Multi-Echelon Inventory Optimization for Fresh Produce

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Abstract

For fresh produce, the product freshness is a key value to end consumers. Retailers try to maximize product freshness at retail stores while maintaining high product availability. Fresh produce that is close to the end of its life cycle will either be scrapped or be sold at a much lower price. With an increasing demand volatility and complication of supply chain network, obsolescence cost from these spoilages has been increasing recently. Our research focuses on the study of multi-echelon inventory optimization for fresh produce. We investigated the impacts of an additional fulfillment center in a supply chain to justify an improvement in product freshness. We analyzed three relevant factors: transit time, inventory dwell time and safety time, which affect the time products spend in a supply chain from the suppliers to the retail stores. Our objective was to create a predictive model that could determine whether product freshness could be improved when those products are shipped through a supply chain network with an additional fulfillment center.

While a fulfillment center increases the total transit time by adding more "touches" of the inventory, it can provide benefits by reducing demand variability through the risk pooling effect. When an fulfillment center aggregates demand from several grocery distribution centers, it pools the demand volatility across various locations, thus reducing the demand volatility and the safety stock. Our model demonstrated that, with a fulfillment center, six product categories (Berries, Watermelons, Cherries, Mixed melons, Stone fruit, and Strawberries) had a decrease in the safety time that is more than the increase in total transit time, resulting in the improved product freshness at retail stores. Further, we defined a term "Enhance Coefficient of Variation (ECV)" to quantify the demand volatility. Finally, we determined a set of minimum ECV ratios in order to make an fulfillment center benefits the product freshness under different replenishment frequencies. Retailers can use this ECV ratio as an indicator to make channeling decisions.

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1. INTRODUCTION

Firm A is a large grocery retailer. Grocery is one of several key business units that are classified as a merchandise- unit. Fresh produce is an important product segment of Firm A's grocery business and represents a significant portion of total revenue in the grocery segment.

While Firm A strives for competitive pricing for all business units, freshness and availability of products are very critical for fresh produce's business. The perishable nature of fresh produce creates difficulties in managing the supply chain. Various suppliers, multiple layers of inventory storage points and retail stores throughout the United States add complexity for supply chain management. Finally, the demand volatility at each retail store made the issue much more challenging.

The focus of our research is on improving complicated supply chain for fresh produce with our key objective in maximizing products' freshness while maintaining high product availability at retail stores.

1.1 Problem Description

In retail business, products flow from multiple suppliers that are considered the back end of the supply chain through the network. Products may be stored and transported to network nodes until they are delivered to retail stores. Finally, customers who are considered the front end of the supply chain purchase these products.

Direct shipment strategy

Between the front end and back end of supply chain, a company can flow products directly from suppliers to retail stores. This approach is called direct shipment strategy that bypasses network nodes such as a distribution center. Key benefit the company gains from this strategy is that products will have short lead time from suppliers and retail stores. In addition, the company can avoid expenses of operating network nodes.

However, the tradeoff of direct shipment strategy is that transportation cost will be very high because the company has to send small trucks to ship small amount of products from suppliers to a retail store. To serve demand in many retail stores, the company will have many small shipments to many locations where their retail stores are located.

<u>Intermediate inventory storage point strategy</u>

Alternatively, a company can create intermediate inventory storage points in the supply chain network. Products flow from suppliers to these intermediate inventory storage points before they are delivered to retail stores. These network nodes can perform valuable functions as the following;

- Temporarily or long term storing products:
- Processing products such as re-packing, labeling
- Disaggregating vehicles load into smaller vehicle load such as disaggregating a large quantity of product from TL shipment from supplier into LTL shipment to retail stores
- Creating SKU assortment
- Aggregating a small quantity into a large quantity of product

As opposed to direct shipment, an intermediate inventory storage point strategy provides a benefit to a company by decreasing transportation cost. Demand from retail stores can be aggregated and the company can transport large quantity in TL truckload from supplier. In addition, value added activities, such as re-packing and labeling, can potentially increase product's value to customers by offering products in preferred size and format. While direct shipments from suppliers to each retail stores minimize time products spend in the supply chain, which can maximize products' freshness, demand volatility requires a company to have an intermediate storage point to hold stock inventory and maintain product availability.

However, disadvantage from this strategy is that the company will have additional expense from operating these network nodes. Also, products will have longer lead time from flowing and storing in these network nodes.

Many supply chain networks of leading companies have at least one intermediate inventory storage point. In rare case, a company adopts direct shipment strategy. However, the number of intermediate inventory storage points which a company has is different between companies in the same industry and is significantly different among companies in different industries.

The decision on adopting either direct shipment or intermediate inventory storage point strategy depends on a company's overall business strategy and demand characteristics. In addition, in case of adopting intermediate inventory storage point strategy, a company has to decide the number of network nodes in the supply chain and, more importantly, on functions of these network nodes.

Network nodes that store inventory are called inventory facilities. These decisions directly affect company's capability in providing products and services to customers which can be key advantages of the company over competitors in the market.

To effectively design and manage the supply chain, company's executives have to consider costs occurred from direct shipment strategy and from intermediate inventory storage point strategy. In addition, lead time, product availability at retail stores, and possible value added activities from network nodes should be included in the consideration.

1.2 Firm A's Fresh Produce Inventory Management

For fresh produce, Firm A currently adopts an intermediate inventory storage point strategy. Fresh produce are sourced from several suppliers both domestic and international. Products flow from these suppliers through these intermediate inventory storage points (i.e, the grocery distribution center (GDC), Cross Dock Consolidation Center etc.) to retail stores in the United States. For product replenishment process, each retail store reviews and creates replenishment order to the GDC Then, a GDC delivers products to retail store according to the replenishment order. A GDC is responsible to store products to serve retail store's orders and to create replenishment orders to suppliers.

With demand volatility, Firm A holds large quantities of products in the supply chain. Firm A's retail store has to store adequate products to ensure that the products will not be out of stock and Firm A can maintain high service level in term of product availability to customers. Since a GDC has to deliver products according to retail stores' orders with varying replenishment quantities, the GDC has to store large quantity of products to ensure that the GDC serves those retail stores with high service level. In addition, the replenishment frequency between a retail store and a GDC is normally higher than that between a GDC and a supplier. For instance, while a retail store can send a replenishment order to a GDC every day, a GDC can send an order to the suppliers only 3 times a week. This imbalance in replenishment frequency makes the GDC to store large quantity of products.

With complicated supply chain network, products do not flow directly from the suppliers to the retail stores, but they flow through several intermediate inventory storage points. Comparing to simple supply chain network without any nodes, this complicated supply network causes those products to stay longer in the supply and Firm A has larger quantities of products between the front end and back end of supply chain.

Both demand volatility and complicated supply chain network significantly reduce products' freshness at a retail store and result in high product obsolescence. Obsolescence means that the products have passed out of usefulness and have no sales value left. Fresh produce can become obsolescent when it is close to the end of its life-cycle. In current practice, Firm A's fresh produce department throws away a significant portion of the fresh produce inventory that has become obsolescent and sells large quantity of fresh produce at markdown due to poor quality condition.

Therefore, Firm A would like to know whether or not any changes to current supply chain network could improve Firm A's supply chain performance by increasing product's freshness at the retail stores which eventually can result in a decrease in product obsolescence. More importantly, the increase in products' freshness must not affect product availability at retail stores, which is a key competitiveness for retail business.

In current supply chain's best practice, a leading strategy to reduce demand volatility in supply chain is the risk pooling. A company can adopt risk pooling strategy by aggregating demand. In Firm A's case, one possible approach is that the volatile demand from GDC can be aggregated at an additional inventory facility for risk pooling which potentially reduce total demand volatility.

Specifically, Firm A is interested in answering following questions.

1. Should Firm A add an upstream facility into its current network?
2. What are key benefits from an additional upstream facility?
3. What are impacts to supply chain network?

1.3 Motivation and Expected Outcome

There are many factors such as inventory policy, current network configuration, demand patterns, and relationship with suppliers, which can affect products' freshness at retail stores. In this thesis, we develop the prototype of a predictive model in which these relevant factors are input to the model. Then, the predictive model could determine whether an additional upstream facility can improve supply chain by increasing product's freshness.

Our objective of this thesis is to answer three questions mentioned above. The first question will be answered by using the predictive model for certain product categories with historical data. Firm A could change the data of the relevant factors in this predictive model to answer this question. We focus on identifying key benefits and other impacts, which an additional upstream facility has to supply chain network.

1.4 Research Scope

This research uses Firm A's supply chain as a case to study relevant factors which affect supply chain performance in order to address challenges of a company whose fresh produce is a significant part of the business.

For fresh produce, Firm A currently has a multi-echelon supply chain. Entities in the supply chain include

- More than 600 Vendors: Vendors are domestic or foreign fresh produce suppliers.
- One Cross Dock Consolidation Center: a cross-dock that is responsible for consolidating shipments in an area where there is a high density of produce vendors and then dispatching trucks to nationwide GDCs.
- More than 40 Grocery Distribution Centers (GDCs): The GDCs are regional warehouses to store inventories and fulfill orders from the retail stores. One GDC, on average, fulfills the demands of 94 Retail Stores.
- More than 4,000 Retail Stores throughout the Unites States. Customers purchase fresh produce directly from the Retail Stores.

