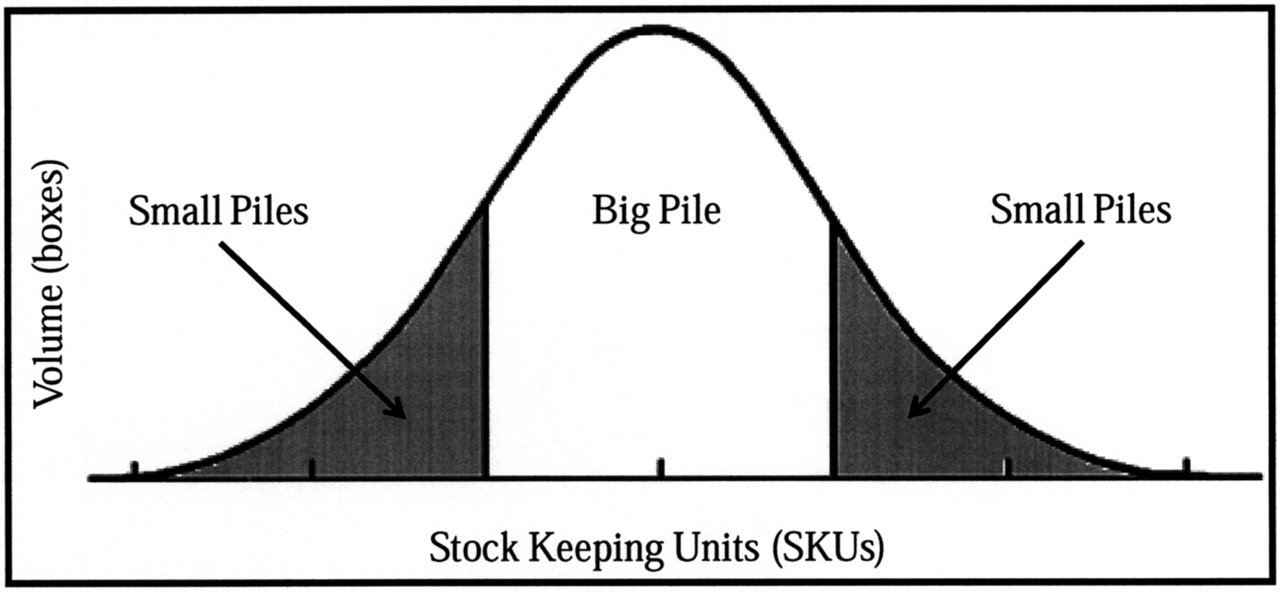


FIGURE 3.1 STYLIZED REPRESENTATION OF PRODUCTION VOLUME IN BOXES PER SKU

3.1.1 WHEN IS FRUIT 'BORN' AND WHY IS OLD FRUIT BAD?

The age of fruit, in terms of days, is a good approximation of fruit quality, a key variable used in making inventory management decisions. While it seems intuitive to start counting the age of fruit when it is first picked from the tree, the industry currently defines age as the number of days since a box of FG inventory was packed. Age is not based on the day that fruit is picked from the tree because this would require traceability of individual pieces of fruit throughout the supply chain. Due to differences in variety, growing region, and even what part of the tree it was grown on, individual pieces of fruit have unique quality conditions at Age 0. Therefore, the relationship between price per box and the age of FG inventory actually represents the discount rate applied by sales managers to aging inventory, as opposed to the actual quality of individual pieces of fruit. However, the current industry definition of age is based on the pack-date, and sales managers use age in their pricing decisions; therefore the relationship between price and age is the appropriate variable to use in predicting price.

From a physiological perspective, oxygen is the enemy of fruit because it fuels an ethylene respiratory process during which starches are converted into sugar. This process can be slowed by controlling the atmosphere and temperature of the storage environment as well as through chemical treatments. Combining these treatments has led to a considerably longer storage life and a higher quality product, as defined in consumer studies. It is generally accepted that customers prefer fruit with a high level of crunchiness and taste and juice content, concepts that can be quantitatively measured in terms of firmness (pounds per inch) and titra-table acid levels (percentage) (Bates 2001). During the ethylene respiration process, both firmness and titra-table acid levels decrease. Bates, a researcher from UC Davis, conducted a study that shows fruit stored in CA storage and treated with 1-MCP has essentially the same firmness after 9.5 months as it did when it was picked. This is just one of many studies showing that industry storage practices are very effective in slowing the ethylene process that causes fruit to decline in quality. Consumers have a universal preference for younger fruit, in terms of days since packing; thus packing managers and sales managers should pursue policies to reduce the average age at which FG inventory is sold.

3.1.2 WHY IS RAW MATERIAL (RM) CONVERTED INTO FINISHED GOODS (FG) BEFORE IT IS SOLD?

In order to minimize FG inventory shrinkage, managers should implement inventory policies designed to reduce levels of on-hand FG inventory. Currently, firms set target levels of on-hand inventory based on the expected sales volume of each SKU or group of SKUs. As shown in Figure 3.2, the majority of FG inventory is sold within ten days of being packed, with around 80% being sold within 21 days. In order to minimize inventory shrinkage due to deterioration, packing managers need to pack fruit that is in demand and sales managers need to sell what has already been packed. However, this proves especially difficult to implement for three reasons: visibility of on-hand raw material inventory by SKU is low, demand forecasting is difficult, and incentives of packing managers and sales managers are not aligned.

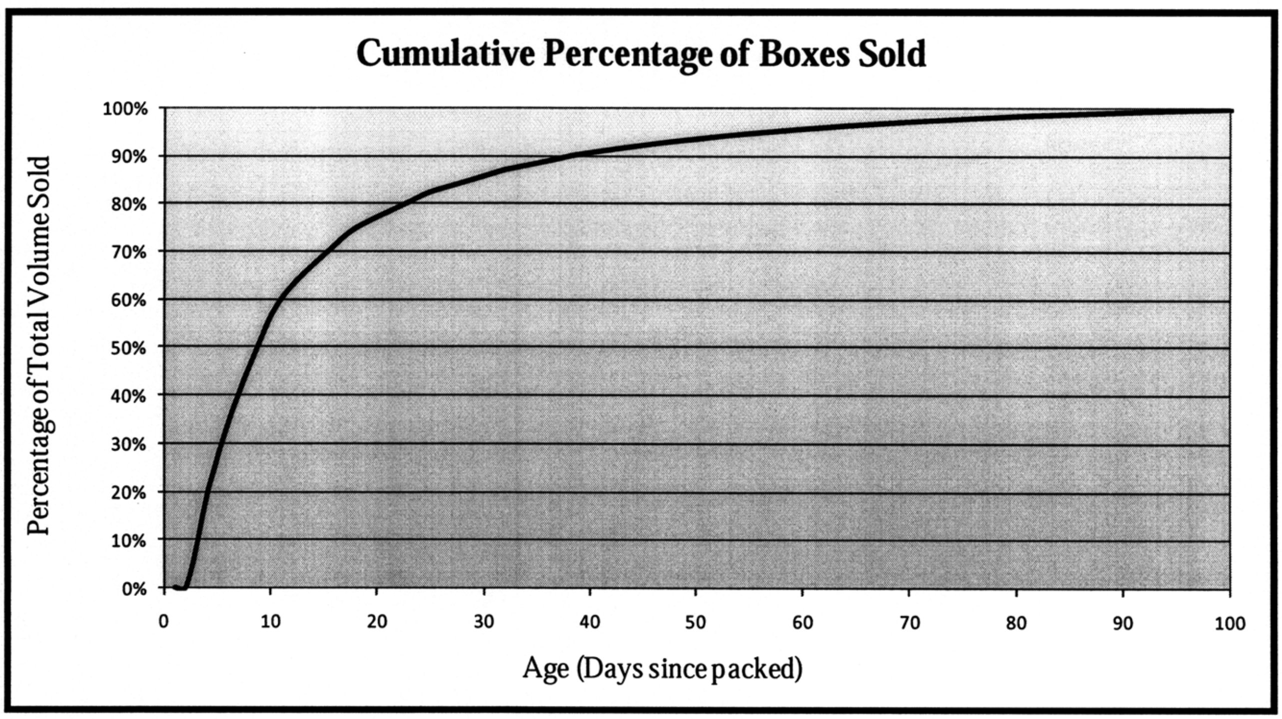


FIGURE 3.2 CUMULATIVE PERCENTAGE OF ALL BOXES SOLD AT EACH AGE

The first reason why fruit is packed before being sold is because packing managers have poor visibility of on-hand RM inventory at the individual SKU level. Packing managers cannot quantify the inventory level by SKU until after packing because each bin has an unpredictable assortment of sizes and color grades. To improve SKU visibility, samples are taken from each incoming truckload during harvest and tested for size, color grade, and a number of other quality metrics; however, sample sizes are so small that reliable results are difficult to come by. Still, managers use the sampling results in conjunction with the historic SKU profiles of the orchard from which the fruit came to make a best possible estimate of volume by SKU. In addition, quality control checks are conducted throughout the year to measure changes in fruit condition; this helps packing managers to keep the sales desk managers informed of likely fruit availability.

A second reason that fruit is packed before being sold is because sales managers want to have enough FG inventory on hand to maintain a high customer service level (CSL). Generally, packing and sales organizations collaborate in analyzing demand forecasts and current RM inventory levels in order to create a pre-scheduled packing plan for the upcoming two-four weeks. However, demand forecasts are rarely accurate and unforeseen orders usually occur. While some orders are placed a week in advance, others are placed for immediate fulfillment, with a truck literally waiting at the loading dock. The lead time of converting RM into FG inventory is only a few hours for CS sheds and one day for CA sheds; this short lead time comes at the cost of interrupting the pre-scheduled packing plan. Sales managers who sell product that is not in-stock run into problems because packing managers do not have the incentive to disrupt their pre-scheduled plan. Due to these inevitable last minute orders and the reluctance of packing managers to be flexible, safety stock must be held in order to maintain a high CSL level.

The third reason that FG inventory is produced before its sale is that storage and packing managers are compensated differently than sales and marketing managers. Storage and packing managers are concerned with minimizing labor costs and increasing equipment capacity utilization. They prefer to produce large batches of the same variety and same package. They avoid midday line changeovers that occur when new packages or new varieties are packed and especially avoid the cleaning required to pack organic fruit. Sales and marketing departments, on the other hand, are concerned with increasing the frequency and size of their sales. Sales managers tend to accept any incoming sales order, even if it is not currently in stock. This results in angry phone calls where packing managers say 'sell what is already packed,' while sales managers say 'pack what I just sold.' This friction tends to occur whether these managers work for the same company or not. Misaligned incentives between supply chain echelons result in piles of unsold inventory on the shed floor that are getting older.

3.2. METHOD: MULTIPLE REGRESSION

To understand the relationship between the price and the age of inventory, I used multiple regression techniques to model and predict the value of the dependant variable price (dollars per box), based on observations of nine groups of independent variables: age, order size, market, customer, year, quarter, size, grade, and variety. Many of these variables are non-quantitative and are introduced into the model as binary variables. Including these binary variables, the model has 141 independent variables that fall within the nine variable groups. The final form of my regression, simplified by variable groups, is:

$$Price = f(age, order\ size, market, customer, year, quarter, size, grade, variety)$$

$$Y_1 = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_{3:4} x_{3:4} + \beta_{5:7} x_{5:7} + \beta_{8:11} x_{8:11} + \beta_{12:15} x_{12:15} + \beta_{16:20} x_{16:20} + \beta_{21:41} \beta_{21:41} + \beta_{42:141} \beta_{42:141} + \varepsilon \qquad \textit{Eq. 3.1}$$

Each of the variables or variable groups requires a baseline value; the y-intercept given is the result of the baseline model. For continuous variables such as age and order size, the baseline of the model is 0. For binary variables, a specific baseline must be chosen to serve as the starting point of the model; it is standard to select the most common variant of each variable. For example, the baseline characteristic within the variable group size is "medium". Thus, the model assumes that all boxes are size "medium" unless told otherwise; to estimate the selling price of any other size the coefficient of the desired characteristic must be added to the baseline. "Domestic" serves as the market variable baseline; "international" is the secondary option. The group "small" customers, defined as ordering less than 3,000 boxes per year, is the baseline for the customer variable; the baseline selling period is the fourth quarter of 2009. The most common varieties and grades serve as the baseline characteristics in the apple and pear models, these being "Red Delicious", "grade WXF" and "Green D'Anjou", "grade US1". A description of each variable can be found in Table 3.2, along with the baseline inputs for two separate regression models; one for apples and one for pears.

