Reducing Shrinkage and Stock-out Costs in the Washington State Tree Fruit Industry

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Summary: This project measured the costs associated with inventory shrinkage and stock-outs in the Washington State tree fruit industry using multivariate regression and optimization techniques. The author provides four qualitative solutions in the form of inventory management policies, and one quantitative solution in the form of a mixed-integer linear program.

KEY INSIGHTS

1. The Washington State tree fruit industry loses 5-12% of potential revenue due to costs associated with inventory shrinkage and 1% of revenue due to costs associated with stock-outs.

2. Managers are paid a sales commission based on the actual revenue received; they do not make efficient inventory management decisions because their compensation scheme does not take the costs of shrinkage and stock-outs into account.

Introduction

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. Historically, the most successful firms were the ones able to achieve low production costs and high sales volumes. Managers at these firms were accustomed to losing a certain percentage of fruit due to physical deterioration, as refrigeration technologies were less developed than they are today. Though technology has changed, the culture of focusing on production costs and sales volumes persists. While continuous improvements have been made in these areas, firms have only recently turned their attention to inventory management.

This project focused on measuring two inventory inefficiencies and finding ways, both qualitative and quantitative, to improve upon them.

1. Shrinkage: Fruit is sold at a discount or thrown away due to physical deterioration when firms have too much on-hand inventory.

2. Stock-outs: Firms incur transportation costs of filling stock-outs from an alternate location when they have too little on-hand inventory.

To determine which problem is more costly to the industry, I quantified their level of inefficiency in terms of lost revenue. Using multivariate regression and optimization techniques, I analyzed a dataset which included 5% of all sales transactions in Washington State from 2006-2009. I find that the industry loses 5-12% of potential revenue due to costs associated with inventory shrinkage and 1% of revenue due to costs associated with stock-outs.

High Levels of Inventory Lead to Shrinkage

Firms in the tree fruit industry maintain on-hand inventory for two reasons. First, fruit is not sorted by stock-keeping unit (SKU) when it is in raw material storage, so packing managers are forced to package a range of SKUs to meet a single order, even when there is no demand for many of those SKUs at the time of packing. Second, firms prefer to maintain a safety stock so they can respond to unforeseen demand; most orders are placed less than 24 hours in advance and production lead-time is 6-24 hours. When firms have high levels of on-hand inventory, they lose revenue in three ways.
(1) Sales managers begin to discount the price of inventory as it gets older because they know it is deteriorating.

(2) When several pieces of fruit in a box have deteriorated, the entire box must be resorted and repacked, a process which incurs labor and material costs, as well as lost volume.

(3) If boxes are shipped containing fruit that have already deteriorated, they will be rejected upon receipt by the retailer; involves a discounted price or costs of being repacked at a third party’s facility.

Thus, to identify the true relationship between the price of fruit and its age (in terms of days since packing), I calculated the expected sale revenue, cost of repack, and cost of rejection using a combination of multivariate regression, analysis of packing contracts, and interviews with industry experts. These three relationships are graphed in Figure 1 as a percentage of full revenue over the age of the fruit.

To calculate the true relationship between the price of fruit and its age, I subtracted the two expected costs from the expected revenue to get the “Adjusted Revenue Curve” shown in Figure 2.

Given the adjusted revenue as a function of age, I calculate the actual revenue that the industry receives by multiplying Figure 2 by the derivative of the curve in Figure 3, which is the “Cumulative Percentage of Boxes Sold” as a function of age. The result can be divided by the maximum amount of revenue the industry could receive, as if all fruit were sold at age 0, to determine what percentage of revenue the industry loses due to costs associated with shrinkage.

Based on this analysis, I find that the industry loses 5-12% of potential revenue due to the costs associated with aging inventory. Firms can improve this inefficiency in four ways:

1. Improve visibility of production by pre-sizing fruit or reducing the number of SKUs offered.

2. Improve visibility of demand by using point-of-sales (POS) data to improve forecasting and establishing vendor-managed inventory (VMI) relationships to reduce demand variability.