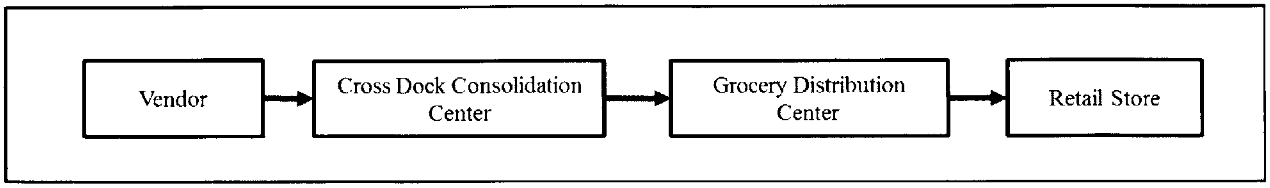


Figure 1: Firm A's current multi-echelon supply chain

Our analysis focuses on one line of Firm A's supply chain network. We chose a GDC in North Texas which serves 84 retail stores. Key criteria for this selection are its high sales volume. For products, we include 21 product categories that are top commodities for fresh product business as the following:

Top 21 product categories for analysis

1. Apples	11. Mixed Melons
2. Avocadoes	12. Mixed Vegetables
3. Bananas	13. Mushroom
4. Berries	14. Nuts-Snacks-Dried Fruit
5. Carrots	15. Onions
6. Cherries	16. Package Salads
7. Citrus	17. Potatoes
8. Cut Fruit	18. Stone Fruit
9. Grapes	19. Strawberries
10. Lettuce	20. Tomato
	21. Watermelons

Products from several vendors flow to this GDC in North Texas. Then, the GDC replenishes products to the retail stores according to the replenishment order. This structure of supply chain is common for Firm A. In addition, top 21 production categories can represent all fresh produce which Firm A has, since several types of fresh products such as soft fruit, vegetable are included. Therefore, we expect that the result from our research is applicable to other Firm A's fresh produce supply chain. Specially, the result will be a basis for us in developing a more complicated predictive model that Firm A can use for other fresh produce in other GDCs and other retail stores.

1.5 Thesis Structure

The thesis continues as follows. In chapter 2, we provide a review of literatures that are relevant to the multi-echelon inventory management and perishable products. In chapter 3, we provide the methodology, the key assumptions, and the concepts of our research and our predictive model. In chapter 4, we document our model and the detailed analysis of data. Finally, in chapter 5, we conclude on key observations and their implications to our research, the key insights, and some recommendations for future research.

2. LITERATURE REVIEW

The thesis project focuses on product flows from the suppliers through network nodes and ends at retail stores. At each network nodes, we focus on the inventory level of each entity in the supply chain network as well as inventory holding period before they are sold at a retail store. We reviewed relevant literature to understand analytical approaches of inventory models and perishable inventory management in order to develop a predictive model. The model is based on both single echelon and multi-echelon inventory models for perishable products.

In section 1, we review the analytical approaches for a single echelon model, which will serve as a basis for analyzing the relevant factors that affect inventory level and product lead time in an inventory facility. In section 2, we review the analytical approaches for a multi- echelon model. None of the existing models combine all relevant factors, such as every conceivable cost, benefit, action and activity, into one single optimization problem. A central question and key objective for inventory management is how to coordinate activities and inventories over multi-echelon stages and locations to keep a low inventory level, while providing a high level of service to end customers. In section 3, we review perishable inventory management for a unique aspect of product with limited lifetime.

2. 1 Single Echelon Models

The most well-known result in inventory control was presented by Harris (1913) through his classical economic order quantity formula. Harris proposed that balancing the fixed cost per order lot against the carrying cost should be the basis for decisions on what quantities one must order to minimize the total cost. Under the assumption that demand is constant and process continues infinitely without quantity constraints, the total annual cost is calculated from:

$$\boldsymbol{TC = CD + A\frac{D}{Q} + r\,C\frac{Q}{2}}$$

Where

- TC is total cost
- C is cost in dollars per unit
- D is demand rates in units per unit time
- A is order cost
- r is inventory holding cost in dollars per dollar per year
- Q is order quantity

Optimal Q where total cost is minimized is calculated from:

$$\boldsymbol{EOQ = Q^* = \sqrt{\frac{2AD}{rC}}}$$

Cycle periods T is calculated from $T = \frac{Q}{D}$ and identifies time supply or period in which the product is in an inventory facility.

Silver, Pike and Peterson (1998) considered the factor of shortage cost into the total cost equation and presented the extended equation for optimal order quantity.

$$\boldsymbol{Q^*\ (with\ shortage\ cost) = EOQ\sqrt{[\,1 + \frac{B_1}{A}\,p_{u\geq}(k)]}}$$

where B_1 is shortage cost per replenishment cycle and $p_{u\geq}(k)$ is the probability of shortage occasion per replenishment cycle. Also, Silver, Pike and Peterson described the two most prevalent inventory policies: continuous review policy and periodic review policy or based-stock inventory policy. For continuous review policy (s,Q), Q is determined by using the EOQ equation, where s is the reorder point. It is calculated by

$$s = D_L + k * \sigma_L$$

where D_L is demand over lead time in units and $k * \sigma_L$ is safety stock where k is safety stock factor and σ_L is standard deviation of the demand over lead time.

For periodic review policy(R,S), R is the review period and S is the based stock level. S is calculated from the equation;

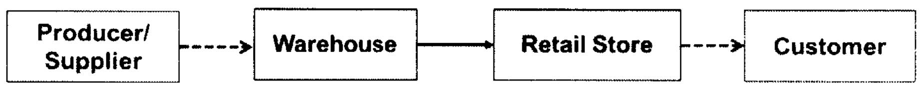
$$S = D_{R+L} + k * \sigma_{R+L}$$

where D_{R+L} is demand over lead time and review period in units and $k * \sigma_{R+L}$ is safety stock where k is safety stock factor and σ_{R+L} is standard deviation of the demand over lead time and review period. Cycle period T is calculated from the equation: $T = \frac{S}{D}$. For both inventory policies, average lead time in inventory is calculated by $\frac{T}{2}$.

2.2 Multi-Echelon Models

Axsater (2006) described a multi-echelon inventory system as a system where several replenishments for each echelon are coupled to each other. To illustrate, a single commodity moves through a supply chain network that consists of an external supplier, distinct warehouses, and retail stores to satisfy the end consumer's demand. Each echelon, which is defined as an inventory facility where products are stored, is supplied by the preceding stage in the serial network. The lowest echelon faces a sequence of stochastic demands over the time horizon since it is closest to consumers. The highest echelon is supplied by an external supplier with infinite capacity. Lee (2003) explained the complexity in managing inventory for a multi-echelon distribution network with multiple tiers of locations which are under internal control of a single enterprise. The objective of multi-echelon inventory management is to deliver the desired end customer service levels at minimum network inventory, with the inventory divided among the various echelons.

According to Silver, Pike and Peterson (1998), the simplest multi-echelon model assumes stocking points are serially connected to serve deterministic demand. For instance, a network includes one central distribution center, one regional distribution center, and one retail store. Each operation has only one predecessor and one successor operation. Figure XX shows this simple model.



In this simplest model, there are two controllable variables for the replenishment process, at the distribution center and retail store: Q_W and Q_R. The relationship between these two variables is defined as:

$$Q_W = nQ_R \qquad where\ n\ 1, 2, 3, \dots$$

Total relevant cost (TRC) for this two stage serial situation is defined as

$$TRC\ (Q_W, Q_R) = \frac{A_W D}{Q_W} + I'_W v'_W r + \frac{A_R D}{Q_R} + I'_R v'_R r$$

Optimal n is derived from the total relevant cost equation and is calculated by using:

$$n^* = \sqrt{\frac{A_W v'_R}{A_R v'_W}}$$

Where

- n is number of stores covered by one warehouse
- D is deterministic demand from customer and occur at retail store in units/year
- A_W and A_R are a fixed cost in dollars for each replenishment cycle at the warehouse and retailers respectively

- v_W and v_R are variable cost in dollars per unit at the warehouse and retailers respectively. v'_R is calculated by the added value when the product is moved from warehouse to retail store . v'_W has no added value and has no predecessor. v'_W and v'_R is calculated as:

$$v'_W = v_W \text{ and } v'_R = v_R - v_W$$

- Q_W and Q_R are replenishment quantity of warehouse and retailer respectively
- r is inventory carrying cost in dollar per dollar value of product per year

Tsiakis, Shah, and Pantelides (2001) used an optimization model to minimize the total cost of the supply chain network in designing the multi-echelon supply chain network. The objective function includes the following costs:

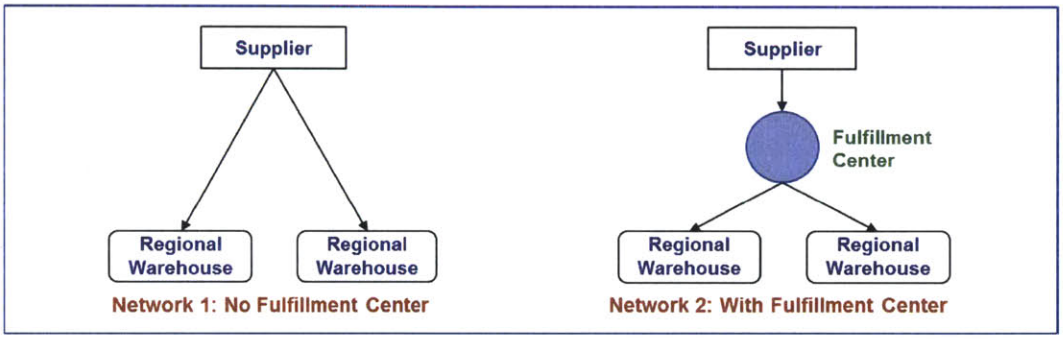
- Fixed Infrastructure costs: cost related to the establishments of a warehouse or a distribution center at a candidate location
- Production cost: cost incurred from the production process
- Material handling cost at the warehouse and distribution centers: cost is considered as a linear function of quantity of product
- Transportation cost: cost incurred in transportation of the material flow between any nodes in the network

The model also considered possible constraints that limit the network capacity. These constraints include network structure constraints, logical constraints for transportation flow, materials balance, production resources, and capacity of warehouse and distribution center. The model was conducted in two scenarios of both deterministic demands and uncertain product demands.

Tsiakis, Shah, and Pantelides concluded that their detailed mathematical programming formulation could address the complexity of designing multi-echelon supply chain networks by taking flexible production facilities, transportation modes with economies of scale effects into the programming formulation. They mentioned the issue of computational complexity in the scenario planning approaches for handling of uncertainty in demand as an important area of improvement.

2.3 Risk Pooling Effect

The concept of risk pooling is widely used to address the demand variability in the supply chain. Demand variability is reduced when demands are aggregated across locations.