TABLE 3.1 REGRESSION VARIABLES AND TWO BASELINE MODELS

Variable Description	Variable	Apple Baseline	Pear Baseline	Units
Price	y_1	0	0	\$/box
Y- intercept (Baseline)	x_0	0	0	\$/box
Age	x_1	0	0	Days
Order Size	x_2	0	0	Boxes
Market	x_3 through x_4	Domestic	Domestic	Binary
Customer	x_5 through x_7	Small Customer	Small Customer	Binary
Year	x_8 through x_{11}	2009	2009	Binary
Quarter	x_{12} through x_{15}	4th Quarter	4th Quarter	Binary
Size	x_{16} through x_{20}	Size Medium	Size Medium	Binary
Grade	x_{21} through x_{41}	WXF	US1	Binary
Variety	x_{42} through x_{141}	Red Delicious	D'Anjou	Binary

Constructing an insightful regression model is a mixture of art of science; the modeler must use intuition to understand the relationships between variables while also avoiding statistical biases such as multicollinearity and omitted variable bias. As a first test, it should be easy to explain why each of the nine variable groups affects the price of fruit. At the same time, the data needs to be checked for errors and the source of the data considered for accuracy. The model should also include enough variables to explain the majority of variation in the dependant variable, or price, and independent variables that correlate amongst themselves should be avoided.

In this model, the direction of many variables with respect to price is intuitive, however, the graphical shape of the relationship may be harder to establish. In order to find the best relationship for each variable, I tested several mathematical functions and evaluated them based on their explanatory power (i.e. R^2 value), significance (i.e. p-value), and rational sensibility. More specifically, to determine the shape of age with respect to price, I tested five different mathematical relationships:

1. $Age = Age$
   Deterioration is linear
2. $Age = \frac{1}{Age}$
   Deterioration is exponential
3. $Age_{0-20} = Age\ (a), Age_{>20} = Age\ (b)$
   Deterioration has two slopes (piecewise linear)
4. $Age_{0-10} = Age\ (a), Age_{10-20} = Age\ (b),\ Age_{>20} = Age\ (c)$
   Deterioration has three different slopes
5. $Age_{0-20} = Age\ (a), x + Age_{>20} = Age\ (b)$
   Deterioration has one slope with a discontinuity

Ultimately, the first equation, the linear function, gave the best statistical representation of the relationship between price and age. Using similar techniques, I found that the relationship between price and order size was also linear. The order size variable was included to capture the presence of a volume discount, but, as I also wanted to capture the purchasing power of first-tier buyers, I created three customer variables for large, medium and small retailers, based on the yearly purchase volume. While fifty different sizes existed in the database, I grouped them into five bins: small, medium, large, extra-large, and custom. These groupings were based on the same sizing standards that determine product look-up (PLU) codes, which appear on the stickers that are placed on each piece of fruit during packing. I left all twenty grades and one hundred variety possibilities in the regression as unique binary variables because their cumulative explanatory power was very high and none of my attempts to aggregate the variables could replicate or improve upon the results. Table 3.3 provides a description of each of the variable and whether they were redefined as groupings. I could not control for at least two biases when constructing this model: first, the sales data comes from a single firm, and second, there are omitted variables such as volume of international imports, inflation rate, post-harvest storage conditions, retailers' visibility of inventory age, and the price of substitute goods.

TABLE 3.2 DESCRIPTION OF VARIABLE GROUPS

Variable	Variable Description
Price	This is the price per packed box in dollars.
Age	The number of days since being packed.
Order Size	The number of boxes being ordered. Captures a volume discount.
Market	Either domestic (US) or international market.
Customer	These were grouped into large (>50,000 boxes), medium (between 10,000 and 50,000 boxes), and small (<10,000 boxes) based on the cumulative order volume over the four years included in the dataset.
Year	The year, between 2006-2009, that the fruit was sold.
Quarter	The quarter the fruit was actually sold.
Size	These were grouped into small (size >125), medium (size 90-125), large (size < 90), and specialty pack (all others).
Grade	This is the official USDA or WA Dept. Agriculture product grade. I did not group grades; all options were included.
Variety	This is the variety of fruit being sold. I did not group varieties, all one hundred varieties that appeared in the dataset were included.

3.3 REGRESSION RESULTS

I constructed two different regression models, one for apples and one for pears. The basic results of these two models are provided in Table 3.4; the apple model has an adjusted $R^2 = 0.692$, which means that nearly 70% of the variation in price can be explained by the nine groups of variables included as independent variables. The pear model has an even higher adjusted $R^2 = 0.766$. The variable that I was most interested in is the coefficient of the variable 'Age'. The apple model predicted that a box of fruit loses $0.044 per day, which means that apples are expected to lose a value of $\$0.044 \div \$17.74 = 0.25\%$ per day, or 2.5% every 10 days. The apple model predicted that a box of fruit loses $0.044 per day, which means that apples are expected to lose a value of $\$0.008 \div \$21.05 = 0.10\%$ per day, or 1.0% every 10 days. The complete statistical output from these two regression models is provided in Appendix A and B.

TABLE 3.3 BASIC RESULTS FROM TWO REGRESSION MODELS

Model	Observations	Adjusted R Squared	Standard Error
Apple	529,875	0.692	4.47053
Pear	85,739	0.766	4.62059

Tables 3.5 and 3.6 show selected results from both the apple and pear models. An example of how to practically use the results of the regression to make pricing predictions is provided in Figure 3.3.

TABLE 3.4 SELECTED RESULTS FROM BASELINE MODEL FOR APPLES

To include the effects of a variable, multiply the variable by the coefficient, and add it to the baseline price.

Considered statistically significant if < 0.05

The coefficient will fall between the lower and upper bound 95% of the time.

Variable	Coefficient (in $)	Significance	95% Lower	95% Upper
Baseline Price	17.740	0.000	17.665	17.819
Age	-0.044	0.000	-0.045	-0.043
Order Size	-0.004	0.000	-0.005	-0.004
Market	-1.500	0.000	-1.538	-1.463
Large Retailer	-0.052	0.005	-0.089	-0.016
Size Small	-5.040	0.000	-5.082	-5.013
Size Large	2.380	0.000	2.347	2.412
Size Custom	10.590	0.000	9.240	11.946
Grade: UXF	-6.300	0.000	-6.361	-6.241
Grade: WFC	-6.190	0.000	-6.286	-6.095
Grade: US1	-7.730	0.000	-7.857	-7.613
Grade: FCY	-10.480	0.000	-10.965	-9.991
Ambrosia	14.950	0.000	13.204	16.710
Braeburn	-1.080	0.000	-1.157	-1.012
Fuji	4.490	0.000	4.445	4.548
Gala	3.360	0.000	3.317	3.409
Granny Smith	2.130	0.000	2.086	2.181
Honeycrisp	28.100	0.000	27.912	28.293

TABLE 3.5 SELECTED RESULTS FROM BASELINE MODEL FOR PEARS

To include the effects of a variable, multiply the variable by the coefficient, and add it to the baseline price.

Considered statistically significant if < 0.05

The coefficient will fall between the lower and upper bound 95% of the time.

Variable	Coefficient (in $)	Significance	95% Lower	95% Upper
Baseline Price	21.050	0.000	20.873	21.229
Age	-0.008	0.000	-0.010	-0.007
Order Size	-0.004	0.000	-0.005	-0.004
Market	-1.510	0.000	-1.594	-1.434
Large Retailer	0.940	0.000	0.831	1.046
Quarter Two	-0.310	0.000	-0.4770	-0.135
Quarter Three	1.480	0.000	1.366	1.593
Size Small	-5.850	0.000	-5.971	-5.722
Size Large	2.170	0.000	2.086	2.251
Size Extra Large	5.490	0.000	5.388	5.582
Size Custom	12.09	0.000	11.789	12.390
Grade: WFC	-6.400	0.000	-6.503	-6.306
Green Bartlett	-2.390	0.000	-2.493	-2.288
Bosc	-0.420	0.004	-0.707	-0.132
Comice	11.120	0.000	10.618	11.628
Organic D'Anjou	12.680	0.000	12.532	12.836
Red D'Anjou	1.610	0.000	1.435	1.781

How to Use the Results: An Example Using the Apple Model

Using selected results from Table 3.5, below is an example of how to interpret the data and predict the sale price of any combination of characteristics. The first variable is the y-intercept, which represents the expected price per box of the baseline model, $17.74. To calculate the impact of variables not included in the baseline model, one can simply lookup the coefficient of each variable and add or subtract it to the baseline price of $17.74 per box. For example, to estimate the selling price of a Fuji, size large, sold domestically to a small customer in May of 2009, grade WFC, in a quantity of 90 boxes, aged 21 days, calculate:

Example Calculation for a Box of Fuji Apples

$	17.74	Baseline price per box: Given by y-intercept
-	0.044*21	Age: Deterioration rate per day
-	0.004*90	Order Size: Volume discount per day
+	0.00	Market: Domestic is the baseline
+	0.00	Customer: Small is the baseline
+	0.00	Year: 2009 is the baseline
+	0.83	Quarter: second Quarter
+	2.38	Size: Size large
-	6.19	Grade: WFC
+	4.49	Variety: Fuji
	$ 17.96	Expected price per box

FIGURE 3.3 EXAMPLE CALCULATION USING THE APPLE MODEL

3.4 THE ADJUSTED VALUE OF FRUIT OVER TIME

"I'd like to say that we're in tune with the decline in value, but in reality it's the decline in quality that's being observed and managed. We do start putting pressure to get stuff moved after it hits about 45 to 60 days, depending on the variety, provided the quality hasn't started declining before that. The Quality Control department is monitoring the fruit for quality and as they start to see issues, they put stuff on the radar screen for the organization. Time and quality are the two triggers."

- Packing Manager

Sales managers can efficiently discount prices in order to shape demand if they know how much value fruit loses over time. Based on the results of the apple and pear regression models the relationship between expected price and the age of fruit can be graphed. However, this curve should not be used as a managerial tool — it does not consider the labor costs and loss of volume due to repack and rejections of inventory for quality reasons. In order to graph what I call the 'adjusted value' of fruit over time, sales managers need to factor in the likelihood that FG inventory will be repacked or rejected as well as the costs and loss of volume when these events do occur.

3.4.1 THE COST OF REPACKING FRUIT

At some point, FG inventory that has been in storage for a period of time begins deteriorating. When these boxes are used to fill an order they are rerun through the packing line or repacked by hand in order to remove the deteriorating fruit. The cost of repacking comes in three forms: the direct labor cost of rerunning the fruit through a packing line, the direct material cost of putting it into a new box, and the loss in yield due to deteriorating fruit. Packing managers whom I interview estimated that the direct labor and material costs of repacking are around \$3 to 4 per box and that the yield after repacking is in the range of 85 to 95% of the original volume. Mathematically the costs of repacking per box equal:

$$Cost\ of\ Repack = \ Expected\ Price * \left(1 - Yield(\%)\right) + \ Direct\ Labor + Material\ Cost \qquad Eq.\ 3.2$$

The decision of repacking fruit is made by the packing manager, however it is the responsibility of both the packing manager and the sales manager to minimize repack events. The first deadline that both packing and sales manager must keep in mind while monitoring the age of FG inventory is fourteen days. By law state inspectors check each box that has been stored in Controlled Atmosphere (CA) storage as it comes off the packing line and apply a CA stamp to certify its quality; inventory not shipped with fourteen days must be re-inspected or sold without the CA stamp. Other than this deadline, each packing manager uses a different rule of thumb to determine when to repack fruit. One manager reported repacking when 2% of the fruit has 'declined' past the point of consumption, but stipulated he waits to repack until he receives an order specifically for that fruit; this avoids a potential third packing. Another packing manager had a different view of quality, saying "as long as 80% of the fruit in the box is okay, I'll sell it." Although the decision of when to repack fruit is made by the packing manager, sales managers have the ability to influence the likelihood of repacking through their pricing decisions. Sales managers should communicate with packing managers to learn when FG inventory will be repacked so they can account for repacking costs in their pricing decisions; currently, this is done by some but not all firms.