3. Improve visibility of on-hand inventory to potential buyers by setting up an e-Commerce platform and posting on-hand inventory by SKU.

4. Shape customer demand through pricing, which should be done based on the Adjusted Revenue curve developed in Figure 2.
Low Levels of Inventory Lead to Stock-outs

Most sales organizations sell fruit on behalf of multiple packing sheds spread throughout Washington State. When a retailer places an order for a SKU that is not in stock at one of these warehouses, the sales manager has four ways to solve the problem: 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. In reality, sales managers never cancel orders because they are paid on commission, and packing managers refuse to conduct emergency production cycles because they are paid on packing line efficiency. Thus, sales managers essentially have only two choices: whether to consolidate fruit within their network of warehouses or buy it from an outside firm. To make this move or buy decision, sales managers need a tool to quickly calculate the costs of each option in a dynamic environment.

The cost of buying inventory from an external firm can be easily found by picking up the phone and getting a price quote. The cost of moving inventory through an intra-shed transfer is more difficult to calculate, and includes a labor cost, a fuel cost, and an inventory cost. The variables that affect these costs are constantly changing; thus, the best way to quickly find the cost of an intra-shed transfer is by using a mixed integer linear program (MILP).

Using the software package What’s Best, I constructed a MILP based on a sales organization in Washington State, which sells fruit on behalf of eight warehouses. There are four costs that must be included in the objective function of the MILP: a fixed labor cost at the sourcing and consolidation location(s), a variable labor cost with respect to the number of boxes moved, a variable fuel and equipment cost with respect to the distance traveled, and a variable inventory cost with respect to the age of fruit being moved. The final formulation of the objective function and all related constraints is shown in Figure 4 and the description of each variable is shown in Figure 5.

Minimize: \[ \sum a_{ijk}(b_{ijk}c_{ijk}) + \sum e_{ijk} + g_{ijk}n_{ijk} + l_{ijk}m_{ijk} + n_{ijk}o_{ijk} \]

Subject to:
\[ \sum a_{ijk} = q_{ij} \]
\[ \sum a_{ijk} \leq r_{ijk} \text{ for all } j \]
\[ \sum a_{ijk} - p_{ijk}e_{ijk} \leq 0 \text{ for all } j \]
\[ \sum a_{ijk} - p_{ijk}e_{ijk} \leq 0 \text{ for all } k \]
\[ g_{ijk} \leq 1 \]
\[ \sum b_{ijk} \leq s_{ijk} \text{ for all } j \]
\[ \sum n_{ijk} \leq t_{ijk} \text{ for all } j \]
\[ \sum a_{ijk} - p_{ijk}e_{ijk} - m_{ijk}n_{ijk} \leq 0 \text{ for all } j \]

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 | m | Number of trailers being used to move FG inventory | Trailer
Decision | n | Binary variable describing whether a warehouse is used for sourcing | Unitless
Decision | o | 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 | Days
First Tier | e | Fixed setup cost per trip between two warehouses using a trailer | $ per trailerload
First Tier | f | Fixed setup cost per trip between two warehouses using a truck | $ per truckload
Second Tier | g | An arbitrary, very large number to ensure binary variable is activated | Unitless
Second Tier | h | How many boxes need to be consolidated | Box
Second Tier | i | How many boxes of FG inventory are on-hand at each warehouse | Box
Second Tier | j | How many trucks are available to move boxes | Truck
Second Tier | k | How many trailers are available to move boxes | Trailer
Second Tier | l | Price of diesel fuel per gallon | $ per gallon
Second Tier | m | Labor cost of one day labor per hour | $ per hour
Second Tier | n | Distance in miles between each warehouse | Miles
Second Tier | o | Capacity of the truck or trailer in terms of boxes | Box
Second Tier | p | How many miles per gallon does the truck or trailer get | Miles per gallon
Second Tier | q | How many boxes can one worker load in one hour | Box per hour
Second Tier | r | Capacity of the truck or trailer in terms of boxes | Box
Second Tier | s | How many boxes of FG inventory are on-hand at each warehouse | Box
Second Tier | t | How many trucks are available to move boxes | Truck
Second Tier | u | How many trailers are available to move boxes | Trailer
Second Tier | v | Price of diesel fuel per gallon | $ per gallon

Figure 4: The Objective Function and Constraints of a Mixed-Integer Linear Program.