In the supply chain, whenever demands in one location are higher than another location. The fulfillment center can reallocate the inventories for the low demand locations to high demand locations. Comparing with a network without a centralized warehouse or a fulfillment center, the network with a fulfillment center has more flexibility and has lower variation in the network. The risk pooling effect will be greater when demand variation is high. (Simchi-Levi, Kaminsky and Simchi-Levi, 2008)

2.4 Perishable Inventory Management

A perishable item has a limited lifetime that can be fixed or variable. Van Zyl (1964) defined a product with a fixed lifetime as "age dependent perishability" and a product with exponential decay as "age independent perishability." Nahmias (1980) explained that most inventory models assume stock can be stored indefinitely to meet future demand. However, perishable products change during storage and they can be partially or entirely unfit for consumption.

For fixed lifetime products, Nahmias (1975) included shortage cost and expected outdating cost into the new model. Compared with the typical model, the new model suggested that the order quantity of perishable items should be smaller and the effect of perishability would be larger when the starting stock has small value. Kouki (2010) noted that perishable items are one of the most important sources of revenue in the grocery industry and, at the same time, is the main source of waste due to limited lifetime. While classical periodic review policy (R,S) ignored the perishability of items, Kouki analyzed periodic inventory policy for an item with random lifetime and presented a new model. His numerical result showed that total cost can be improved by taking the lifetime's randomness into consideration in the model.

Liu and Yang (1999) presented a model of continuous review policy (s,S) of a product with exponential lifetime. The model assumed stochastic demand with passion distribution and showed that a policy for an item with a random lifetime should have a larger replenishment quantity and the reorder point should be lower.

For random lifetime, Ghare and Schrader (1963) included the effect of exponential decay into the standard EOQ formula. Covert and Phillip (1973) modified Ghare and Schrader's model by replacing exponential law with Weibull distribution and Tadikamalla(1978) used a gamma to govern lifetime of individual items.

For multi-echelon inventory system with perishable products, Prastacos (1978) suggested that a rotation policy should be implemented. His policy minimized expected shortage and outdated cost through his proposed two-stage allocation procedure. First, items that were scheduled to be outdated would be allocated to several warehouses so that the probability of having outdated product for each warehouse was equal. Then remaining stocks were allocated to several warehouses so that the probability of shortage for each warehouse was equal. Prastocos concluded in the paper that the allocation policy depended on the specific unit cost of outdating and shortage cost.

3. METHODOLOGY

Our methodology in this thesis is divided into two steps;

- **Step I: A predictive model**

  We developed the prototype of a predictive model to determine whether or not an additional upstream facility can improve supply chain by increasing products' freshness.

- **Step II: Simulations of the inventory levels in supply chain**

  We studied and monitored inventory level at each inventory facility and total average inventory level in the supply chain

There are two ways to increase product's freshness at retail store. The first way is to reduce the physical transportation time. Given that technology to optimize transportation has already been implemented at Firm A, there is little room to further reduce transportation time. The second way is to change the inventory policies and reconfigure supply chain network. This thesis focuses on the second way and analyzes the effect of adding a fulfillment center to the supply chain in order to achieve risk-pool effect that potentially reduces the demand volatility of the whole supply chain.

Firstly, for both Step I and Step II, we outlined assumptions we used in the analysis and created different scenarios for comparison. In Step I, we documented how we developed a predictive model. We investigated Firm A's current replenishment process, inventory policy, and performance metrics. Since the products' freshness is a key objective for supply chain improvement in this case, we deliberately focused on the time that products take flowing from the vendors to the retail stores. Specially, we investigated the time that products spend in transportation and the time that products spend in each inventory facility. We used existing supply chain network as the base case to compare with a proposed supply chain with the fulfillment center.

Finally, in Step II, we focused on inventory level and total average inventory in both cases in order to identify an impact of the Fulfillment Center. Inventory level is the primary concern in the supply chain management for Firm A's grocery business.

3.1 Assumptions

For both Step I and Step II analysis, we made the following assumptions in our analysis. We termed an additional upstream facility as a fulfillment center (FFC) in the proposed supply chain network

- The daily demands of the fresh produce in each inventory facilities: the retail stores, the grocery distribution centers (GDCs) and the fulfillment center (FFC) are normally distributed.
- The average demand and demand standard deviation of each fresh produce category is identical cross all stores.
- The demand pattern of each store is independent with zero correction.

We did not concern the possible monetary savings of obsolescent, the transportation cost, and the management cost in this thesis. Our focus on this thesis is to improve the current supply chain by increase products' freshness. Additional capital cost and operating cost from changes in the supply chain, together with increase in revenue from increase in product's freshness, will be included in the further research.

3.2 Scenarios for Analysis

For both Step I and Step II analysis, we developed two scenarios to compare and identify the improvements resulting by adding an FFC to the existing supply chain network.

3.2.1 Scenario 1: Existing supply chain network

Scenario 1 is the existing Firm A's supply chain network. We used this scenario as a base case. Since the Cross Dock Consolidation Center acts as a cross-docking facility and has a function in aggregating supplies from the vendors, we neglected the Cross Dock Consolidation Center in our scenarios for analysis

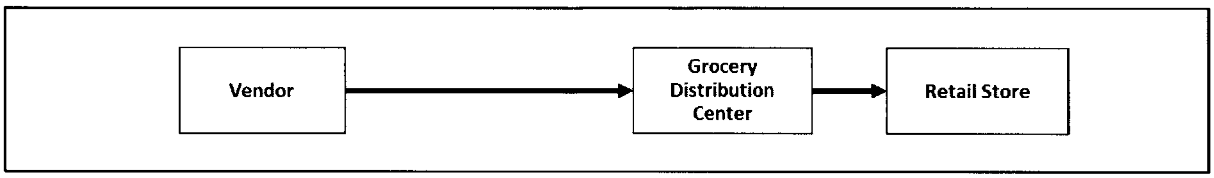


Figure 2: Firm A's existing supply chain network without the Cross Dock Consolidation Center

3.2.2 Scenario 2: Proposed supply chain network with a fulfillment center

To gain the benefits of risk pooling, a Fulfillment Center (FFC) is added into the supply chain between the Vendors and the GDCs in the proposed supply chain network, as Figure 3 shows.

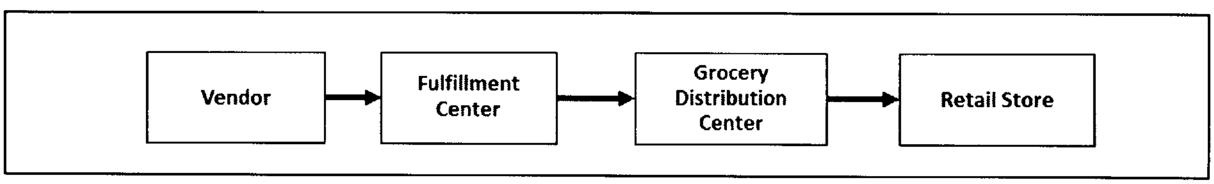


Figure 3: Firm A's proposed supply chain with a fulfillment center

The FFC will be a centralized warehouse to store inventories and fulfill orders from assigned GDCs. One FFC will be responsible for eight GDCs on average. Then, the function of those GDCs will also be changed from regional warehouses to regional cross-dockings facilities. This means GDC will no longer store products. Instead, a GDC will have a new function of disaggregating products from the FFC into smaller shipments and delivering them to each retail store.

In the proposed supply chain network, an FFC will aggregate demands across assigned GDCs, making the possibility that high demand from one GDC will be offset by low demand from another one. Thus, at FFC, the total demand variability of those GDCs will be reduced. The reduction in variability allows a decrease in safety stock and therefore reduces the average inventory level. This phenomenon is called risk-pooling effect.

3.3 Step I: A predictive model

3.3.1 Supply Chain Performance Metric

The scope of this thesis is to study how to improve the multi-echelon supply chain by adopting risk pooling, in order to increase product freshness. In step 1, we defined a term called "Total Supply Chain Cycle time" as the key supply chain performance metric.

Total supply chain cycle time is a total time which a product spends in the supply chain beginning from the vendor until it is sold. We used this metric to quantify products' freshness. By comparing the Scenario 1 and the Scenario 2, a decrease in total supply chain cycle time means that product stays shorter in the supply chain. This can be implied that product has improved freshness at the retail store.

3.3.2 (Q, R) Inventory Policy

In Step I, in order to simplify the mathematical equations for the inventory study, we assumed that Firm A managed inventories in the GDC and the retail stores by adopting continuous inventory policy with fixed order quantity (Q, R). Both the retail stores and the GDC make replenishment order with fixed quantity (Q) in every period (R)

3.3.3 Total Supply Chain Cycle time

To capture the time a product spend in the supply chain, the total supply chain cycle time composes of three components as follows;

- Transit time
- Inventory dwell time
- Safety time

3.3.3.1 Transit time

Transit time is the first part of the total supply chain cycle time and covers the time spent on transporting fresh produce on the road. It represents the transportation time to move products from one entity to another entity in the supply chain.

In Firm A's current supply chain network, in the case that the shipments from the vendors are not in full truckload (FTL), those vendors will firstly ship products to Firm A's Cross Dock Consolidation Center for consolidation. Then, the Cross Dock Consolidation Center aggregates those products into a full truckload (FTL), and delivers them to the GDCs. However, in the case that the shipments from vendors are in a full truckload (FTL), those vendors will bypass the Cross Dock Consolidation Center and ship the products to the GDCs directly.

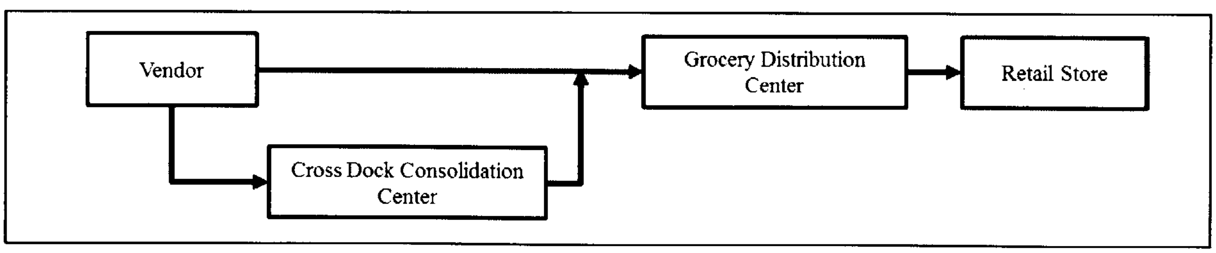


Figure 4: Transportation arrangements of Firm A's current supply chain

According to the interviews with a Logistics Manager of Inbound Transportation Department, it takes on average 2-3 days to ship fresh produce from the Cross Dock Consolidation Center to the GDCs. It takes on average another day to ship from the GDCs to the retail stores.