Fruit is not repacked based on its age but rather on the results of daily quality control (QC) checks conducted by packing managers. Therefore the best method of estimating when a certain pile of FG inventory will be repacked is to work closely with the packing manager to monitor the condition of inventory. To graph the general case of when fruit is expected to be repacked, I estimate that, on average, fruit will be repacked at an age of 40 days and again at an age of 80 days. From days 0 to 30 very little fruit will be repacked, from days 30-50 an exponential curve from 0% to 100% will be repacked, from days 50 to 60 very little fruit will be repacked, and from days 60 to 80 an exponential curve from 0% 100% will be repacked. Very little fruit is repacked between 50 and 60 days because the boxes have already been repacked and all the deteriorating fruit have been removed by that time. In reality, the likelihood of repack will depend on the variety and particular condition of the fruit; however, the general shape of the curve presented in Figure 3.4 remains the same. This can be shown mathematically in the formula:

$$Likelihood\ of\ Repack = Age * 0_{Age\ 0-30} + Age * 0.001^{0.5}_{Age\ 30-50} + Age * 0_{Age\ 50-60} + Age * 0.001^{0.5}_{Age\ 60-80} \quad \textit{Eq. 3.3}$$

3.4.2 The Cost of Customer Rejections

Occasionally, retailers do not pay for fruit upon receipt if they are dissatisfied with its quality. When fruit is rejected by a retailer, it is taken to a nearby food processing facility where it can be "reworked" or it will be sold directly to a wholesaler, or donated to a food bank. Rework can be thought of as "repacking" in a third party facility; there will be some direct labor and material cost and some loss of volume. Selling at wholesale implies a markdown from the original price; donating or dumping FG inventory will receive a near $0 salvage value. The yield and cost of rework are approximately within the same range as repacking, while the markdown to wholesalers would be between 20% and 50%. Depending on whether fruit is reworked, sold to a wholesaler, or donated to a food bank, the expected cost of repack can be graphed with:

$$Cost\ of\ Rejection = Expected\ Price * (1 - Yield(\%)) + Labor + Material\ Cost \qquad Eq.\ 3.4$$

OR

$$Cost\ of\ Rejection\ (Wholesale) = Expected\ Price - Wholesale\ Price \qquad Eq.\ 3.5$$

OR

$$Cost\ of\ Rejection\ (Donation) = Expected\ Price - Charitable\ Tax\ Deduction \qquad Eq.\ 3.6$$

Based on feedback from interviews with packing and sales managers, I estimate the average percentage of rejection in the tree fruit industry is <1% of the total volume sold. Using age as a proxy for quality, I estimate that the percentage of rejections would start near 0% when fruit is first packed and slowly increase until fruit is repacked or sold. Upon repack, all the poor quality fruit is removed; the likelihood of rejections thus returns to nearly 0% before beginning to rise again, an abrupt drop which creates the step-like shape of the curve. The exact size of the drop and ensuing increase in likelihood of rejection will depend on the cause of the initial repack, such as scald, sunburn, lenticels breakdown, or bitter-pit, and whether similar symptoms are more likely to reoccur. Regardless, the general form of the likelihood of customer rejections can be quantified with the following function:

$$Chance\ of\ Rejection = Age * 0.00001^{2}_{Age\ 0-50} + Age * 0.0001^{2}_{Age\ 50-80} + Age * 0.001^{0.25}_{Age>80} \qquad Eq.\ 3.7$$

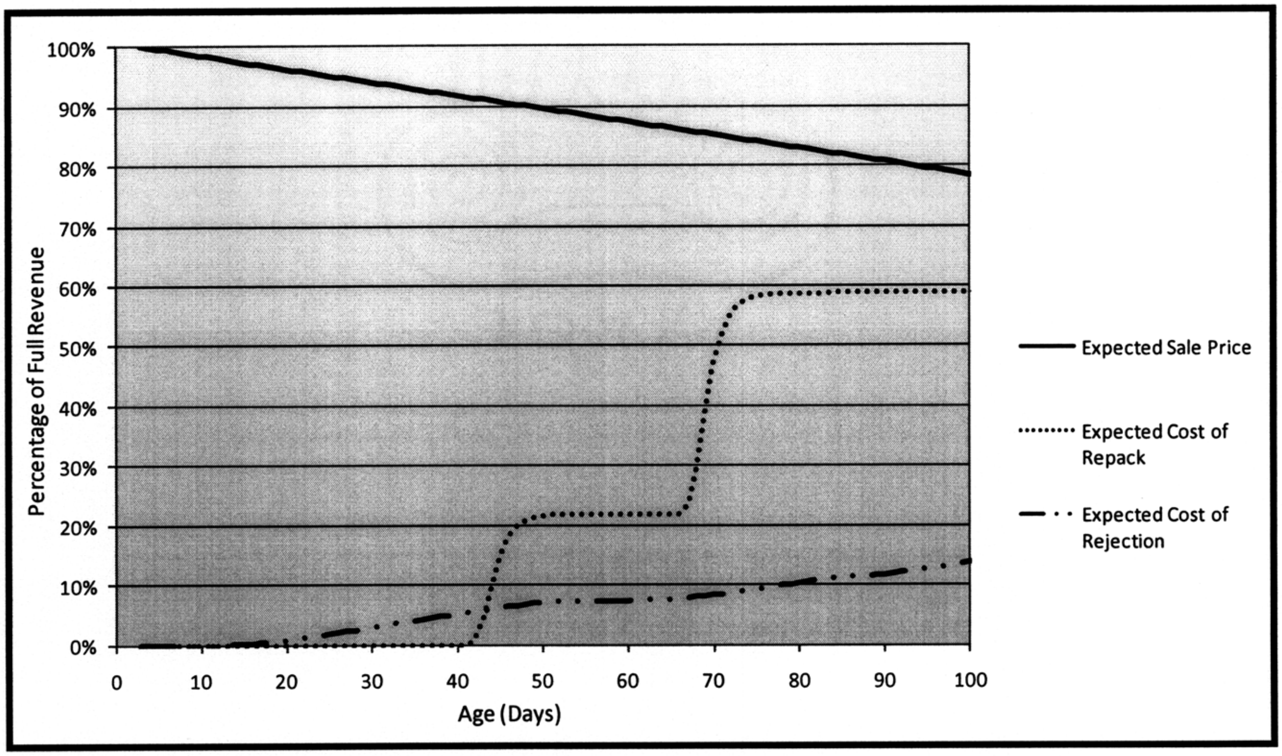


FIGURE 3.4 EXPECTED PRICE, COSTS OF REPACKING AND REJECTIONS AS % OF FULL PRICE

Figure 3.4 shows the expected price and expected costs of repack and rejections as a percentage of the expected price when fruit is first packed (given by the y-intercept). The expected price curve derives from the results of the apple regression model, which has a negative slope of 0.044 per day. The total expected cost of repacking and rejections is divided by the full expected price in order to be displayed as a percentage of the full price. The most notable characteristic of the graph is the large step-up in cost of repack around 40 and 70 days; the first increase owes to the exponential nature of deterioration, the ensuing flat portion of the graph indicates a repack, and the final increase evidences renewed decline in quality post-repack. While the cost per rejection exceeds the cost per repack, the expected cost of rejection is lower than the expected cost repack because rejections are less frequent.

3.4.3 THE RELATIONSHIP BETWEEN 'ADJUSTED PRICE' AND AGE

To measure the true value of fruit over time, sales managers should take into account the expected price of fruit based on its age and the expected costs and loss of volume due to repack and rejections. Given the relationship between price and age and the expected likelihood and costs of repacking and rejections, I graph the general form of the adjusted relationship between price and age in Figure 3.5 using the following equation:

$$A = P - L_k(C_k + (S_k * P) - L_r(C_r + (S_r * P) * P \qquad \textit{Eq. 3.6}$$

Where: A = *Adjusted Price of FG inventory*

P = *Expected Retail Price (given as y-intercept in regression model)*

L_k = *Likelihood (%) that FG inventory is repacked*

C_k = *Cost of labor associated with repacking*

S_k = *Shrinkage (%) of volume*

L_r = *Likelihood (%) that FG inventory is rejected*

C_r = *Cost of labor associated with rejection*

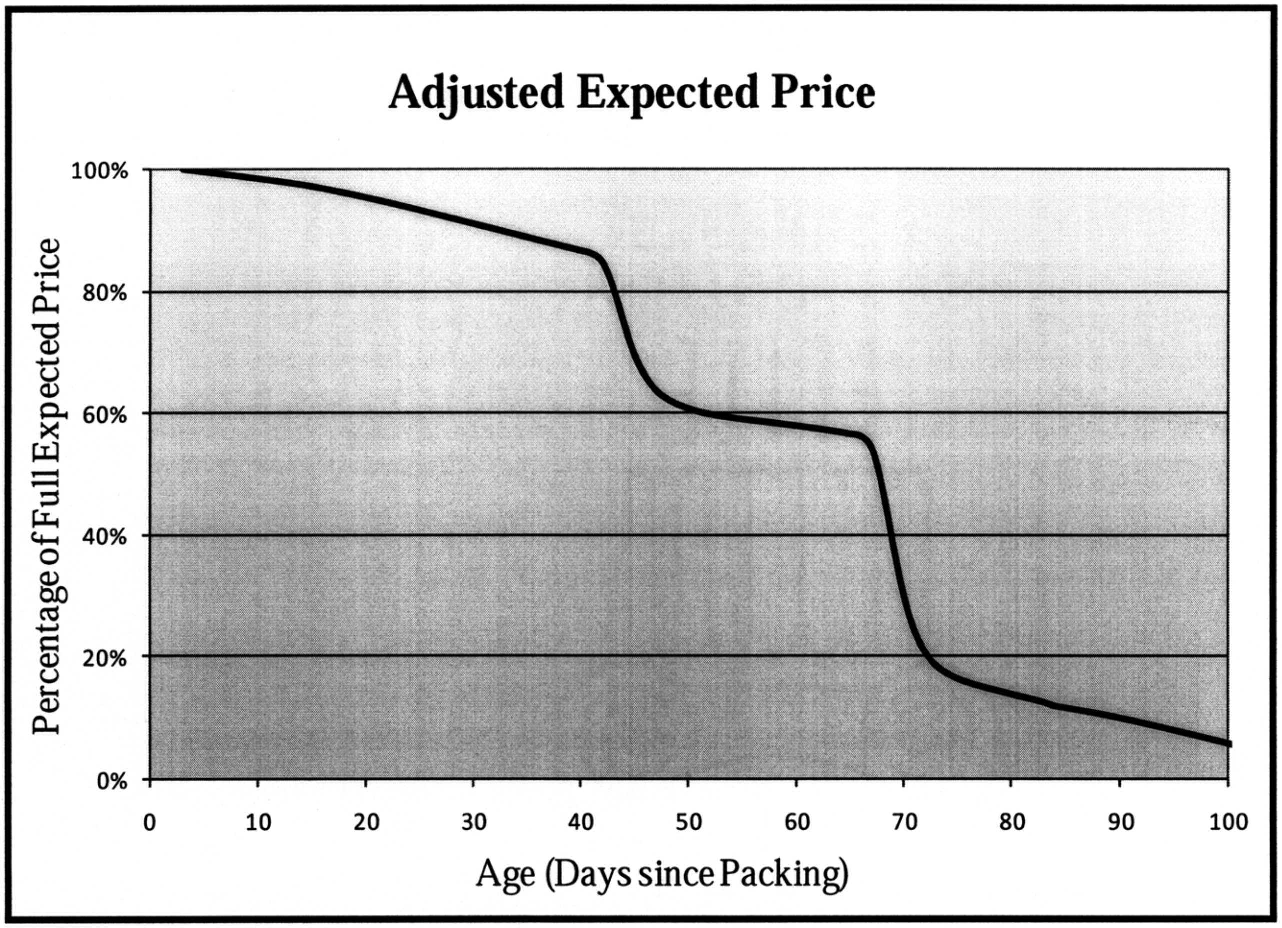


FIGURE 3.5 ADJUSTED PRICE PER BOX BASED ON THE AGE OF FRUIT SINCE PACKING

The general form is not particularly useful in making dynamic pricing discounting decisions because (1) each pile of inventory will be repacked at a different time based on its condition and (2) the percentage of costs are dependent upon the selling price, which differs for each SKU. In order for the sales manager to take the costs of repack and rejections into account, they cannot rely on a static model that predicts when fruit will be repacked; rather, they need a dynamic tool that can update the condition of a particular pile of inventory and then produce a graph that includes the expected price, costs of repacking, and costs of rejections. This can be done by modifying existing databases, which contain the age of fruit by lot number, to include a quality condition ranking by lot number. This data could be connected to a simple program on the sales manager's computer, which would provide real time suggested pricing information.

3.4.4 How Efficient are Current Industry Practices?

Given the total volume sold over time presented in Figure 3.2, we know the percentage of fruit sold by age. Given the adjusted price in Figure 3.5, we also know how the value of fruit by age. With these curves, we can estimate the magnitude of loss in the tree fruit industry attributable to labor costs and shrinkage by comparing the total realized value to the full value as if all fruit had been sold without a discount. If all fruit was sold at full price, there would be no lost revenue due to inventory shrinkage. However, many boxes are discounted and some incur additional handling costs and loss of yield due to shrinkage. To calculate the percentage of revenue lost due to inventory shrinkage, the adjusted price for each day can be multiplied by the percentage of boxes sold that day to find the adjusted revenue. The summation of this calculation for all ages can then be divided by the total volume sold multiplied by the full price to determine how efficient current industry practices are.

Actual revenue received – Repack Costs – Rejection Costs

Revenue received if all fruit was sold at Age = 0

$$Industry\ Efficiency = \frac{Adjusted\ Revenue}{Full\ Revenue} \qquad \text{Equation 3.7}$$

$$\text{Where: } Adjusted\ Revenue = \sum_{Age=0}^{100} Volume(\%) * Adjusted\ Price\ (\$) \qquad \text{Equation 3.8}$$

$$\text{Where: } Full\ Revenue = \sum_{Age=0}^{100} Volume(\%) * Expected\ Price\ (\$) \qquad \text{Equation 3.9}$$

TABLE 3.6 SENSITIVITY ANALYSIS OF INDUSTRY EFFICIENCY

Industry Efficiency (% of potential revenue realized)	95.2%	94.2%	92.5%	91.5%	89.1%	87.6%
Expected Price ($/box)	$25.00	$20.00	$15.00	$15.00	$10.00	$10.00
Repack Cost ($/box)	$3.00	$3.00	$3.00	$4.00	$3.00	$4.00
Rejection Cost ($/box)	$3.25	$3.25	$3.25	$4.25	$3.25	$4.25
Volume Lost : 1st Repack	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Volume Lost : 2nd Repack	7.0%	7.0%	7.0%	7.0%	7.0%	7.0%
Average Age: 1st Repack	40	30	30	30	40	30

Based on a range of inputs for expected price, the cost of repack and rejections, and the average age of repack, lost revenue due to FG inventory shrinkage in the Washington State tree fruit industry is 5% to 12% of the expected value of newly packed fruit. These losses are due to shrinkage of FG inventory, above and beyond the initial amount of RM shrinkage associated with the original packing process. This number is obviously non-trivial; FG shrinkage reduces potential revenue more than enough to merit the industry's attention. Fortunately, several potential policy solutions exist; these may provide a way for the industry to capture a larger percentage of revenue lost due to inventory inefficiency.