Figure 5: A Description of the Variables Included in the MILP.
In the event of a stock-out, a sales manager can use the MILP by entering five variables into a simple user interface on a web browser: what SKU is needed, how many boxes are needed, how many pickup locations are allowed, and the price of diesel. The optimization model is also linked to a database within the organization, from which it can retrieve current on-hand inventory levels at each warehouse, the age of fruit, the availability of trucks, and the costs of labor. The model uses all these variables, as well as those shown in Figure 5, to quickly find the lowest cost solution.

Upon completion, a simple set of instructions will be provided to the sales manager. Figure 6 shows the sales organization interface as it would look on a web browser after the model has found an optimal solution.

Sales Organization Interface

<table>
<thead>
<tr>
<th>Stock Keeping Unit (i.e. P.ORO.WFC.042.X2AL.CPK.X.X.X.83916)</th>
<th>P.ORO.WFC.042.X2AL.CPK.X.X.X.83916</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Boxes Ordered (i.e. 30 or 131 or 1070)</td>
<td>399</td>
</tr>
<tr>
<td>Maximum Pickup Locations Allowed (i.e. 1 or 2 or 3)</td>
<td>1</td>
</tr>
<tr>
<td>Diesel Price ($/gallon) (i.e. 2.14)</td>
<td>2.25</td>
</tr>
<tr>
<td>Total Cost of this Transfer (don’t enter anything here, cost will be entered for you)</td>
<td>$604.05</td>
</tr>
</tbody>
</table>

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.

Figure 6: Sales Organization Interface

Sales managers can use a tool like this MILP to quickly calculate the lowest cost of consolidating fruit within their own organization, which can then be compared to the price quote of purchasing fruit from an external firm in order to make the lowest-cost sourcing solution.

Management Insights

Firms in the tree fruit industry systematically maintain high levels of on-hand inventory, resulting in shrinkage costs of 5-12% of potential revenue. Despite having high levels of on-hand inventory, stock-outs occur during 5-7% of all incoming orders, resulting in sourcing costs of 1% of revenue. Both the packing and sales managers have the power to implement new policies designed to reduce levels of on-hand inventory, including: pre-sizing fruit, reducing available SKUs, establishing vendor-managed inventory relationships, and shaping demand through pricing.

If firms implement policies to reduce the average level of on-hand inventory, the likelihood of stock-outs may increase. To minimize any increase in sourcing costs, managers should implement optimization software to identify the lowest-cost way to move inventory during an intra-shed transfer. By comparing this cost to the premium paid for fruit from an external organization, sales managers can make a clear cost comparison and make the most efficient move or buy decision.

Implementation Challenges

Currently, few firms in the market have the incentive to invest a significant amount of effort and capital to reduce inventory shrinkage. Packing sheds are paid each time they process a box, so they have no incentive to reduce the number of repack occurrences unless the fruit is from company-owned orchards. Packing managers only need to keep the repack rate low enough that growers do not get so angry that they take their fruit away; packing sheds are fixed-costs businesses that need to run at full capacity to be profitable. Thus, packing sheds with a high percentage of internal fruit seek to reduce shrinkage, while those who rely on outside fruit have less of an incentive to improve in this area. Sales organizations make money based on a commission of every box they sell, a compensation scheme which incentivizes them to accept all incoming orders, even when they cannot be filled from their own warehouse. This commission is based on the actual price paid by the retailer, which does not take into account any costs associated with repacking fruit or quality rejections. Thus, the firms that bear the majority of the costs associated with inventory shrinkage and stock-outs are growers, who have little control over the inventory management process because they are small, numerous, and lack power within the tree fruit industry.