The logistics manager also mentioned that Firm A has already optimized the transportation and reached its fastest transportation speed to move fresh produce among each entity in the supply chain. The only way to reduce the transit time is to use air shipping. However, the cost of air shipping will dramatically lower the profitability of fresh produce since unit margin is so low. Firm A will not consider this option. Therefore, in this thesis, we do not consider increasing product freshness by reducing transit time.

Scenario 1: Existing supply chain network

$$\textbf{Transit time} = T_{V-GDC} + T_{GDC-S}$$

T_{V-GDC}: Time spent on transporting fresh produce from the vendors to the GDCs.

T_{GDC-S}: Time spent on transporting fresh produce from the GDCs to the retail stores.

Scenario 2: Proposed supply chain network with a fulfillment center

$$\textbf{Transit time} = T_{V-FFC} + T_{FFC-GDC} + T_{GDC-S}'$$

T_{V-FFC}: Time spent on transporting fresh produce from the vendors to the FFC.

$T_{FFC-GDC}$: Time spent on transporting fresh produce from the FFC to the GDCs. This time includes processing time for cross-docking process.

T_{GDC-S}': Time spent on transporting fresh produce from the GDCs to the retail stores.

3.3.3.2 Inventory Dwell Time

Each inventory facility has two types of inventory

- Cycle stock: an inventory to meet average demand over lead time and review time
- Safety stock: an extra stock that is maintained to mitigate the risk of stock outs due to the demand volatility

Inventory dwell time captures the average time a cycle stock stays at an inventory facility in one replenishment cycle, before it is consumed by the next level echelon or by retail stores' customers.

In current situation, inventory dwell time at the retail stores is high. According to the interviews with a Replenishment Manager of Produce, one possible explanation is that Firm A generally moves excessive inventories at the GDCs to the retail stores due to the GDCs' limited storage capacity. This practice leaves stores with a significant high level of extra inventories compared to their actual needs. The storage condition in stores is the worst among all inventory facilities because fresh produce are exposed to the warm air until they are sold. There is not enough cold storage space of excessive inventories due to the limited space of the retail stores. Therefore, in term of storage condition, positioning inventory at the GDC or the FFC is better.

Calculation of inventory dwell time for each scenario;

<u>Scenario 1: Existing supply chain network</u>

$$\textbf{\textit{Inventory dwell time}} = T_{store} + T_{GDC}$$

$$T_{store} = \frac{Q_{store}}{2\times\bar{D}_{store}} \quad (1)$$

$$T_{GDC} = \frac{Q_{GDC}}{2\times\bar{D}_{GDC}} \quad (2)$$

With the (Q,R) inventory policy, each retail store has the same order quantity (Q) for one fresh produce category. We also assumed that each retail stores has the same average demand $\overline{D}$ for one fresh produce category, thus

$$T_{GDC} = \frac{Q_{GDC}}{2 \times n \times \overline{D}_{store}} \qquad (3)$$

$$Q = \overline{D} \times R \qquad (4)$$

T_{store} : Average time which inventory stays at store before being sold

T_{GDC} : Average time which inventory stays at the GDCs before being transported to the retail stores

n : Number of stores covered by one GDC

Q : Order quantity

$\overline{D}$: Average demand at one retail store

R : Inventory review time

<u>Scenario 2: Proposed supply chain network with a fulfillment center</u>

$$\textbf{\textit{Inventory dwell time}} = T_{store} + T_{FFC}$$

$$T_{FFC} = \frac{Q_{FFC}}{2 \times \overline{D}_{FFC}} \qquad (5)$$

With (Q,R) inventory policy, each retail store has the same order quantity (Q) for one fresh produced category. We also assumed that each retail store has the same average demand $\overline{D}$, thus

$$T_{FFC} = \frac{Q_{FFC}}{2 \times N \times n \times \overline{D}_{store}} \qquad (6)$$

T_{FFC} : Average time which inventor stays at the FFC before being transported to GDC

N : Number of GDCs covered by one FFC

Adding an FFC between the vendors and the GDCs changes the replenishment schedule of the GDCs. For example, the GDCs order apples 3 times a week from vendors in the current supply chain. If we add an FFC, GDCs will order apples 7 times a week from the FFC, which means the order quantities of GDCs (Q_{GDC}) will be reduced. However, since the function of GDCs has been switched from regional warehouses to cross-dockings, GDC will not store inventory, thus, the inventory dwell time at GDC (T_{GDC}) will be zero. In this case, the reduction in order quantities from GDCs does not affect inventory dwell time.

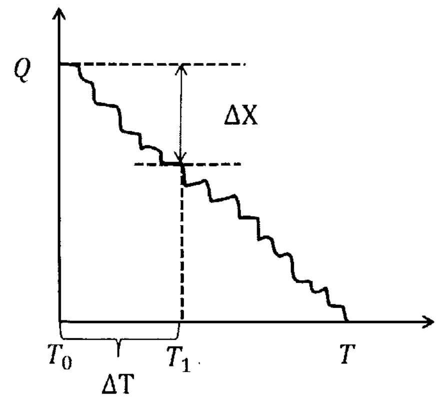
3.3.3.3 Safety Time

Safety time is time equivalent of safety stock. As opposed to inventory dwell time which captures cycle stock, safety time captures safety stock and demand volatility at retail stores. Since the demand is not stable at the retail stores, safety time reflects the additional time a product spends in the supply chain due to demand volatility.

In proposed supply chain network with a fulfillment center, according to risk pooling effect, the FFC will aggregate demand from each assigned GDC in order to reduce demand variation at those GDCs. The decrease in demand variation will reduce safety stock and will eventually result in a decrease in the safety time. The reduction of the safety time possibly contributes to the major reduction of total supply chain cycle time.

Calculation of safety time for each scenario

Under (Q, R) Replenishment Policy, Q quantity of inventory will be ordered every R period.



The beginning inventory level is Q. The current inventory level equals to the beginning inventory Q minus the average demand $\bar{D}$ over the period T_i. (Francisco Jauffred, MIT, 2013)

$$\boldsymbol{X_0 = Q} \qquad (7)$$

$$\boldsymbol{X_1 = Q - \bar{D} \times T_1} \qquad (8)$$

$$\boldsymbol{\Delta X = X_0 - X_1} \qquad (9)$$

Thus

$$\boldsymbol{\Delta X = -\bar{D} \times \Delta T} \qquad (10)$$

When the period is a full cycle $\boldsymbol{\Delta T = T}$

Thus $\boldsymbol{\Delta X = -\bar{D} \times T}$ (11)

Q : Beginning inventory level

$\bar{D}$: Average demand

T_i: Time period i

X : Current Inventory Level

ΔX : Change of Inventory Level

Because the inventory level is normally distributed, the change of the inventory level ΔX over period ΔT includes the average demand over period ΔT and the random normal noise over period ΔT. (Kurt Jacobs, 2010)

$$\Delta \boldsymbol{X} = \overline{\boldsymbol{D}} \times \Delta \boldsymbol{T} + \boldsymbol{\sigma} \times \Delta \boldsymbol{W} \quad (12)$$

$$\boldsymbol{VAR}[\Delta \boldsymbol{X}] = \boldsymbol{VAR}[\overline{\boldsymbol{D}} \times \Delta \boldsymbol{T}] + \boldsymbol{VAR}[\boldsymbol{\sigma} \times \Delta \boldsymbol{W}] \quad (13)$$

σ : Demand standard deviation

ΔW : Random normal noise

Because the average demand $\overline{D}$ and period ΔT is deterministic, the variance of average demand over period ΔT is zero.

$$\boldsymbol{VAR}[\Delta \boldsymbol{X}] = \boldsymbol{VAR}[\boldsymbol{\sigma} \times \Delta \boldsymbol{W}] \quad (14)$$

$$\boldsymbol{VAR}[\Delta \boldsymbol{X}] = \boldsymbol{\sigma}^2 \times \Delta \boldsymbol{T} \quad (15)$$

Substitute

$$\Delta \boldsymbol{X} = -\overline{\boldsymbol{D}} \times \boldsymbol{T} \quad (16)$$

$$\boldsymbol{VAR}[\Delta \boldsymbol{X}] = \boldsymbol{VAR}[-\overline{\boldsymbol{D}} \times \boldsymbol{T}] = \boldsymbol{\sigma}^2 \times \Delta \boldsymbol{T} \quad (17)$$

When

$$\Delta \boldsymbol{T} = \boldsymbol{T}$$

Thus

$$\boldsymbol{VAR}[\Delta \boldsymbol{X}] = \boldsymbol{VAR}[-\overline{\boldsymbol{D}} \times \boldsymbol{T}] = \boldsymbol{\sigma}^2 \times \Delta \boldsymbol{T} = \boldsymbol{\sigma}^2 \times \boldsymbol{T} \quad (18)$$

$$\boldsymbol{VAR}[\Delta \boldsymbol{X}] = \boldsymbol{VAR}[-\overline{\boldsymbol{D}} \times \boldsymbol{T}] = \overline{\boldsymbol{D}}^2 \times \boldsymbol{VAR}[\boldsymbol{T}] \quad (19)$$