3.5 POLICIES DESIGNED TO REDUCE INVENTORY SHRINKAGE

"Packers run one variety for an entire week because it is efficient. Sellers make random sales and want packers to pack on demand. There is a need for a firm system to tell packers what to do but (sales and) marketers don't have the influence to optimize the system."

- CEO, Large Sales and Packing Organization

The traditional low cost supply chain pushes product into the market in large batches, although many companies today are moving to a more customizable pull system by implementing a more flexible and responsive supply chain (Singh 2009). In the tree fruit industry, the need to hold finished goods (FG) inventory levels can be lessened by reducing the lead-time and variability of production and ordering. Packing managers can do this by pre-sorting fruit and improving the operational execution of their packing facilities. Sales managers can do this by shaping demand through pricing discounts, forming strategic partnerships with retailers in order to reduce variability in ordering, driving demand higher through effective marketing, aligning their sales plan across multiple firms in the industry and decreasing the number of SKUs available. Most importantly, packing and sales managers can work together to align their packing and sales plan while setting up incentives to deter deviations from those plans. All of these policies lead to a reduction in on-hand levels of FG inventory, thus reducing the revenue lost to inventory shrinkage, while maintaining a high customer service level (CSL).

3.5.1 PRE-SORT OR PRE-SIZE

"We operate one of the newest and largest pre-size facilities in the country. Equipment is continually updated as new technology becomes available to increase efficiency and improve fruit handling. There are many benefits to running a pre-size operation. Most significantly, it allows us to maintain a "just-in-time" inventory. The normal industry turn time for packed fruit is 25 to 30 days; our turn time is 3-5 days. Three packing lines and two bagging lines give us the flexibility to pack multiple varieties and packages simultaneously. No other packer in the business can respond to last minute packaging requests as fast as we can."

- Rainer Fruit Company Website

In the tree fruit industry, on-hand FG inventory is a result of natural batching in production. One policy designed to reduce the level of on-hand FG inventory is to sort fruit by SKU before it is placed into storage. This would immediately solve the problem that packing and sales managers have with low visibility of volume per SKU; it would also reduce the quantity of "small piles", or the odd sizes and grades that tend to be packed without an order. Additionally, if the pre-sorted inventory is stored in a network of small CA and CS sheds, managers can keep inventory in a CA environment longer. Currently no firms pre-sort fruit at the time of harvest because there is not enough line capacity to process all the incoming fruit in such a short period of time.

A more realistic method to improve visibility of RM while in storage is using a pre-sizing line in conjunction with the packing line, as referenced in the quote from Rainer Fruit Company above. Under this setup, a packing manager can choose to pack certain sizes into FG boxes while diverting other sizes into bins for placement back into CS or CA storage. This gives sales managers much greater visibility of on-hand RM inventory levels of the fruit that has been pre-sized; furthermore, packing managers will be able to selectively pack certain sizes because they have already been separated, decreasing the level of on-hand FG inventory. The costs of this policy include the capital expenditure necessary for the line, the labor cost of additional handling, and the loss of volume due to additional shrinkage causes from the pre-sizing line.

A technologically-based advancement would be the development of packing lines that use infrared technology to sort fruit by brix, or some other quantifiable metric that is highly correlated with future shelf life. This would enable packing managers to selectively pack fruit at the right time while avoiding placement of overripe fruit back into storage.

3.5.2 Demand Shaping Through Price Discounting

"These were sold at $15.75 per box. When nearly 10,000 boxes are sold so significantly below the market price it will tend to suck the average down significantly. Condition issues, a desire to be done with (that variety) or some combination thereof may help explain these sales."

- Manager, Sales and Marketing Association

Fruit shrinkage can be compared to technological obsolescence. Once you convert raw materials into a finished product, there is always a risk that demand will change and the product will become worthless. Faced with this problem, Dell Computer successfully implemented a price discounting policy that increased their inventory turns. With a dwindling cash supply, Dell began to cut back on inventory levels of raw material and FG inventory, increasing the number of stock-outs. To solve the stock-out problem, Dell focused on reducing production lead-time and developed the ability to quickly build personal computers to the specifications of individual customers. In this "build-to-order" system, Dell had little FG inventory on-hand, and thus rarely had to throw away product due to technological obsolescence. When they did have FG inventory on hand, they manipulated the price at the individual SKU level on an e-Commerce platform in order to create demand for the product before it became worthless. This combination of short production lead-times, product customization, and demand-shaping pricing strategies was very successful in reducing inventory obsolescence, or shrinkage, while maintaining a high customer service level.

Sales managers in the tree fruit industry could emulate Dell's pricing strategy by discounting certain piles of FG inventory when it is overstocked and deteriorating in quality. To make more efficient decisions, managers can use the quantitative relationships described in this chapter when discounting fruit. Based on their assessment of current market conditions, managers can use the relationship between price and age to identify the best channel for a particular pile of inventory.

3.5.3 Vendor Managed Inventory

In a vendor managed inventory (VMI) system, suppliers are responsible for ensuring the availability of their product at the retailer. A supplier essentially "rents" shelf space from the retailer, subject to meeting certain pricing, inventory turn, and customer service levels. From the retailer's perspective, this removes some of the supervising and ordering responsibility while leveraging the supplier's expertise in a given product category. In successful VMI relationships, suppliers maintain a high customer service level while decreasing inventory levels, resulting in a higher inventory turn rate and profitability for both parties. Retailers use inventory turn rates to calculate profitability per square foot, which is the primary metric used in evaluating the profitability of their suppliers, where the inventory turnover rate equals annual sales divided by average inventory levels. VMI relationships tend to start tentatively, with the retailer continuing to provide oversight, but they are designed to result in into full supplier autonomy. A successful

VMI system relies on an accurate and timely flow of information and a deep understanding of consumer behavior. Bar codes are scanned at the checkout counter, generating point of sales (POS) data that is transferred to the relevant suppliers via electronic data interchange (EDI) or a secure internet connection. Suppliers monitor this information on a daily basis to predict demand, plan shipments, and coordinate production plans with packing managers.

Several sales organizations in the fruit industry have VMI relationships with large domestic retailers; these require packing sheds to individually label each individual piece of fruit with a barcode. The barcode system stands to fundamentally change the custody of ownership throughout the supply chain. At present, the grower owns fruit until the retailer picks it up at the packing shed. The price paid by retailers is FOB, or free-on-board from the packing shed's loading dock. However, most VMI systems are based upon consignment. In this agreement, the retailer never actually owns the fruit until the brief moment it is scanned at the checkout counter before being placed into the customer's shopping bag. Retailers prefer this system, since it lowers their inventory holding costs and incentivizes suppliers to manage the quality of their inventory. However, it adds significant risk to fruit suppliers, as they may be held accountability for quality issues after the product leaves their control.

3.5.4 Reduce SKU Complexity

"When I listen to the sales desks negotiate with a retailer, I hear them talk about large and small, premium or fancy, that's it. Then they negotiate a SKU that is closest to that description."

- Head of Information Technology (IT) at a major sales organization

Reducing the number of SKUs offered to retailers can reduce variability in production and thus levels of on-hand inventory. The gradual increase of product offerings over time, often called SKU proliferation, can be found in many industries; it is a common behavior for companies that are constantly trying to expand sales through new product offerings. The problem SKU proliferation causes is that adding SKUs vastly increases the complexity of warehousing, packing, and management of sales; the fact that older SKUs are rarely eliminated aggravates the problem. Reducing SKUs will reduce the required level of on-hand inventory while maintaining customer service levels, improving forecasting through aggregation, and reducing stock-outs.

Some sources of SKU complexity cannot be reduced in the tree fruit industry due to constraints of nature or consumer demand. For example, growers cannot choose to produce certain sizes or quality grades of fruit exclusively because trees do not produce uniform SKU profiles. Fruit is picked at the same time, so the packing managers cannot reduce raw materials inventory. Consumers demand a mix of varieties and, more recently, organic options; thus, these are not realistic areas of SKU reduction.

Sources of complexity that could be eliminated include sizes and packaging. A retired sales manager who worked for two years studying the possibility of SKU reduction in the Washington State tree fruit industry estimated that, although the barriers of dealing with multiple federal, state and private organizations were high, savings from SKU reduction could amount to savings of $1 per box. His recommendations included eliminating every other size, which would reduce the size options from fifteen to eight, and eliminating several redundant packaging types, which would reduce the average number of packaging options from fifteen to twelve. After constructing a detailed implementation plan, an attempt was made to gain industry-wide support, but two key detractors provided enough resistance to stop the entire proposal; this is an example of a beneficial inventory policy that was not implemented due to misaligned incentives between echelons in the tree fruit supply chain.

For many companies, however, packaging is the most likely cause, and remedy, of SKU proliferation. In the tree fruit industry, retailers have the following packaging options: tray pack, cell pack, heavy tray pack, standard tight fill, euro pack, 3 to 5 pound poly bag, 6 to 10 pound poly bag, 3 to 5 pound mesh bag, 6 to 10 pound mesh bag, one layer panta, two layer panta, half cartons, and other specialty packs. Multiple packaging increases costs for packing sheds through the higher labor costs associated with more frequent production line changeovers, higher material inventory costs, and the higher administrative costs associated with the complexity of paperwork and orders. Ironically, packaging is removed prior to product merchandising, with the exception of mesh bags and some boxes used in retail displays, so packaging is not a value added activity. Packing sheds could achieve significant savings by reducing their spending on direct materials through new procurement strategies.

4 REDUCING INTERNAL TRANSPORTATION COSTS

Many packing organizations have outsourced their sales function, resulting in a consolidated base of sales organizations that sell the majority of fruit in Washington State. Due to the commission-based compensation scheme that most sales organizations follow, virtually all incoming orders are accepted, which creates the appearance of a 100% order fill rate, or customer service level (CSL), from the perspective of the retailer. In reality, sales managers often accept orders even when they do not have on-hand inventory necessary to fill the order. When a stock-out like this occurs, the sales manager can solve the problem in one of four ways, listed in order of prevalence: intra-shed transfer, inter-shed purchase, emergency production, or order cancellation.

In other words, the sales manager can *move, buy, make* or *cancel* the order to solve the stock-out problem. Sales managers rarely convince packing managers to conduct an emergency production run and hardly ever cancel the order; they usually decide between moving fruit within their own organization and buying it from an outside firm. The cost of buying finished goods (FG) inventory can easily be ascertained via a price quote from an external firm. Calculating the cost of moving fruit, or an intra-shed transfer, is more difficult, and is the subject of this chapter. Once a sales manager has a tool to calculate the cost of an intra-shed transfer, he or she can compare it to the price of purchasing FG inventory and make the lowest-cost sourcing decision.

This chapter has four sections. In the first section I explain the sourcing problem faced by sales managers. I move on to describe a computer based tool that can be used in real-time to find the optimal sourcing solution for intra-shed transfers in the second section. In the third section, I present the results of the optimization model and estimate the cost of intra-shed transportation per box. Based on the same dataset I calculate the average premium paid per box for inter-shed purchases. In the fourth section I explain how a firm might practically implement the results of the model and make optimal sourcing decisions during daily operations. I do not address the costs of emergency production or order cancellations here; they are far less prevalent in practice than intra-shed transfers and inter-shed purchases.

4.1 THE SOURCING PROBLEM

Sales and marketing organizations in Washington State frequently sell fruit on behalf of multiple packing warehouses located throughout central Washington, all the way from Canada to Oregon. Sales managers receive orders from retailers, who typically pay a free-on-board (FOB) price; retailers are responsible for picking up FG inventory in Washington State and transporting it to its retail destination. When an incoming order cannot be filled with on-hand inventory from a single warehouse represented by the sales organization, the sales manager has to make one of four decisions in order to fill the shortage, which are listed in order of prevalence:

Move. Intra-shed: Move FG inventory from a warehouse within their network

Buy. Inter-shed: Purchase FG inventory from a warehouse outside their network

Make. Have one of their packing sheds conduct an emergency production run

Cancel. Call the retailer back and refuse to fill the order

Under current practices sales managers use a computer to look up on-hand inventory levels by SKU at each of their internal warehouses. If they have enough FG inventory on-hand, they use common sense to choose the source(s) of supply and the consolidation location, in which case the following conversation may take place.