Since $$VAR[\Delta X] = VAR[-\bar{D} \times T] = \sigma^2 \times T \tag{20}$$

$$\bar{D}^2 \times VAR[T] = \sigma^2 \times T \tag{21}$$

$$VAR[T] = \frac{\sigma^2 \times T}{\bar{D}^2} \tag{22}$$

When the period is a full cycle $Q = \bar{D} \times T$

$$T = \frac{Q}{\bar{D}} \tag{23}$$

Thus $$VAR[T] = \frac{\sigma^2 \times T}{\bar{D}^2} = \frac{\sigma^2 \times Q}{\bar{D}^3} \tag{24}$$

$$\textit{Standard Deviation of } T = \frac{\sigma}{\bar{D}} \times \sqrt{\frac{Q}{\bar{D}}} \tag{25}$$

According to equation (23),

$$VAR[T] = \frac{\sigma^2 \times T}{\bar{D}^2} = \frac{\sigma^2 \times Q}{\bar{D}^3} \tag{26}$$

<u>Scenario 1: Existing supply chain network</u>

The safety time for Scenario 1 (T_{ss}) is

$$T_{ss} = k \times \sqrt{\frac{(n \times \sigma_{store}^2) \times Q_{GDC}}{(n \times \bar{D}_{store})^3}} = k \times \sqrt{\frac{\sigma_{store}^2 \times Q_{GDC}}{n^2 \times \bar{D}_{store}^3}} \tag{27}$$

k : Safety factor

<u>Scenario 2: Proposed supply chain network with a fulfillment center</u>

The safety time for Scenario 2 (T_{ss}') is

$$\boldsymbol{T_{ss}}' = \boldsymbol{k} \times \sqrt{\frac{(N \times n \times \sigma_{store}^2) \times Q_{FFC}}{(N \times n \times \bar{D}_{store})^3}} = \boldsymbol{k} \times \sqrt{\frac{\sigma_{store}^2 \times Q_{FFC}}{N^2 n^2 \times \bar{D}_{store}^3}} \tag{28}$$

3.3.3.4 Safety Stock

Equation (27) and (28) shows the calculation of the safety time. The total safety stock can be calculated based on Equation (28) and (28) as the following equations show. (Francisco Jauffred, MIT, 2013)

Scenario 1: Existing supply chain network

The safety stock ($\boldsymbol{SS}$) for Scenario 1 is

$$\boldsymbol{SS} = \boldsymbol{n} \times \bar{\boldsymbol{D}}_{store} \times \boldsymbol{T}_{ss} = \boldsymbol{n} \times \bar{\boldsymbol{D}}_{store} \times \boldsymbol{k} \times \sqrt{\frac{\sigma_{store}^2 \times Q_{GDC}}{n^2 \times \bar{D}_{store}^3}} \tag{29}$$

Scenario 2: Proposed supply chain network with a fulfillment center

The safety stock ($\boldsymbol{SS}'$) for Scenario 2 is

$$\boldsymbol{SS}' = \boldsymbol{n} \times \bar{\boldsymbol{D}}_{store} \times \boldsymbol{T}'_{ss} = \boldsymbol{n} \times \bar{\boldsymbol{D}}_{store} \times \boldsymbol{k} \times \sqrt{\frac{\sigma_{store}^2 \times Q_{FFC}}{N^2 n^2 \times \bar{D}_{store}^3}} \tag{30}$$

3.3.3.5 Total Supply Chain Cycle Time

Total supply chain cycle time records the total life cycle of fresh produce from the Vendors until it is sold at stores. Section 3.3.3.1 to 3.3.3.3 provide detailed calculation for each component of the total supply chain cycle time.

Scenario 1: Existing supply chain network

Total supply chain cycle time ($\tilde{T}$) for Scenario 1 is

$$\widetilde{T} = T_{V-GDC} + T_{GDC} + T_{GDC-S} + T_{store} + T_{SS}$$

$$\widetilde{T} = T_{V-GDC} + \frac{Q_{GDC}}{2\times\bar{D}_{GDC}} + T_{GDC-S} + k \times \sqrt{\frac{\sigma_{store}^2 \times Q_{GDC}}{n^2 \times \bar{D}_{store}^3}} \quad (31)$$

Scenario 2: Proposed supply chain network with a fulfillment center

Total supply chain cycle time ($\widetilde{T}'$) for Scenario 2 is

$$\widetilde{T}' = T_{V-FFC} + T_{FFC} + T_{FFC-GDC} + T_{GDC-S}' + T_{store} + T_{SS}' \quad (32)$$

$$\widetilde{T}' = T_{V-FFC} + \frac{Q_{FFC}}{2\times\bar{D}_{FFC}} + T_{FFC-GDC} + T_{GDC-S}' + \frac{Q_{store}}{2\times\bar{D}_{store}} + k \times \sqrt{\frac{\sigma_{store}^2 \times Q_{FFC}}{N^2 n^2 \times \bar{D}_{store}^3}} \quad (33)$$

3.3.4 Enhanced Coefficient of Variation (ECV)

Since safety time significantly depends on demand volatility, we planned to use the coefficient of variation (CV) to measure the relative demand volatility among product categories. However, the unit of average store demand is $lbs/week$, and the unit of demand standard deviation is $lbs/\sqrt{week}$. In order to cancel out the units to make this ratio dimensionless, we defined a new term "Enhanced coefficient of variation (ECV)" to measure the relative demand volatility among product categories. The equation for ECV is defined as follows. (Francisco Jauffred, MIT, 2013)

$$ECV = \frac{\sigma_{store}}{\bar{D}_{store}} \times \frac{1}{\sqrt{\frac{Q_{store}}{\bar{D}_{store}}}} \quad (34)$$

$$= \frac{\sigma_{store}}{\bar{D}_{store}} \times \sqrt{\frac{\bar{D}_{store}}{Q_{store}}} \quad (35)$$

The large ECV shows the high degree of demand volatility. Since safety stock is correlated to the ECV, safety time (T_{SS}) can be presented in the term of ECV.

Scenario 1: Existing supply chain network

The safety time (T_{ss}) in term of ECV for Scenario 1 is shown as follows: (Francisco Jauffred, MIT, 2013)

$$\boldsymbol{T_{ss}} = \boldsymbol{k} \times \sqrt{\frac{\sigma^2_{store} \times Q_{GDC}}{n^2 \times \bar{D}^3_{store}}}$$

$$= \boldsymbol{k} \times \frac{\sigma_{store}}{\bar{D}_{store}} \times \sqrt{\frac{Q_{GDC}}{n^2 \times \bar{D}_{store}}}$$

$$= \boldsymbol{k} \times \frac{\sigma_{store}}{\bar{D}_{store}} \times \sqrt{\frac{n \times Q_{store}}{n^2 \times \bar{D}_{store}}}$$

$$= \boldsymbol{k} \times \frac{\sigma_{store}}{\bar{D}_{store}} \times \sqrt{\frac{\bar{D}_{store}}{Q_{store}}} \times \frac{Q_{store}}{D_{store}} \times \sqrt{\frac{1}{n}}$$

$$= \boldsymbol{k} \times \boldsymbol{ECV} \times \frac{Q_{store}}{D_{store}} \times \sqrt{\frac{1}{n}} \tag{36}$$

Scenario 2: Proposed supply chain network with a fulfillment center

The safety time (T_{ss}') in term of ECV for Scenario 2 is shown as follows: (Francisco Jauffred, MIT, 2013)

$$\boldsymbol{T'_{ss}} = \boldsymbol{k} \times \sqrt{\frac{(N \times n \times \sigma^2_{store}) \times Q_{FFC}}{(N \times n \times \bar{D}_{store})^3}}$$

$$= \boldsymbol{k} \times \sqrt{\frac{\sigma^2_{store} \times Q_{FFC}}{N^2 \times n^2 \times \bar{D}^3_{store}}}$$

$$= \boldsymbol{k} \times \frac{\sigma_{store}}{\bar{D}_{store}} \times \sqrt{\frac{Q_{FFC}}{N^2 \times n^2 \times \bar{D}_{store}}}$$

$$= \boldsymbol{k} \times \frac{\sigma_{store}}{\bar{D}_{store}} \times \sqrt{\frac{N \times n \times Q_{store}}{N^2 \times n^2 \times \bar{D}_{store}}}$$

$$= \boldsymbol{k} \times \frac{\sigma_{store}}{\bar{D}_{store}} \times \sqrt{\frac{\bar{D}_{store}}{Q_{store}}} \times \frac{Q_{store}}{D_{store}} \times \sqrt{\frac{1}{N \times n}}$$

$$= \boldsymbol{k \times ECV \times \frac{Q_{store}}{D_{store}} \times \sqrt{\frac{1}{N^2 \times n}}} \tag{37}$$

3.4 Step II: Simulations of the Inventory Level in Supply Chain

While we focus on time products spend in the supply chain in Step I, we focus on inventory level at each inventory facility in Step II. We relaxed the assumptions that Firm A adopted continuous inventory policy (Q, R). In Step II, the analysis is based on current Firm A' inventory policy which is periodic inventory policy. We built an inventory model to follow this realistic inventory policy (R, s, S).

3.4.1 Supply Chain Performance Metric

Since our focus in Step 2 is on inventory in supply chain, we used "Average Inventory Level" and "Days of Supply (DOS)" as the key supply chain performance metric.

Days of Supply (DOS) represents how many days of demand are covered by the current inventory level. The smaller DOS, the lower inventory level at a storage facility. The equations for the average inventory level and DOS are as follows;

$$\boldsymbol{Average\ Inventory\ Level = \frac{Beginning\ Inventory + End\ Inventory}{2}} \tag{38}$$

$$\boldsymbol{DOS = \frac{Average\ Inventory\ Level}{Average\ Demand}} \tag{39}$$

In Scenario 2, a fulfillment center, which is an additional network node in the supply chain, bring the risk pooling effect. The risk-pooling effect will be observed by the change of the average inventory level of total supply chain, and the change of DOS of each inventory facility. The smaller DOS, the lower inventory level at a storage facility. By comparing Scenario 1 and Scenario 2, lower average inventory level and lower DOS means that Firm A store less inventory in the supply chain, given that customer service level is maintained at the same level for both scenarios. This can be implied that

Firm A could have savings from both non-capital related inventory holding costs such as labor cost, warehouse cost, and capital related inventory holding cost such as opportunity cost for other investments.

3.4.2 (R, s, S) Inventory Policy

Under (R, s, S) periodic inventory policy, inventory is reviewed every *R* period. In the case that inventory level drops below an order point (s) or Buffer-Order-Point (BOP), which is the minimum inventory level, replenishment ordered will be created so that the inventory level will be raised to an order up to level (S) or Order-Up-To-Level (OUT), which is the maximum inventory level.

Each storage facility (e.g. the retail stores, the GDCs and the FFC) follows this inventory policy. The replenishment manager provided us the following equations to calculate BOP and OUT.

$$\boldsymbol{BOP = \overline{D} \times (L + 0.9 \times R) + k \times \sigma \times \sqrt{L + R}} \tag{37}$$

$$\boldsymbol{OUT = \overline{D} \times (L + R) + k \times \sigma \times \sqrt{L + R}} \tag{38}$$

$\overline{D}$ = Average daily demand

L = Lead time

R = Review time

k = Safety factor

σ = Demand standard deviation

Scenario 1: Existing supply chain network

Retail stores monitor inventory level and create replenishment orders according to the inventory policy mentioned above, before sending the orders to the GDCs. The GDCs receive the orders from the assigned retail stores (94 stores on average) and deliver products according to the replenishment quantities identified in the orders. Same as retail stores, the GDCs monitor inventory level and create replenishment orders according to inventory policy mentioned above, before sending order to the vendors.

Scenario 2: Proposed supply chain network with a fulfillment center

Retail stores monitor inventory level and create replenishment orders according to the inventory policy mentioned above, before passing orders through the GDCs to the FFC. The FFC receives the orders from the assigned GDCs (8 GDCs on average) and deliver products according to replenishment quantities identified in the orders to the GDCs by cross-docking. Same as the retail stores, the FFC monitors inventory level and creates replenishment orders according to the inventory policy mentioned above, before sending orders to the vendors. The GDCs only has a function of passing orders from the retail stores to the FFC, and serves as a cross-docking when receives products from the FFC, and sends them to the retail stores.

3.4.3 Retail Store Demands

We assumed that demand at each retail store is normally distributed. In our inventory model, we use a function in Microsoft Excel to create a sample set of Point-of-Sales (POS) or the daily demand data with normal distribution. Generated POS data has the same average daily demand and standard deviation as historical the POS data that is collected from April 2012 to April 2013.

Microsoft Excel's function: *NORMINV (RAND ( ), Average daily demand, Standard Deviation)*

3.4.4 Simple Moving Average Demand Forecasting

In our inventory model, demand is forecasted by using simple moving average model. The simple moving average method is appropriate when demand is modeled as a level with noise. (Silver, Ed, David and Rein, 1998)

$$x_i = \alpha + \varepsilon_i \tag{36}$$

x_i = Demand at period i

α = Demand level

ε_i = Random noise at period i

The simple N-period moving average, as of the end of period i is given by

$$\bar{x}_{t,i} = (x_t + x_{t-1} + x_{t-2} + \cdots + x_{t-N+1})/N \qquad (37)$$

$\bar{x}_{t,i}$ = The forecast of the average demand at period i made at the end of period t

x_t = The actual average demand at the end of period t

N = The number of most recent periods

In order to apply simple moving average procedure, we firstly used daily demand (POS data) from historical date for five periods as initial values. With this demand forecasting, we provided an equal weight to the five most recent demand data with no weight to demand data prior to that.

3.3.5 Replenishment Order Quantity (Q)

If the Day End Inventory Level (DEI) is below the Buffer-Order-Point (BOP), a replenishment order will be created. The replenishment quantity is the difference between the Order-Up-To-Point (OUT) and the Day End Inventory. Equations for the replenishment quality (Q_i) and Day End Inventory (DEI) are as follows;

$$Q_i = OUT_i - Day\ End\ Inventory_i \qquad (38)$$

$$Day\ End\ Inventory_i = Day\ End\ Inventory_{i-1} + Q_{I-1} - D_i \qquad (39)$$

Qi: Order quantity of Day i

$Day\ End\ Inventory_i$: Inventory level at the end of the Day i

D_i: Actual Daily Demand

4. DATA ANALYSIS

In this chapter, we demonstrate the result of our predictive model, and the interpretations of these results. Our objective is to justify whether or not an additional upstream facility can improve supply chain by increasing products' freshness.

In our model, a fulfillment center, which is an additional upstream facility, can improve supply chain by increasing products' freshness when

1. Total supply chain cycle time of Scenario 2 is less than that of Scenario 1
2. Average inventory level of Scenario 2 is less than Scenario 1

4.1 Step I: A predictive model

In Step I, we created a predictive model under the (Q, R) inventory policy. The results are measured by a term called "Total Supply Chain Cycle time", which includes inventory dwell time, transit time and safety time.

4.1.1 Input Parameters

Inputs to our predictive model include parameters of the network configuration, the transit times, the parameters from the inventory policy, and the average daily demand at the retail stores. As we aim to develop a model that is flexible to any changes in the demand characteristics, and is applicable to Firm A's entire fresh produce supply chain, these inputs are not fixed to the model and can be updated according to new conditions.

4.1.1.1 Network Configuration

Tables 1 show the basic parameters we input in the predicative model.

Table 1: Parameters for network configuration

Network configuration	Value
Expected number of the GDCs under one FFC	**8**
Representative GDC #	**6064**
GDC Location	**Texas**
Number of stores under GDC	**84**

4.1.1.2 Transit Time

Table 2 shows the input of transit time between each echelon.

Table 2: Transit time

Product Category		Scenario 1		Scenario 2			
		From Vendors to GDC *(days)*	**From GDCs to Stores** *(days)*	**From Suppliers to FFC** *(days)*	**From FFC to GDCs** *(days)*	**GDC Processing Time for cross-docking** *(days)*	**From GDC to Store** *(days)*
1	**Berries**	4.00	1.00	3.00	1.00	0.30	1.00
2	**Watermelons**	5.00	1.00	4.00	1.00	0.30	1.00
3	**Cherries**	6.00	1.00	5.00	1.00	0.30	1.00
4	**Mixed Melons**	5.00	1.00	4.00	1.00	0.30	1.00
5	**Stone Fruit**	4.00	1.00	3.00	1.00	0.30	1.00
6	**Strawberries**	5.00	1.00	4.00	1.00	0.30	1.00
7	**Citrus**	4.00	1.00	3.00	1.00	0.30	1.00
8	**Nuts-Snacks-Dried Fruits**	5.00	1.00	4.00	1.00	0.30	1.00
9	**Grapes**	5.00	1.00	4.00	1.00	0.30	1.00
10	**Avocadoes**	4.00	1.00	3.00	1.00	0.30	1.00
11	**Potatoes**	5.00	1.00	4.00	1.00	0.30	1.00
12	**Cut Fruit**	4.00	1.00	3.00	1.00	0.30	1.00
13	**Apples**	5.00	1.00	4.00	1.00	0.30	1.00
14	**Mushroom**	6.00	1.00	5.00	1.00	0.30	1.00
15	**Mixed Vegetables**	6.00	1.00	5.00	1.00	0.30	1.00
16	**Carrots**	5.00	1.00	4.00	1.00	0.30	1.00
17	**Onions**	4.00	1.00	3.00	1.00	0.30	1.00
18	**Lettuce**	4.00	1.00	3.00	1.00	0.30	1.00
19	**Tomato**	2.00	1.00	1.00	1.00	0.30	1.00
20	**Pkg Salads**	3.00	1.00	2.00	1.00	0.30	1.00
21	**Bananas**	5.00	1.00	4.00	1.00	0.30	1.00

4.1.1.3 Inventory Policy

In Scenario 2, the Fulfillment Center (FFC) will follow the same vendor replenishment schedule as the Grocery Distribution Centers (GDCs). The GDCs no longer order from vendors, instead, they will order from the FFC every day. Table 3 shows the order frequencies of each echelon.

Table 3: Parameters for inventory policy

Product Category		Scenario 1		Scenario 2		
		Store Replenishment Frequency *(time/week)*	GDC Replenishment Frequency *(time/week)*	Store Replenishment Frequency *(time/week)*	GDC Replenishment Frequency *(time/week)*	FFC Replenishment Frequency *(time/week)*
1	Berries	7	2	7	7	2
2	Watermelons	7	2	7	7	2
3	Cherries	7	3	7	7	3
4	Mixed Melons	7	3	7	7	3
5	Stone Fruit	7	3	7	7	3
6	Strawberries	7	2	7	7	2
7	Citrus	7	2	7	7	2
8	Nuts-Snacks-Dried Fruits	7	2	7	7	2
9	Grapes	7	2	7	7	2
10	Avocadoes	7	2	7	7	2
11	Potatoes	7	2	7	7	2
12	Cut Fruit	7	2	7	7	2
13	Apples	7	3	7	7	3
14	Mushroom	7	2	7	7	2
15	Mixed Vegetables	7	3	7	7	3
16	Carrots	7	3	7	7	3
17	Onions	7	3	7	7	3
18	Lettuce	7	3	7	7	3
19	Tomato	7	4	7	7	4
20	Pkg Salads	7	4	7	7	4
21	Bananas	7	4	7	7	4

4.1.1.4 Demand Characteristics

Store average daily demand is historical data that was collected from Point of Sales (POS) data from April 2012 to April 2013. Store standard deviation of daily demand is the standard deviation of that set of POS data.

Some types of fresh produce are seasonal products and Firm A does not store those products during off-season. Therefore, we exclude off-season sales for those products because zero sales during the off-season period is not due to no demand but because there is no supply. Seasonal products include:

- Watermelon
- Cherries
- Stone Fruit
- Berries

Table 4 shows the adjusted store average daily demand and demand standard deviation after we filtered out the off-season data.