> *"Hey Fred, this is sales. I need you to move 115 boxes of Red Delicious, grade WXF, size 110 to the loading dock down in South Yakima. I just sold 500 boxes to Safeway but South Yakima only had 385 boxes on-hand. Safeway is picking it up at 8am tomorrow morning; make sure those boxes get there before then."*

Although this solves the immediate shortage problem, it is unlikely to be the lowest cost way to do so. The cost per movement may be relatively small, but large organizations move fruit between their own warehouses so frequently that such movements add up to a significant cost, especially when diesel prices are high. To make an optimal decision, managers need a tool to quantify the cost of moving FG inventory so that they can make a cost-minimizing choice between an intra-shed transfer and an intra-shed purchase. When the optimal choice is an intra-shed transfer, managers need a tool that can quickly provide the optimal source of FG inventory, the consolidation location, and the mode of transport. A computer-based, linear optimization program can provide both of these services in real-time with limited computational requirements or user expertise.

4.2 METHOD- MIXED INTEGER LINEAR PROGRAM

To model the costs of an intra-shed transfer I use a mixed integer linear program, which can be constructed in three steps. First, I define the five decisions that a sales manager makes during a sourcing decision. I then define eighteen parameters and divide them into two tiers, based on whether they are explicitly included in the final cost equation or not. These parameters, such as fuel or labor prices, are not determined by the sales manager, but are needed to calculate the cost of an intra-shed transfer. Second, I define the objective function, or cost equation, of an intra-shed transfer, the amount being minimized. Third, I define the constraints and provide a complete mathematical formulation of the program.

As a tool to run the calculations, I use *What's Best* modeling software from LINDO Systems. *What's Best* is an add-on to Microsoft Excel, which increases the computational speed and complexity handled by the Windows based platform without requiring the user to learn a new interface.

4.2.1 DECISION VARIABLES, FIRST TIER, AND SECOND TIER PARAMETERS

Decision variables represent the discrete decisions that a sales manager must make when conducting an intra-shed transfer of FG inventory. Despite the apparent complexity of the sourcing problem, the sales manager only has the power to influence six variables;

1. *What SKU needs to be moved?*
2. *How many boxes of FG inventory need to be moved?*
3. *From which warehouse do I source the FG inventory?*

4. *At which shed(s) do I consolidate the FG inventory?*
5. *How many trucks should I use to transport the FG inventory?*
6. *How many trailers should I use to transport the FG inventory?*

First-tier parameters are exogenous to the system, meaning that that the sales manager cannot influence their value. I call them first-tier parameters, rather than decision variables, because they must be included in the objective function in order for the cost of an intra-shed transfer to be calculated correctly and are not decided by the sales manager. For example, a sales manager cannot decide the rate of fruit decay, so it is not a decision variable, but it is an essential factor in the calculation of the cost of an intra-shed transfer; thus it becomes a first-tier parameter. I include seven first tier parameters in the model:

1. *The variable labor cost to move FG inventory from one warehouse to another.*
2. *The fixed setup cost at the warehouse from which inventory is source.*
3. *The fixed setup cost at the warehouse at which inventory is consolidated.*
4. *The semi-variable transportation cost to move FG inventory from one warehouse to another in a truck.*
5. *The semi-variable transportation cost to move FG inventory from one warehouse to another in a trailer.*
6. *The decay rate of the particular SKU being moved in terms of $/box/day.*
7. *The age of the FG inventory being moved in terms of days.*

Second-tier parameters are also exogenous to the system but they do not appear directly in the objective function. For example, the price of diesel will not appear directly in the cost function because it needs to be converted to a variable cost; that is, it needs to be multiplied by the fuel efficiency rate and the mileage between sheds. I include eleven second-tier parameters in the model:

1. *An arbitrary large number that acts as a link to turn binary variables on and off.*
2. *The fixed setup cost at the warehouse from which I am sourcing inventory.*
3. *The on-hand FG inventory level at each warehouse.*
4. *The number of trucks available to move FG inventory.*
5. *The number of trailers available to move FG inventory.*
6. *The current diesel price in dollars per gallon.*
7. *The current hourly labor rate for employees likely to be moving boxes.*
8. *The driving distance between each of the warehouses.*
9. *The capacity of the truck or trailer being used to transport FG inventory.*
10. *The fuel efficiency of the truck or trailer being used to transport FG inventory.*
11. *Labor efficiency rate; how many boxes one worker can load in one hour.*

Table 4.1 provides the symbol, description, and units of each of the six decision variables, the seven first-tier parameters, and the eleven second-tier parameters used to model the cost of intra-shed transportation. Together, these capture the fixed labor costs associated with coordinating the order, the variable labor costs associated with moving boxes, the variable fuel costs of moving FG inventory between sheds, and the inventory cost associated with deteriorating inventory.

TABLE 4.1 LIST OF VARIABLES AND PARAMETERS INCLUDED IN THE MILP (SORTED BY TYPE)

Type	Symbol	Description of Variable	Units
Decision	a	The number of boxes of FG inventory being moved	Box
Decision	i	Represents the unique SKU, or stock keeping unit, that is being moved	Unitless
Decision	j	Represents the warehouse being used as the source of FG inventory	Unitless
Decision	k	Represents the warehouse being used as the consolidation point of FG inventory	Unitless
Decision	l	Number of trucks being used to move FG inventory	Truck
Decision	n	Number of trailers being used to move FG inventory	Trailer
Decision	e	Binary variable describing whether a warehouse is used for sourcing	Unitless
Decision	g	Binary variable describing whether a warehouse is used for consolidation	Unitless
First Tier	b	Variable labor cost to move one box of FG inventory	$ per Box
First Tier	c	The price decline due to the age of FG inventory in $ per box per day	$ per Box per Day
First Tier	d	Average age of the FG inventory being moved in days	Day
First Tier	f	Fixed setup cost at the warehouse which sources FG inventory	$ per shipment
First Tier	h	Fixed setup cost at the warehouse which receives FG inventory	$ per shipment
First Tier	m	Fixed setup cost per trip between two warehouses using a truck	$ per truckload
First Tier	o	Fixed setup cost per trip between two warehouses using a trailer	$ per trailerload
Second Tier	p	An arbitrary, very large number to ensure binary variable is activated	Unitless
Second Tier	q	How many boxes need to be consolidated	Box
Second Tier	r	How many boxes of FG inventory are on-hand at each warehouse	Box
Second Tier	s	How many trucks are available to move boxes	Truck
Second Tier	t	How many trailers are available to move boxes	Trailer
Second Tier	u	Price of diesel fuel per gallon	$ per gallon
Second Tier	v	Labor cost of one day laborer per hour	$ per hour
Second Tier	w	Distance in miles between each warehouse	Miles
Second Tier	x	Capacity of the truck or trailer in terms of boxes	Box
Second Tier	y	How many miles per gallon does the truck or trailer get	Miles per gallon
Second Tier	z	How many boxes can one worker load in one hour	Box per hour

4.2.2 Objective Function

The objective function represents the cost of moving FG inventory. It includes a fixed labor cost, a variable labor cost, a transportation cost, and an inventory cost which are represented by binary, continuous, and integer variables. The optimal intra-shed transfer decision is the set of variables that minimize this equation, subject to satisfying the constraints listed in the next subsection.

$$Minimize \ \sum a_{ijk} \left(b_{ijk} - c_i \, d_{ijk}\right) + e_j f_j + g_k h_k + l_{ijk} m_{ijk} + n_{ijk} o_{ijk} \qquad Eq.\ 4.1$$

Equation 4.1 can be more easily understood by breaking down each of the five cost categories, all in dollars. The first cost, $a_{ijk} \left(b_{ijk} - c_i \, d_{ijk}\right)$, is the number of boxes (a) of SKU i moved from warehouse j to warehouse k multiplied by the cost per box (b) to move SKU i from location j to location k minus the decay factor (c) of SKU i (\$/box/day) multiplied by the age of SKU i (d) being moved from warehouse j to warehouse k. In other words, it is the variable labor cost minus the inventory adjustment due to deteriorating fruit.

The second cost, $e_j f_j$ is a binary variable (e) representing whether warehouse j is used as a sourcing location multiplied by the setup cost (f) at the sourcing warehouse j. In other words, it is the fixed labor cost required to setup the receiving end of an intra-shed transfer.

The third cost, $g_k h_k$, is a binary variable (g) representing whether warehouse k is used as a consolidation location multiplied by the setup cost (h) at the consolidation warehouse k. In other words, it is the fixed setup cost to setup the shipping end of an intra-shed transfer.

The fourth cost, $l_{ijk}m_{ijk}$, is the cost (l) to move one box of SKU i from location j to location k using a truck multiplied by the total number of trucks (m) used to move SKU i from location j to location k. In other words, it is the variable cost to move one box of FG inventory using a truck.

The fifth cost, $n_{ijk}o_{ijk}$, is the cost (n) to move one box of SKU i from location j to location k using a trailer multiplied by the total number of trailers (o) used to move SKU i from location j to location k. In other words, it is the variable cost to move one box of FG inventory using a trailer.

All of the costs above are cash costs with the exception of $c_i\, d_{ijk}$. This group of variables represents the theoretical non-cash cost associated with lost revenue due to the deterioration of fruit. Even though it is not a cash cost, the deterioration of fruit needs to be accounted for by sales managers to make an optimal decision. Subtracting $c_i\, d_{ijk}$ from the number of boxes being moved favors older fruit by giving it a lower cost. This cost is variable with respect to the number of boxes being shipped and is included in the first cost group where it is directly subtracted from the variable cost of moving one box from location j to location k, b_{ijk}.

4.2.3 CONSTRAINTS

The range of acceptable values for each variable must be included in the MILP. I include twelve constraints in this MILP, represented by equations 4.2-4.13, which can be written as the following facts:

The total quantity of boxes moved must equal the quantity demanded. *Eq. 4.2*

Quantity shipped from a shed cannot exceed inventories at that shed. *Eq. 4.3*

If any boxes are shipped from a warehouse, a fixed setup cost is included. *Eq. 4.4*

If any boxes are received at a warehouse, a fixed setup cost is included. *Eq. 4.5*

The number of consolidation locations must be less or equal to some fixed number determined by the customer. *Eq. 4.6*

The number of trucks used cannot exceed the number of trucks available. *Eq. 4.7*

The number of trailers used cannot exceed the number of trailers available. *Eq. 4.8*

The combined capacity of trucks and trailers used must be enough to ship the required number of boxes. *Eq. 4.9*

B, c, f, h, m, and o are continuous variables. *Eq.4.10*

E and g are binary variables. *Eq. 4.11*

A, d, i, j, k, l, n, q, r, s, and t are integer variables. *Eq.4.12*

None of the variables can be less than zero. *Eq. 4.13*

Complete Mathematical Formulation

Minimize	$\sum a_{ijk}\left(b_{ijk} - c_i\, d_{ijk}\right) + e_j f_j + g_k h_k + l_{ijk} m_{ijk} + n_{ijk} o_{ijk}$	*Eq. 4.1*
Subject to:	$\sum\sum a_{ijk} = q_i$	*Eq. 4.2*
	$\sum a_{ijk} \leq r_{ij\ for\ all\ j}$	*Eq. 4.3*
	$\sum a_{ijk} - p_1 e_j \leq 0_{for\ all\ j}$	*Eq. 4.4*
	$\sum a_{ijk} - p_2 y_{ik} \leq 0_{for\ all\ k}$	*Eq. 4.5*
	$\sum g_k \leq 1$	*Eq. 4.6*
	$\sum l_{ijk} \leq s_{ijk\ for\ all\ j}$	*Eq. 4.7*
	$\sum n_{ijk} \leq t_{ijk\ for\ all\ j}$	*Eq. 4.8*
	$\sum a_{ijk} - p_3 l_{ijk} - p_4 n_{ijk} \leq 0_{for\ all\ j}$	*Eq. 4.9*
	$b, c, f, h, m, o = continuous$	*Eq. 4.10*
	$e, g = binary$	*Eq. 4.11*
	$a, d, i, j, k, l, n, q, r, s, t = integer$	*Eq. 4.12*
	$Where\ a\ through\ z\ \geq 0$	*Eq. 4.13*

4.3 RESULTS: HOW MUCH DO FIRMS SPENT PER BOX ON INTRA-SHED TRANSFER?

"We have a dedicated truck that works every day, all day, specifically for the purpose of moving FG boxes of fruit back and forth between sheds to meet customer orders."

- Packing Shed Manager, Mid-size Firm

All firms have different network setups, supplier contracts, and inventory policies, so spending on intra-shed transfer will differ; however, the firm-specific amount spent per box on intra-shed transfer can be estimated using historical inventory records, as well as anecdotal interviews with sales managers.

Twenty six inputs are necessary to produce a cost estimate for an intra-shed transfer. Some of these inputs are facts unique to the firm implementing the model, such as distance between warehouses or the current inventory levels on-hand, and some, such as diesel fuel prices and hourly labor rated, can be measured precisely. Other assumptions have higher variability and are more difficult to measure, such as the rate of fruit deterioration (dollars per box per day) and labor efficiency rates (boxes per hour); in these cases a range of estimates from industry experts is used.