Table 4: Point-of-sales and standard deviation

	Product Category	Store average daily demand (POS) *(lbs)*	Store standard deviation of daily demand *(lbs)*
1	Berries	15.15	29.87
2	Watermelons	57.00	62.49
3	Cherries	64.45	60.20
4	Mixed Melons	56.86	48.70
5	Stone Fruit	164.94	132.76
6	Strawberries	175.95	112.67
7	Citrus	195.15	87.92
8	Nuts-Snacks-Dried Fruits	34.95	15.30
9	Grapes	317.19	117.43
10	Avocadoes	340.37	125.40
11	Potatoes	106.59	34.61
12	Cut Fruit	108.76	35.20
13	Apples	331.30	105.46
14	Mushroom	44.46	11.42
15	Mixed Vegetables	151.26	46.71
16	Carrots	103.74	25.97
17	Onions	297.30	74.33
18	Lettuce	202.99	48.66
19	Tomato	434.49	85.62
20	Pkg Salads	292.49	56.75
21	Bananas	1,427.05	237.67

4.1.2 Total Supply Chain Cycle Time

Total supply chain cycle time contains three parts: total inventory dwell time, total transit time and safety time.

4.1.2.1 Total Transit Time

Transit time covers the time products spend on transportation between entities in the supply chain network. Table 5, which were the data from Firm A's transportation department shows the transit time between each echelon. Because different vendors supply each product category, transit times from vendors to GDCs and FFCs are different among product categories, as shown in Figure 1.

Table 5: Total transit time summary

Product Category		Scenario 1			Scenario 2			
		From Vendors to GDC *(days)* T_{V-GDC}	From GDC to Stores *(days)* T_{GDC-S}	Total Transit Time *(days)*	From Vendors to FFC *(days)* T_{V-USF}	From FFC to GDC *(days)* $T_{USF-GDC}$	From GDC to Stores *(days)* T_{GDC-S}	Total Transit Time *(days)*
1	Berries	4.00	1.00	5.00	3.00	1.30	1.00	5.30
2	Watermelons	5.00	1.00	6.00	4.00	1.30	1.00	6.30
3	Cherries	6.00	1.00	7.00	5.00	1.30	1.00	7.30
4	Mixed Melons	5.00	1.00	6.00	4.00	1.30	1.00	6.30
5	Stone Fruit	4.00	1.00	5.00	3.00	1.30	1.00	5.30
6	Strawberries	5.00	1.00	6.00	4.00	1.30	1.00	6.30
7	Citrus	4.00	1.00	5.00	3.00	1.30	1.00	5.30
8	Nuts-Snacks-Dried Fruits	5.00	1.00	6.00	4.00	1.30	1.00	6.30
9	Grapes	5.00	1.00	6.00	4.00	1.30	1.00	6.30
10	Avocadoes	4.00	1.00	5.00	3.00	1.30	1.00	5.30
11	Potatoes	5.00	1.00	6.00	4.00	1.30	1.00	6.30
12	Cut Fruit	4.00	1.00	5.00	3.00	1.30	1.00	5.30
13	Apples	5.00	1.00	6.00	4.00	1.30	1.00	6.30
14	Mushroom	6.00	1.00	7.00	5.00	1.30	1.00	7.30
15	Mixed Vegetables	6.00	1.00	7.00	5.00	1.30	1.00	7.30
16	Carrots	5.00	1.00	6.00	4.00	1.30	1.00	6.30
17	Onions	4.00	1.00	5.00	3.00	1.30	1.00	5.30
18	Lettuce	4.00	1.00	5.00	3.00	1.30	1.00	5.30
19	Tomato	2.00	1.00	3.00	1.00	1.30	1.00	3.30
20	Pkg Salads	3.00	1.00	4.00	2.00	1.30	1.00	4.30
21	Bananas	5.00	1.00	6.00	4.00	1.30	1.00	6.30

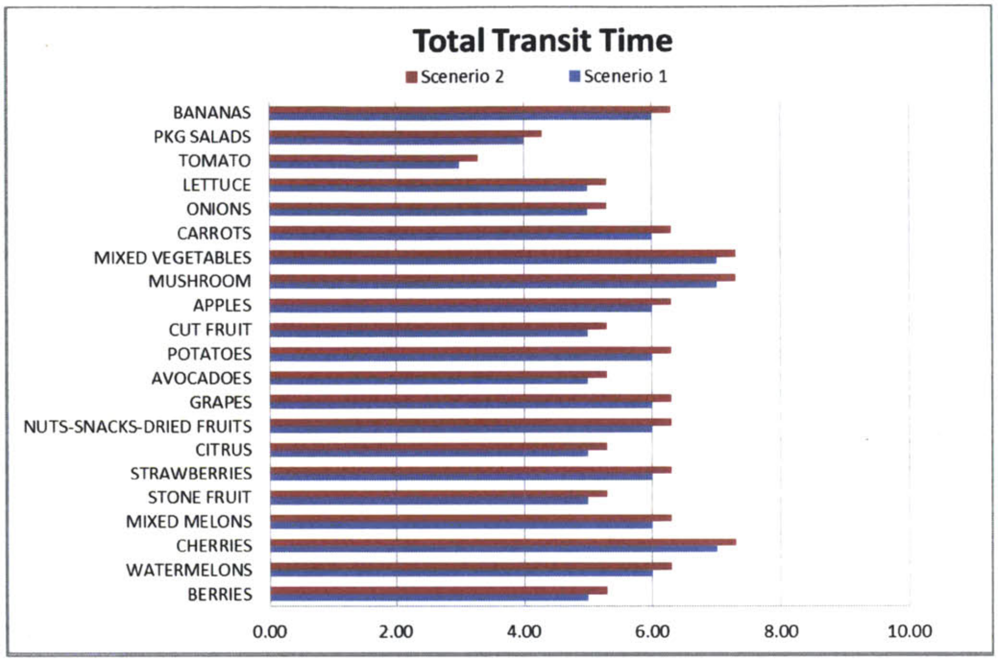


Figure 5: Total transit time for each product category (unit: days)

Because the FFC is located between the vendors and the GDCs, we assumed that the transit time from the vendors to the FFC is 1 day less than the transit time from the vendors to the GDCs, and shipping from the FFC to the GDCs takes 1 day. Thus, transit time on the road did not change when we added the FFC to the supply chain network.

However, the FFC adds one more "touch" of the inventory, which requires an extra 0.3 day process time in the FFC for the cross-docking process to disaggregate products from the FFC to a smaller quantity for each retail store. Thus the total transit time of Scenario 2 will be 0.3 days longer than the transit time of Scenario 1.

4.1.2.2 Total Inventory Dwell Time

The inventory dwell time is the average time products stay at either the FFC or the GDCs, or the retail stores before they are consumed by next level echelon or store customers. Inventory dwell time depends on replenishment quantity and average demand, as shown in equation (1) - (6), in the Section 3.3.3.2.

According to interviews with the Firm A replenishment and transportation team, Firm A has comparably low minimum order quantity requirement to the vendors (~1,261 lbs on average). Because Firm A has strong buyer power, they do not necessarily need to order more than the exact required amount in order to meet this minimum order quantity limit. Because the order quantity according to demand is small, Firm A further minimizes the transportation cost by using the Cross Dock Consolidation Center.

Inventory dwell times for each product category are different and depend only on vendor replenishment frequency since Firm A can place order according to demand, not to minimum order quantity. Table 6 shows the total inventory dwell time summary of both scenarios. Figure 6 visualizes the difference of the total inventory dwell time between each category.

Table 6: Total inventory dwell time summary

	Product Category	Scenario 1			Scenario 2		
		Store Inventory Dwell Time *(days)*	GDC Inventory Dwell Time *(days)*	Total Inventory Dwell Time *(days)*	Store Inventory Dwell Time *(days)*	FFC Inventory Dwell Time *(days)*	Total Inventory Dwell Time *(days)*
		T_{store}	T_{GDC}		T_{store}	T_{FFC}	
1	**Berries**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
2	**Watermelons**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
3	**Cherries**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
4	**Mixed Melons**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
5	**Stone Fruit**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
6	**Strawberries**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
7	**Citrus**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
8	**Nuts-Snacks-Dried Fruits**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
9	**Grapes**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
10	**Avocadoes**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
11	**Potatoes**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
12	**Cut Fruit**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
13	**Apples**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
14	**Mushroom**	0.50	1.75	**2.25**	0.50	1.75	**2.25**
15	**Mixed Vegetables**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
16	**Carrots**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
17	**Onions**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
18	**Lettuce**	0.50	1.17	**1.67**	0.50	1.17	**1.67**
19	**Tomato**	0.50	0.88	**1.38**	0.50	0.88	**1.38**
20	**Pkg Salads**	0.50	0.88	**1.38**	0.50	0.88	**1.38**
21	**Bananas**	0.50	0.88	**1.38**	0.50	0.88	**1.38**

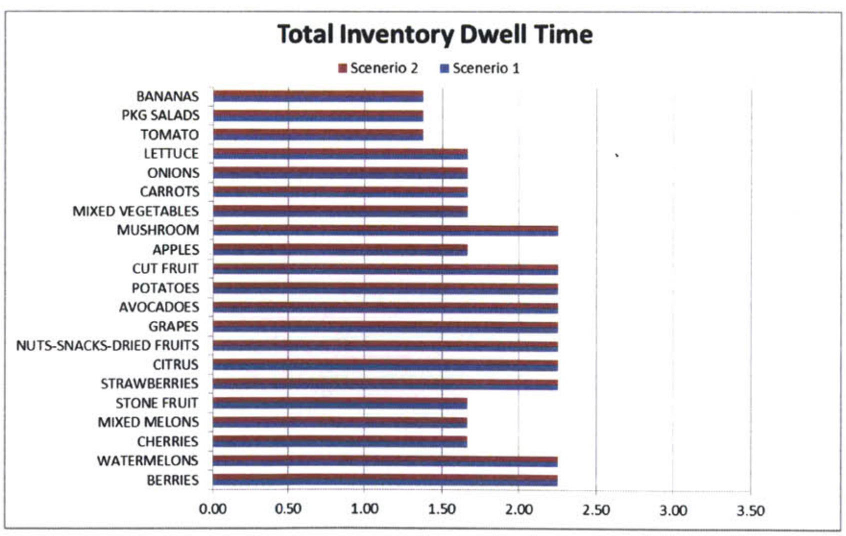


Figure 6: Total inventory dwell time for each product category

4.1.2.3 Safety Time

The safety time is the time safety stock stays in the inventory before it is consumed. We assumed that both the GDCs and the FFC maintain a high service level to ensure that products will have a low chance of stock outs. We used 99% customer service level (CSL) as an input to the model. The corresponding safety factor (k) can be calculated by the following equation in Excel and the result was 2.33.