4.3.1 Cost Estimate Produced by MILP, Using inputs from Historical Sales Records

A complete list of the MILP output is provided in Appendix C. Some of my initial inputs include: diesel price of $2.25 per gallon, one consolidation point required, labor cost of $8.50 per hour, truck capacity of 1,000 boxes, trailer capacity of 250 boxes, fuel economy rate of 8 miles per gallon, and a deterioration rate $0.04 per box per day, as found in Chapter 3. To get an estimate of how many boxes are moved on average per day, I used average numbers from the dataset of historical sales and inventory transactions are used. Over a period of 245 days in 2008-09, [Firm name removed] sold 7,320,986 boxes; of these, 373,319, or 5.1%, needed to be consolidated through an intra-shed movement. According to the transaction log, 9,009 entries out of 137,174 entries, or 6.6%, were intra-shed transfer requests. On a per day basis, 37 intra-shed transfer requests were placed and 1,524 boxes were moved each day.

In the first iteration, I assume that a firm waits until the end of each day to make a consolidated intra-shed transfer decision; therefore 1,524, the average number of boxes moved based on historical records of the firm, was used as the number of boxes ordered; this results in a cost of $601.58 per movement. When this cost is allocated to 1,524 boxes, the cost of intra-shed transfer is $0.40 per box. This figure is a minimum estimate, however, because firms are unlikely to wait until the end of the day to consolidate intra-shed transfer requests.

In reality, firms conduct intra-shed transfers throughout the day. One industry packing manager explained his firm's policy of using one dedicated transfer truck to "work every day, all day, specifically for the purpose of moving FG boxes of fruit back and forth between sheds." He said that at the beginning of each day the truck was generally full, though by the end of the day it would be moving very small loads to fill last minute transfer requests.

Recalculating the cost of intra-shed transfer based on this scenario – given the same inputs as before, but using a conservative assumption that three intra-shed transfer are conducted each day – firms will spend $1203.16 per day, or $0.79 per box moved, an estimate that falls within the estimated range of an industry expert.

4.3.2 Cost Estimate of Intra-shed Transfer Based on Anecdotal Estimates

An executive of a large sales organization [name removed] estimated that 5% of all boxes sold undergo intra-shed transfer, and that it costs $0.50 to $1.00 to move each box. These numbers are consistent with the observed rate of 5.1% and the estimate of $0.79 per box produced by the MILP. Given the range of $0.50 to $1.00 per box, the interesting question is: how much savings could be realized by consistently using the MILP as a decision making tool?

In practice, the amount of realized savings will largely depend on how close the current decisions made by sales managers are to optimal. The only way to make this determination is to use the MILP in a real-time environment and compare its suggested decisions with the actual decisions made by sales managers. This would be impractical due to the fast paced nature of a sales desk; furthermore, as soon as decisions differed, variables such as inventory levels would change and thus future decisions would no longer be comparable unless the computer reset its inputs.

The most important observation from the results of the MILP is that the biggest potential driver of cost savings may not be route optimization, but a firm's truck dispatching policy. A majority of the intra-shed transfer costs are fixed setup and consolidation costs and variable fuel costs; thus a policy that minimizes the number of intra-shed transfers is likely to provide near optimal results, even if the sourcing and consolidation location are chosen on gut instinct instead of using the MILP. If such a policy could reduce intra-shed transfer costs by 20%, a firm would save $0.10 to $0.20 per box moved. Since about 5% of all boxes are moved, the potential savings when allocated across all boxes sold are $0.02 to $0.04 per box. With typical profit margins in the range of $0.50 to $1.00 per box, reducing the cost for all boxes sold by $0.0 to $0.04 would increase profit margins by 2% to 8%. While 2% to 8% is not a game-changing cost reduction, it is very typical of an operational level, "continuous improvement" type project.

4.3.3 Frequency and Cost of Inter-shed Purchases

During the same 245 day time period analyzed, [Firm name removed] purchased 116,927 boxes from external organizations, equaling 1.2% of the total volume sold, at an average price of $25.80. Assuming that the SKU profile purchased from external organizations is similar to the SKU profile a firm normally produces, $25.80 includes an 8% premium over the average selling price of $23.93. This confirms the intuition that a firm pays a premium when it runs out of FG inventory and needs to purchase them from a competitor.

Based on the dataset of inventory transactions, sales managers faced the *move, buy, make, or cancel* decision 5% to 10% of the time. They choose to *move* inventory, via intra-shed transfer, four times as often as they choose to *buy* inventory from another firm, the figures being 5.1% and 1.2%, respectively. Estimates from the MILP, industry experts and historical data confirm that intra-shed transfers are, on average, cheaper than inter-shed purchases. I do not explore the costs of emergency production runs and order cancellations in this analysis, but based on the same logic they are likely to be even higher than inter-shed purchases costs given their lower frequency. Further study should be done to quantify these two costs in order to build a complete comparative cost model for sales managers to use when making sourcing decisions.

4.4 Implementing A MILP Into the Decision Making Process

In order for a sales organization to use a MILP as a decision making tool, they must integrate it into their information technology (IT) system and then educate sales managers about how to use the tool to supplement their current decisions. Assuming that a company-wide network exists, the integration phase consists of installing the program onto an administrator's profile and providing all sales managers with read-only access, and then linking certain variables in the program to the firm's inventory database. A recommended training plan would include sales managers making their sourcing decision as they have always done, and then running the model to compare results; although the MILP provides a mathematically optimal solution, a sales manager could always override the decision if they had information they felt was not reflected in the computer model.

After completion of the IT integration and training program, when a sales manager receives an order that cannot be filled from a single warehouse, he or she can simply open the program, enter four variables, and run the model. In seconds, the program will provide an optimized solution, including the SKU and number of boxes moved, the sourcing warehouse, the consolidation warehouse, the mode of transportation, and the total cost of the intra-shed transfer.

From an interface perspective, it is critical to make the tool as user friendly as possible. One way of doing this is to divide it into three parts: (1) the Sales Organization Interface, which is the only screen sales managers will use; (2) the Variable Input Page, which is linked to the inventory database, and (3) the actual MILP, which pulls data from both the Sales Organization Interface and the Variable Input Page. After receiving an order, the manager enters the SKU ordered, the maximum pickup locations allowed, the total number of boxes ordered, and the current price of diesel into the Sales Organization Interface shown in Figure 4.2.

Sales Organization Interface	
Stock Keeping Unit (i.e. P.ORO.WFC.042.X2AL.CP.K.X.X.X.83916)	P.ORA.WFC.042.X2AL.CP.K.X.X.X.83916
Total Boxes Ordered (i.e. 30 or 131 or 1070)	399
Maximum Pickup Locations Allowed (i.e. 1 or 2 or 3)	1
Diesel Price ($/gallon) (i.e. 2.14)	2.25
Total Cost of this Transfer (don't enter anything here, cost will be entered for you)	

Click Here When Done

TABLE 4.2 SALES ORGANIZATION INTERFACE *BEFORE* THE MODEL IS RUN

When the sales manager clicks the 'Click Here When Done' button, the inputs will be sent to the actual page containing the MILP, which simultaneously pulls data from the Variable Input Page, which contains the bulk of the direct and indirect variables used in the model. The Variable Input Page is linked to the firm's internal database, from which it pulls current on-hand inventory at each warehouse by SKU, the average age of on-hand inventory at each warehouse by SKU, and the number of trucks and trailers available at each warehouse. It includes variables that are fixed, such as distance in miles between each warehouse, as well as some variables that may need to be periodically updated, such as the hourly wage rate, or the fuel efficiency of the firm's trucks or trailers; thus this screen needs to be accessible by an administrator but not the end user. Again, no end-user would ever see the screen below; the variables are updated through a database link and passed through to the actual MILP.

INTERMEDIATE TAB

Warehouse Number	Warehouse 1	Warehouse 2	Warehouse 3	Warehouse 4	Warehouse 5	Warehouse 6	Warehouse 7	Warehouse 8	Units
SKU Inventory	846	909	1,099	520	233	702	649	599	box
SKU Age	20.4	24.6	15.4	16.9	27.2	29.5	21.5	17.8	day
Truck Inventory	4	3	3	5	6	4	7	3	truck
Trailer Inventory	4	3	3	2	9	8	3	2	trailer

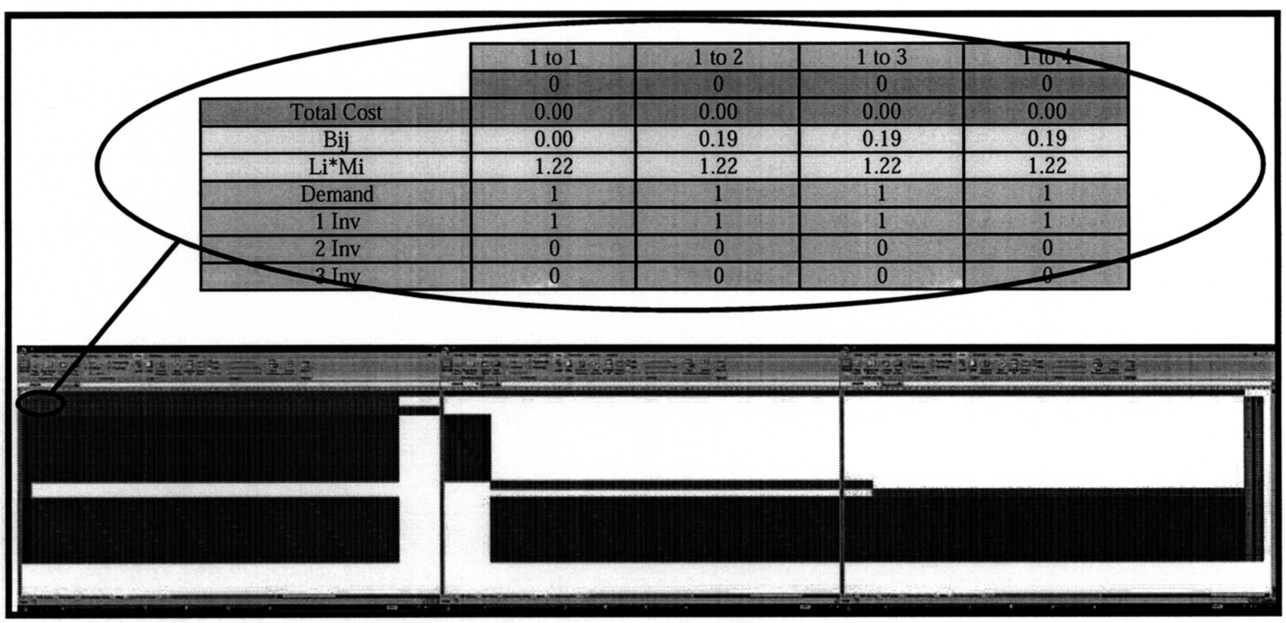
Mileage table	Warehouse 1	Warehouse 2	Warehouse 3	Warehouse 4	Warehouse 5	Warehouse 6	Warehouse 7	Warehouse 8	Units
Warehouse 1	0	45	18	12	15	11	14	13	mile
Warehouse 2	45	0	9	18	14	19	21	27	mile
Warehouse 3	18	9	0	18	14	60	9	11	mile
Warehouse 4	12	18	18	0	12	10	17	50	mile
Warehouse 5	15	14	14	12	0	17	19	6	mile
Warehouse 6	11	19	60	10	17	0	24	18	mile
Warehouse 7	14	21	9	17	19	24	0	7	mile
Warehouse 8	13	27	11	50	6	18	7	0	mile

Labor	9.50	$/hour
Truck Fuel Economy	5.00	MPG
Trailer Fuel Economy	10.00	MPG
Truck Capacity	1,000.00	box
Trailer Capacity	250.00	box
Boxes Loaded	50.00	box/hour
Decay Factor	0.06	$/day/box

TABLE 4.3 VARIABLE INPUT PAGE- THIS IS LINKED TO AN INVENTORY DATABASE

When the sales manager clicks the 'Click Here When Done' button, the MILP pulls data from the Sales Organization Interface and the Variable Input Page and begins to solve the problem. The MILP is not seen by the user or administrator because it never needs to be changed. Figure 4.1 shows three screen shots of the entire program in Microsoft Excel, measuring 170 rows x 186 columns, as well as a small magnified portion provided to show the relative size of the program. In total, the MILP includes 208 adjustable variables, 162 constraints, 192 integers/binaries, and 1271 coefficients; the general settings include a delta coefficient of 0.000001 and a big M coefficient of 100000.

FIGURE 4.1 THREE SCREENSHOTS OF THE MILP IN EXCEL, WITH A MAGNIFIED PORTION



Seconds later, when the MILP has reached an optimal solution, the sales manager will receive a set of sourcing instructions in the Sales Organization Interface, including the total cost of the transfer, the source(s) and consolidation location of FG inventory, and the mode for each leg of transfer. Table 4.4 shows an example of what the Sales Organization Interface looks like after the MILP has provided a solution; all updated data is highlighted in bold. Based on this example, the sales manager knows the optimal sourcing decision and can make the *move* or *buy* decision: if he or she can purchase 399 boxes and have them delivered to Silverstone for less than $604.05, it would be cheaper than the optimal intra-shed transfer.

Sales Organization Interface	
Stock Keeping Unit (i.e. P.ORO.WFC.042.X2AL.CP.K.X.X.X.83916)	P.ORA.WFC.042.X2AL.CP.K.X.X.X.83916
Total Boxes Ordered (i.e. 30 or 131 or 1070)	399
Maximum Pickup Locations Allowed (i.e. 1 or 2 or 3)	1
Diesel Price ($/gallon) (i.e. 2.14)	2.25
Total Cost of this Transfer (don't enter anything here, cost will be entered for you)	**$604.05**

Click Here When Done

Instructions	
	Move **250** boxes from **Apple-House** to **Silverstone** using **1** trailer.
	Move **29** boxes from **Greenlake** to **Silverstone** using **1** trailer.
	Silverstone has **120** boxes of inventory on-hand.
	The retailer pickup location is **Silverstone.**

TABLE 4.4 SALES ORGANIZATION INTERFACE *AFTER* THE MODEL IS RUN

5 SUMMARY AND CONCLUSIONS

The biggest challenge in the tree fruit industry is for packing managers, who have low visibility of raw material inventory at the SKU level, to match their production of finished goods inventory to demand. In terms of production, although packing managers take samples from each unsorted bin in order to estimate the volume by SKU, the actual profile remains unknown until packing. At the same time, although sales managers study market research reports and consumer demand, order volumes by SKU are not known until each order is placed. The presence of uncertainty with respect to both supply and demand makes it difficult to eliminate on-hand inventory; this, in turn, results in lost revenue caused by price markdowns and reduced volume levels from inventory shrinkage. As a result of these inefficiencies, the Washington State tree fruit industry loses 5% to 12% of its potential revenue each year. The industry also suffers from inefficient sourcing decisions and higher transportation costs during stock-out events. These inefficiencies persist because few firms in the tree fruit supply chain have the incentive to assume the financial burden and increased risk associated with pursuing more efficient strategies.

Yet the costs associated with inefficient supply chain decisions persist and merit the industry's attention. Firms in the industry must design their supply chains to match their strategic visions and construct compensation schemes that incentivize strategically consistent managerial decisions. The optimal supply chain for each firm will be unique, of course, depending on its organizational structure, product selection, customer base, and core competencies. As a result, some of these recommendations will fit some firms and not others; they can be used individually or in combination as inventory management initiatives.

5.1 OPERATIONAL RECOMMENDATIONS TO IMPROVE INVENTORY INEFFICIENCIES

Invest in a pre-sizing line to reduce inventory shrinkage of FG inventory.

Pre-sizing fruit can improve visibility of RM on-hand inventory at the SKU level, thus enabling packing managers and sales managers to establish an integrated production and sales plan. Firms should conduct a cost-benefit calculation of reducing on-hand inventory levels to determine the amount of inventory cost that a pre-sizing line could save. For example, if a packing operation that produces 1 million FG boxes per year reduces the average level of on-hand inventory by one day, it could save $1{,}000{,}000\ boxes * \$0.04\ decay\ per\ day = \$40{,}000$. If the savings that stand to be gained are significant, firms should conduct a more detailed net present value (NPV) analysis on the investment of a pre-size packaging line using a weighted adjusted price curve based on the relative percentage of varieties packed.

Implement network optimization software to minimize transportation costs of intra-shed transportation.

Firms spend $0.50 to $1.00 per box on intra-shed transfers. Although this is a relatively small operational cost, it can be easily reduced with inexpensive software that is commercially available. Factors such as age and condition of fruit which managers do not always take into consideration can be easily factored into sourcing decisions. These results can be used to make efficient, *move, buy, make, or cancel* decisions in the event of a stock-out. This type of software can also be used to optimize the distribution of empty bins to growers before harvest each fall.

Reduce the number of SKUs offered.

Firms cannot be everything to everyone; sometimes it makes sense to say "no" to the customer, especially with respect to SKU's that are not profitable. Firms should calculate the profitability of each SKU and customer, and identify avoidable costs of these product offerings, such as direct materials and costs associated with inventory shrinkage. They should consider sourcing low-volume SKUs from external organizations or removing them from their product offerings altogether. At a broader industry level, key organizations in the industry should analyze the costs and benefits associated with the increasing number of SKUs offered in the industry to determine inefficient sources of complexity.

Shape Demand Through Pricing

Sales managers should use an adjusted price expectation curve as a tool to determine pricing according to the age of inventory, which will allow them to shape demand in order to minimize repacking and rejection costs. This curve should take into account the expected costs of repacking and rejections, as well as the quality condition of each lot, or pile, of FG inventory. Currently, sales managers alternately over-value and under-value fruit by failing to take these costs into account.

Establish long term relationships with retailers through IT integration or VMI.

The key to reducing variability in demand is establishing visibility downstream to the consumer level. Sales firms should conduct a pilot VMI program with a regional retailer to see whether they can maintain high customer service levels while reducing their own on-hand FG inventory. Standing re-order points, long term contracts, or VMI relationships increase the changeover cost for retailers, which make long term, stable relationships more likely.

Change how sales commissions are calculated.

Sales managers should be paid a commission based on the adjusted price curve, which includes costs of repack and rejections, rather than the actual price received. Packing managers should be paid a commission based on the adjusted price curve minus the costs of intra-shed transportation. These compensation schemes will force mangers to internalize the true costs of their behavior and will give them an incentive to find new ways to efficiently manage inventory.

Establish an alternative sales channel using an e-commerce platform.

Real-time on-hand inventory levels that currently exist in internal databases can be published online by packing or sales organizations. This will improve the visibility and accuracy that sales managers have of inventory levels as they make marketing and pricing decisions. It will also provide a faster means of matching potential customers with current on-hand inventory, which will, in turn, increase the inventory turn rate and reduce inventory inefficiencies. Establishing an e-Commerce platform has the potential to be a paradigm shift in the tree fruit industry; sales organizations would fight against such a platform because it would allow each packing organizations to (re)integrate into the sales area.

Develop an emergency sales channel to provide an outlet for deteriorating FG inventory.

Firms should choose a retailer with whom a VMI relationship has been established who will also regularly accept off-sizes and grades of FG inventory that is hard to move. Alternately, if there was industry-wide participation to commit 1 million boxes per month to a charitable cause such as the World Food Programme or the US Armed Forces, deteriorating inventory could be moved, firms would get a tax benefit, and prices would increase because of the reduction in overall domestic supply.

5.2 AREAS OF FURTHER RESEARCH

The Washington State tree fruit industry must continually find new ways to improve its value proposition to compete with both foreign and domestic competition. Growers must continually find ways to reduce labor and chemical costs and increase their crop yield per acre. Packers must continually improve their operations, not only via inventory management, but in procurement of direct materials, reducing labor costs, and hastening technological adoption. Sales organizations must continually work with retailers to understand consumer tastes and communicate with industry insiders to create new products, thereby keeping the industry aligned with consumer tastes. Key public and private organizations must stay abreast of political opportunities and challenges related to international import and export regulations, labor rules, and potential federal funds available to promote the Washington State and domestic tree fruit industry. Research is an essential component of each of these areas of improvement. Should further research be done on the topics covered in this thesis, I would suggest the following subject areas:

Chapter 3 provides estimates of the cost of intra-shed transfers and inter-shed purchases, but not the cost of an emergency production run or order cancellation. Further study should be done to calculate the costs of emergency production runs and lost sales due to stock-outs and poor customer service. Cost estimates in these areas will allow sales managers to make even more efficient sourcing decisions than those possible with the optimization model constructed in this thesis. Techniques to quantify these costs can be found in Inventory Management, Production Planning and Scheduling (Silver 1998). This thesis also omits a discussion of the direct materials cost of packaging and storage material, which make up a significant operating cost for packing sheds. A study could be done to determine whether on-hand inventory levels or availability of packaging material drive production cycles and whether strategic sourcing could reduce procurement costs.

Another area of future research presents itself in Chapter 4, which uses estimates of the likelihood of repacking based on the age of FG inventory. In practice, the relationship is a dynamic one that is determined by fruit variety, growing region, and storage conditions, among other things. Further research is needed to establish a relationship between other measurable physiological factors such as brix (percentage), firmness (pounds), and titra-table acid levels (percentage), and the likelihood of repack. The results could be incorporated into a database that calculates expected adjusted prices based not only on the SKU, but the particular physiological condition of fruit by lot or shed number.

Also, managers coordinating outbound logistics should analyze rail options and be prepared with a transition plan to move capacity away from traditional 3PL carriers towards rail in the event of dramatic changes in diesel prices. Research should be done to estimate the fuel price at which the transition from truck to rail should start to take place and to estimate the costs associated with switching modes.

Further research should also be done on the likely behavior of consumers and retailers in the event of a food-borne illnesses associated with fresh fruit products from Washington State. With the proliferation of PLUs and barcodes, and the ever shrinking size of RFID tags, traceability of individual pieces of fruit is becoming less costly. Consumers will continue to put pressure on legislators to hold firms accountable for visibility and food safety at every step of the food supply cahin. When individual pieces of fruit can be traced from an orchard block to the checkout stand, the tree fruit industry will face a potential paradigmatic change in determining how the risks associated with holding inventory are distributed throughout the supply chain and how firms will be compensated. Packing and sales organizations will reward higher quality growers with returns based on that particular growers fruit, as opposed to the returns of respective grower 'pools.' Retailers will have more visibility on age and condition of fruit, and liability will be pushed further upstream in the tree fruit supply chain.

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Appendix A: Apple Model Regression Results

Number of Observations (n) 615,612

Model Summary

Model	R			
	COMMODITY = A	R Square	Adjusted R Square	Std. Error of the Estimate
1	.832[a]	.692	.692	4.47053

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.202E7	97	226980.895	11357.190	.000[a]
	Residual	9815654.956	491135	19.986		
	Total	3.183E7	491232			

Coefficients[a,b]

Model	Unstandardized Coefficients		Standard Coefficient			95.0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound

1	(Constant)	17.742	.039		450.347	.000	17.665	17.819
	FRUITAGE	-.044	.000	-.089	-107.082	.000	-.045	-.043
	SHIPMENTSIZE	-.004	.000	-.024	-29.247	.000	-.005	-.004
	Destination_	-1.500	.019	-.067	-78.348	.000	-1.538	-1.463
	CUSTOMER_1	-.052	.019	-.003	-2.800	.005	-.089	-.016
	CUSTOMER_2	1.203	.015	.070	79.829	.000	1.173	1.232
	Q1	-.080	.020	-.005	-4.090	.000	-.118	-.042
	Q2	.831	.020	.042	40.572	.000	.791	.871
	Q3	2.643	.022	.118	122.745	.000	2.601	2.685
	@2006	2.060	.035	.095	59.174	.000	1.991	2.128
	@2007	2.687	.029	.167	93.994	.000	2.631	2.743
	@2008	4.282	.029	.243	146.548	.000	4.225	4.339
	NSSMALL	-5.047	.018	-.287	-287.847	.000	-5.082	-5.013
	NSLARGE	2.380	.016	.140	144.286	.000	2.347	2.412
	NSXL	2.513	.029	.076	86.101	.000	2.455	2.570
	NSSPEC	10.593	.690	.038	15.341	.000	9.240	11.946
	GRADE_WXB	-2.644	.022	-.105	-120.228	.000	-2.687	-2.601
	GRADE_WXP	.792	.029	.028	27.672	.000	.736	.848
	GRADE_UXF	-6.301	.031	-.175	-204.864	.000	-6.361	-6.241
	GRADE_WRS	-1.027	.046	-.018	-22.313	.000	-1.117	-.937

GRADE_WFC	-6.190	.049	-.104	-126.991	.000	-6.286	-6.095
GRADE_US1	-7.735	.062	-.102	-124.270	.000	-7.857	-7.613
GRADE_FCY	-10.478	.248	-.095	-42.180	.000	-10.965	-9.991
GRADE_EF1	-5.119	.255	-.037	-20.046	.000	-5.620	-4.619
GRADE_GIF1	17.338	1.753	.104	9.890	.000	13.902	20.774
GRADE_WNC	-.052	.138	.000	-.374	.709	-.323	.219
GRADE_WRR	.129	.292	.001	.442	.659	-.443	.701
GRADE_GIF2	17.351	1.760	.067	9.860	.000	13.902	20.800
GRADE_WXR	-2.024	.247	-.007	-8.188	.000	-2.509	-1.540
GRADE_WX2	-2.574	.329	-.006	-7.828	.000	-3.218	-1.929
GRADE_PRE	-5.408	.366	-.014	-14.787	.000	-6.124	-4.691
GRADE_CXF	2.934	.502	.005	5.839	.000	1.949	3.919
GRADE_GIF	16.772	2.738	.022	6.126	.000	11.406	22.138
GRADE_CAT1	2.482	.934	.002	2.658	.008	.652	4.313
GRADE_USF	-2.336	1.119	-.002	-2.088	.037	-4.528	-.143
GRADE_UXF1	-6.698	2.235	-.002	-2.996	.003	-11.080	-2.317
VARIETY_AMB	14.957	.894	.013	16.722	.000	13.204	16.710
VARIETY_AUR	5.918	.817	.006	7.247	.000	4.318	7.519
VARIETY_BFU	-1.183	1.057	.000	-1.119	.263	-3.255	.888
VARIETY_BRA	-1.085	.037	-.028	-29.457	.000	-1.157	-1.012

VARIETY_CAM	-.637	.047	-.012	-13.478	.000	-.730	-.544
VARIETY_CBR	4.507	.371	.013	12.138	.000	3.779	5.234
VARIETY_CCM	10.488	.478	.021	21.920	.000	9.551	11.426
VARIETY_CFU	10.217	.343	.035	29.752	.000	9.544	10.890
VARIETY_CPK	7.593	.056	.116	135.743	.000	7.483	7.702
VARIETY_CRD	10.398	1.030	.008	10.095	.000	8.379	12.417
VARIETY_FUJ	4.496	.026	.160	169.997	.000	4.445	4.548
VARIETY_GAL	3.363	.024	.146	142.937	.000	3.317	3.409
VARIETY_GOL	4.892	.024	.220	207.385	.000	4.846	4.938
VARIETY_GRA	2.133	.024	.087	87.449	.000	2.086	2.181
VARIETY_GRP	23.980	.741	.074	32.353	.000	22.527	25.433
VARIETY_GSM	6.479	.278	.036	23.297	.000	5.934	7.024
VARIETY_GSU	4.181	.168	.020	24.838	.000	3.851	4.511
VARIETY_HON	28.102	.097	.235	289.444	.000	27.912	28.293
VARIETY_JGO	.486	.066	.006	7.419	.000	.358	.615
VARIETY_JON	14.964	.675	.018	22.168	.000	13.641	16.287
VARIETY_MXO	-6.501	1.748	-.045	-3.719	.000	-9.927	-3.075
VARIETY_MXP	21.668	2.889	.027	7.500	.000	16.005	27.330
VARIETY_NFU	12.478	1.146	.009	10.884	.000	10.231	14.725
VARIETY_NGR	8.182	.898	.008	9.116	.000	6.423	9.941

VARIETY_NOB	21.756	1.057	.017	20.584	.000	19.685	23.828
VARIETY_NOF	20.145	.743	.023	27.099	.000	18.688	21.602
VARIETY_NOG	22.479	.492	.042	45.686	.000	21.515	23.443
VARIETY_NOO	9.280	2.594	.003	3.578	.000	4.196	14.363
VARIETY_NOP	27.537	1.316	.017	20.931	.000	24.958	30.115
VARIETY_NOS	22.764	1.512	.012	15.056	.000	19.801	25.728
VARIETY_NRG	8.444	3.171	.002	2.662	.008	2.228	14.660
VARIETY_NRO	9.499	1.843	.004	5.155	.000	5.887	13.112
VARIETY_OAC	31.687	1.182	.022	26.803	.000	29.370	34.004
VARIETY_OAM	23.058	.175	.112	131.892	.000	22.715	23.400
VARIETY_OBR	10.510	.077	.114	135.842	.000	10.359	10.662
VARIETY_OCA	10.489	.121	.071	86.962	.000	10.252	10.725
VARIETY_OCP	16.736	.099	.136	168.321	.000	16.541	16.930
VARIETY_OFU	15.455	.056	.228	275.638	.000	15.345	15.565
VARIETY_OGA	14.056	.041	.297	346.480	.000	13.976	14.135
VARIETY_OGG	11.159	.221	.040	50.473	.000	10.726	11.592
VARIETY_OGO	13.072	.038	.300	345.837	.000	12.998	13.146
VARIETY_OGR	12.122	.047	.216	256.961	.000	12.030	12.215
VARIETY_OGS	14.341	.535	.021	26.803	.000	13.293	15.390
VARIETY_OHC	43.184	.109	.322	395.149	.000	42.970	43.398

VARIETY_OJG	6.907	.198	.028	34.899	.000	6.519	7.295
VARIETY_OMO	-3.437	1.827	-.005	-1.882	.060	-7.018	.143
VARIETY_OPI	18.397	.114	.130	160.772	.000	18.172	18.621
VARIETY_OPL	15.821	.084	.155	188.747	.000	15.657	15.986
VARIETY_OR1	13.970	.682	.016	20.480	.000	12.633	15.307
VARIETY_ORE	6.235	.043	.123	144.936	.000	6.151	6.319
VARIETY_ORO	4.240	.515	.008	8.240	.000	3.231	5.249
VARIETY_PAR	24.594	.325	.061	75.779	.000	23.958	25.231
VARIETY_PKL	7.786	.051	.133	152.344	.000	7.686	7.886
VARIETY_PNT	16.564	.084	.160	196.113	.000	16.399	16.730
VARIETY_RGA	7.523	.255	.061	29.539	.000	7.024	8.022
VARIETY_RGO	1.022	3.161	.000	.323	.747	-5.174	7.218
VARIETY_ROM	-1.419	.235	-.008	-6.049	.000	-1.879	-.959
VARIETY_ROS	13.319	.791	.013	16.844	.000	11.769	14.868
VARIETY_SEK	21.321	1.464	.013	14.567	.000	18.452	24.190
VARIETY_SNY	19.606	4.471	.003	4.385	.000	10.843	28.368
VARIETY_THC	28.383	.566	.040	50.144	.000	27.274	29.493
VARIETY_WIN	14.242	4.471	.003	3.186	.001	5.480	23.004

Appendix B: Pear Model Regression Results

Number of Observations (n) 615,612

Model Summary

Model	R			
	COMMODITY = P	R Square	Adjusted R Square	Std. Error of the Estimate
1	.875[a]	.766	.766	4.62059

ANOVA[b,c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5992651.116	63	95121.446	4455.365	.000[a]
	Residual	1829128.527	85674	21.350		
	Total	7821779.643	85737			

Coefficients[a,b]

Model	Unstandardized Coefficients		Standard Coefficient			95.0% Confidence Interval for B	
	B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound

1	(Constant)	21.051	.091		231.808	.000	20.873	21.229
	FRUITAGE	-.008	.001	-.023	-12.226	.000	-.010	-.007
	SHIPMENTSIZE	-.004	.000	-.024	-14.137	.000	-.005	-.004
	Destination_	-1.514	.041	-.072	-36.959	.000	-1.594	-1.434
	CUSTOMER_1	.938	.055	.035	17.112	.000	.831	1.046
	CUSTOMER_2	1.201	.042	.055	28.923	.000	1.120	1.282
	Q1	.100	.047	.005	2.141	.032	.008	.191
	Q2	-.306	.087	-.006	-3.507	.000	-.477	-.135
	Q3	1.480	.058	.049	25.568	.000	1.366	1.593
	@2006	2.625	.084	.115	31.414	.000	2.461	2.789
	@2007	1.845	.073	.092	25.336	.000	1.702	1.987
	@2008	2.011	.071	.100	28.129	.000	1.871	2.151
	NSSMALL	-5.847	.063	-.178	-92.174	.000	-5.971	-5.722
	NSLARGE	2.169	.042	.104	51.432	.000	2.086	2.251
	NSXL	5.485	.049	.253	111.033	.000	5.388	5.582
	NSSPEC	12.089	.153	.204	78.832	.000	11.789	12.390
	GRADE_WFC	-6.404	.050	-.245	-127.666	.000	-6.503	-6.306
	GRADE_BOS	-1.005	.175	-.016	-5.730	.000	-1.349	-.661
	GRADE_RBO	.267	.196	.003	1.365	.172	-.117	.651
	GRADE_ORS	.935	.487	.011	1.918	.055	-.020	1.890

GRADE_3RD	-8.374	.155	-.094	-54.085	.000	-8.677	-8.070
GRADE_GRU	.249	.228	.002	1.092	.275	-.198	.697
GRADE_OBO	.114	.679	.000	.169	.866	-1.216	1.445
GRADE_OGB	5.705	.861	.013	6.625	.000	4.017	7.392
GRADE_US1A	-2.522	.775	-.005	-3.256	.001	-4.040	-1.004
GRADE_USC	4.333	1.888	.004	2.294	.022	.631	8.034
GRADE_WAC	-8.840	1.062	-.014	-8.325	.000	-10.921	-6.759
VARIETY_ADA	-2.667	1.036	-.004	-2.574	.010	-4.697	-.636
VARIETY_ARB	-1.725	1.035	-.003	-1.667	.096	-3.752	.303
VARIETY_ATB	8.409	2.669	.005	3.150	.002	3.177	13.640
VARIETY_AWL	-3.011	.256	-.020	-11.743	.000	-3.514	-2.509
VARIETY_BAR	-2.391	.052	-.100	-45.600	.000	-2.493	-2.288
VARIETY_BOS	-.420	.147	-.011	-2.864	.004	-.707	-.132
VARIETY_CBO	.215	.893	.000	.241	.810	-1.535	1.965
VARIETY_COM	11.123	.258	.073	43.162	.000	10.618	11.628
VARIETY_CON	2.554	.147	.030	17.421	.000	2.267	2.842
VARIETY_CPA	-8.597	.628	-.023	-13.693	.000	-9.828	-7.367
VARIETY_FBU	16.289	3.268	.008	4.984	.000	9.884	22.695
VARIETY_FOR	30.805	.783	.065	39.356	.000	29.271	32.339
VARIETY_MPR	2.191	.862	.004	2.543	.011	.502	3.879

VARIETY_MXP	.701	.987	.001	.711	.477	-1.233	2.636
VARIETY_OAP	-8.051	.786	-.017	-10.245	.000	-9.592	-6.511
VARIETY_OAW	11.035	1.090	.017	10.121	.000	8.898	13.172
VARIETY_OBA	13.907	.099	.254	140.880	.000	13.713	14.100
VARIETY_OBO	10.150	.468	.132	21.668	.000	9.232	11.068
VARIETY_OCM	21.894	1.283	.028	17.069	.000	19.380	24.408
VARIETY_OCN	14.698	.255	.097	57.663	.000	14.198	15.197
VARIETY_OCR	13.382	.194	.118	69.046	.000	13.002	13.762
VARIETY_ODA	12.684	.078	.291	163.469	.000	12.532	12.836
VARIETY_ORA	24.841	.208	.269	119.471	.000	24.433	25.248
VARIETY_ORB	8.779	.169	.089	51.958	.000	8.448	9.110
VARIETY_ORD	14.510	.142	.177	102.262	.000	14.232	14.788
VARIETY_ORS	13.763	.104	.229	132.322	.000	13.559	13.967
VARIETY_OSA	26.365	.387	.120	68.176	.000	25.607	27.123
VARIETY_PAC	1.233	.547	.004	2.256	.024	.162	2.305
VARIETY_PMX	.062	2.669	.000	.023	.982	-5.169	5.292
VARIETY_RAS	15.623	.254	.122	61.504	.000	15.125	16.120
VARIETY_RBA	.273	.106	.005	2.582	.010	.066	.481
VARIETY_RBO	-1.509	.066	-.041	-22.742	.000	-1.639	-1.379
VARIETY_RDA	1.608	.088	.032	18.240	.000	1.435	1.781

VARIETY_SAS	11.276	1.340	.014	8.414	.000	8.649	13.902
VARIETY_SEC	15.758	.167	.170	94.398	.000	15.431	16.085
VARIETY_STK	2.901	.213	.023	13.644	.000	2.484	3.317
VARIETY_TAY	7.831	.392	.033	19.951	.000	7.061	8.600

Excluded Variables[b]

Model						Collinearity Statistics
		Beta In	t	Sig.	Partial Correlation	Tolerance
1	GRADE_NGR	.[a]	.	.	.	.000
	GRADE_CAT1	.[a]	.	.	.	.000
	GRADE_GIF	.[a]	.	.	.	.000

Appendix C

What'sBest!® 9.0.3.3 (Sep 08, 2008) - Library 5.0.1.307 - Status Report -

DATE GENERATED: Apr 06, 2009 01:20 AM

MODEL INFORMATION:

CLASSIFICATION DATA	Current	Capacity Limits
Numerics	38543	
Variables	533	
Adjustables	208	8000
Constraints	162	4000
Integers/Binaries	192/16	800
Nonlinears	0	800
Coefficients	1271	

Minimum coefficient value: 1 on Final Values!D9
Minimum coefficient in formula: Final Values!D9
Maximum coefficient value: 1534 on <RHS>
Maximum coefficient in formula: MILP!HC9

MODEL TYPE: Mixed Integer / Linear

SOLUTION STATUS: GLOBALLY OPTIMAL

OBJECTIVE VALUE: 604.05

DIRECTION: Minimize

SOLVER TYPE: Branch-and-Bound

TRIES: 8155

INFEASIBILITY: 6.838973831691e-014

BEST OBJECTIVE BOUND: 604.05

STEPS: 28

ACTIVE: 0

SOLUTION TIME: 0 Hours 0 Minutes 1 Seconds

NON-DEFAULT SETTINGS:

General Options / Solver Feasibility Tolerance: 1.000000e-011

End of Report