Microsoft Excel function to converse CSL to safety factor (K): NORM.INV (0.99, 0, 1)

Table 7: Safety time summary

Product Category		Scenario 1 Safety Time *(days)*	Scenario 2 Safety Time (days)
1	Berries	1.50	0.53
2	Watermelons	0.83	0.29
3	Cherries	0.58	0.20
4	Mixed Melons	0.53	0.19
5	Stone Fruit	0.50	0.18
6	Strawberries	0.49	0.17
7	Citrus	0.34	0.12
8	Nuts-Snacks-Dried Fruits	0.33	0.12
9	Grapes	0.28	0.10
10	Avocadoes	0.28	0.10
11	Potatoes	0.25	0.09
12	Cut Fruit	0.25	0.09
13	Apples	0.20	0.07
14	Mushroom	0.19	0.07
15	Mixed Vegetables	0.19	0.07
16	Carrots	0.16	0.05
17	Onions	0.15	0.05
18	Lettuce	0.15	0.05
19	Tomato	0.11	0.04
20	Pkg Salads	0.10	0.04
21	Bananas	0.09	0.03

Safety time depends on average daily demand, replenishment quantity, and standard deviation. In Scenario 2, the FFC aggregates demand from the GDCs, which results in lower demand variation because of risk pooling effect. Therefore, safety time in Scenario 2 is lower than in Scenario 1 in all product categories. Figure 7 shows the differences in safety time among product categories.

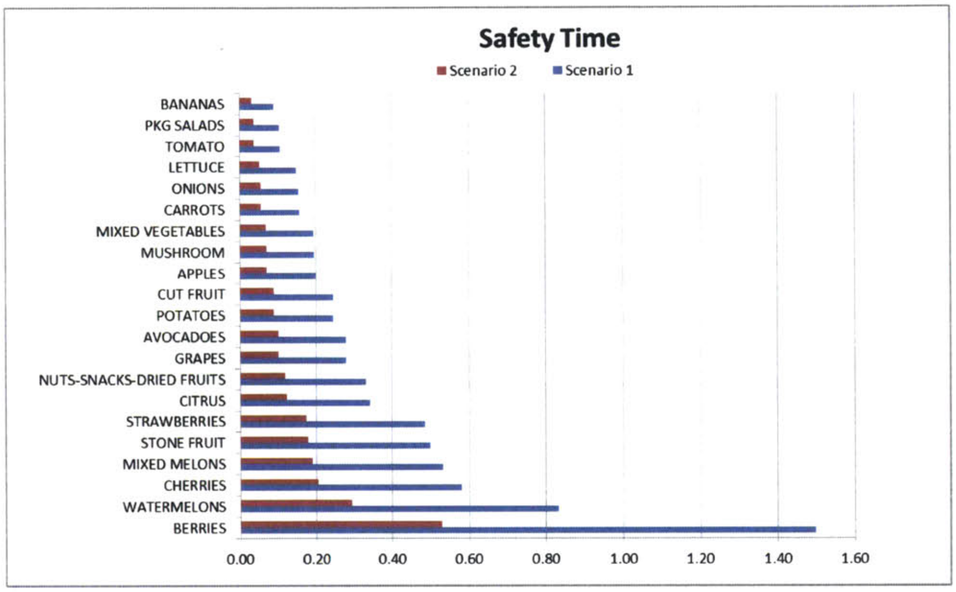


Figure 7: Safety time for each product category

4.1.2.4 Total Supply Chain Cycle Time

The total supply chain cycle time is the sum of the total transit time, total inventory dwell time and the safety time. As we have discussed in Section 4.1.2.2, the total inventory dwell time does not change when we added the FFC to the supply chain. Therefore, any change in the total supply chain cycle time is from changes in safety time and total transit time.

The benefit of the FFC is to reduce demand variation by aggregating demand. A decrease in demand variation will reduce safety time. However, the impact of the FFC to the supply chain is that the extra process time at the GDCs is added, and eventually increases the total transit time. To analyze this tradeoff, we compared the increase of total transit time and the decrease of the total safety time. If the reduction of safety time is more than the increase of total transit time, then that fresh produce category should move to the supply chain with the FFC. Otherwise, it should still continue using the current supply chain network.

Table 8 shows the changes in safety time, the transit time, and the total supply chain cycle time when comparing Scenario 2 with Scenario 1. There is "Saving" when time in Scenario 2 is less than time in Scenario 1, and there is additional time in when time in Scenario 2 is more than time in Scenario 1.

Table 8: Changes of safety time and transit time by comparing Scenario 2 and Scenario 1

Product Category		Increment / (Saving) in Safety Time *(days)*	Increment / (Saving) in Transit Time *(days)*	Increment/ (Saving) in Total Supply Chain Cycle Time *(days)*
1	Berries	(0.97)	0.3	(0.47)
2	Watermelons	(0.54)	0.3	(0.24)
3	Cherries	(0.38)	0.3	(0.08)
4	Mixed Melons	(0.34)	0.3	(0.04)
5	Stone Fruit	(0.32)	0.3	(0.02)
6	Strawberries	(0.31)	0.3	(0.01)
7	Citrus	(0.22)	0.3	0.08
8	Nuts-Snacks-Dried Fruits	(0.21)	0.3	0.09
9	Grapes	(0.18)	0.3	0.12
10	Avocadoes	(0.18)	0.3	0.12
11	Potatoes	(0.16)	0.3	0.14
12	Cut Fruit	(0.16)	0.3	0.14
13	Apples	(0.13)	0.3	0.17
14	Mushroom	(0.13)	0.3	0.17
15	Mixed Vegetables	(0.12)	0.3	0.18
16	Carrots	(0.10)	0.3	0.20
17	Onions	(0.10)	0.3	0.20
18	Lettuce	(0.10)	0.3	0.20
19	Tomato	(0.07)	0.3	0.23
20	Pkg Salads	(0.07)	0.3	0.23
21	Bananas	(0.06)	0.3	0.24

Total supply chain cycle time of first six categories in Scenario 2 are less than in Scenario1. These six product categories are

- Berries
- Watermelons
- Cherries
- Mixed melons
- Stone fruit
- Strawberries

The reduction in total supply chain cycle time indicated that these six product categories products would stay a shorter in the supply chain with an FFC, as shown in Figure 8. Thus, the freshness of these products would increase. In contrast, the total supply chain cycle time of other categories increased, and these products would stay longer in the supply chain with an FFC.

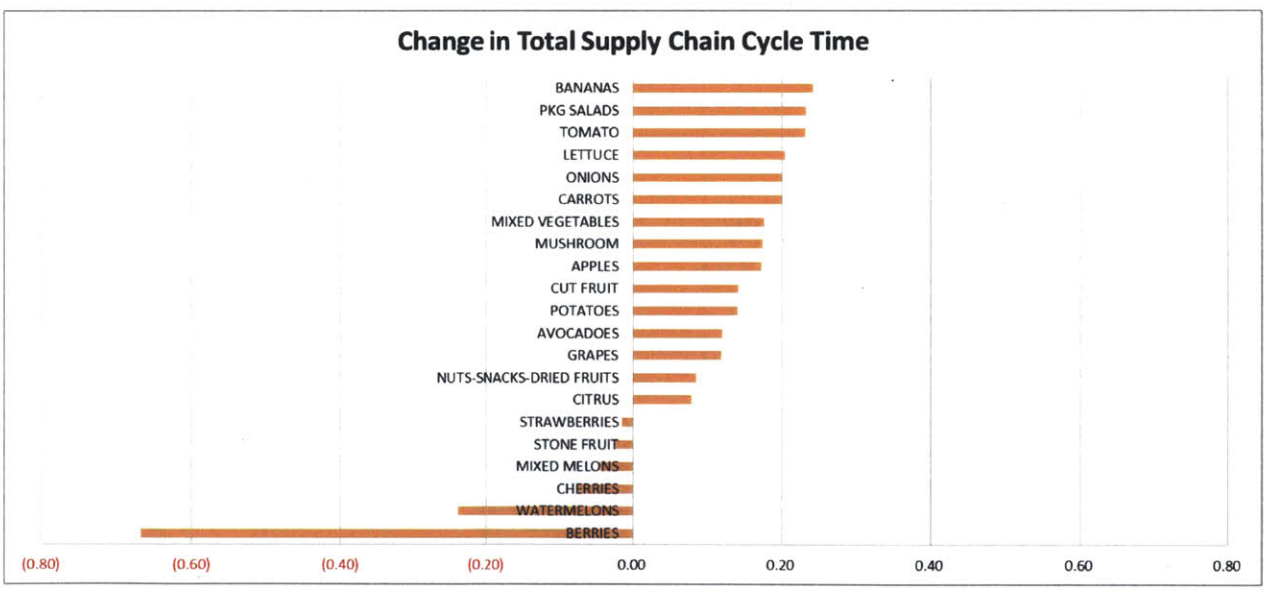


Figure 8: Changes of the total supply chain cycle time (unit: days)

4.1.3 Safety Stock

With an FFC, safety stocks in the supply chain decrease for all product categories due to risk pooling effect. As safety stock depends on demand variation, the FFC reduces the demand variations in the supply chain and eventually reduces the safety stock, as shown in Table 9.

Table 9: Reduction in safety stock for each product category

	Product Category	Increment / (Saving) in Total supply chain cycle time (days)	Reduction in Safety Stock (lbs)
1	Berries	(0.47)	1,231
2	Watermelons	(0.24)	2,576
3	Cherries	(0.07)	2,026
4	Mixed Melons	(0.04)	1,639
5	Stone Fruit	(0.02)	4,468
6	Strawberries	(0.01)	4,645
7	Citrus	0.08	3,624
8	Nuts-Snacks-Dried Fruits	0.09	631
9	Grapes	0.12	4,841
10	Avocadoes	0.12	5,169
11	Potatoes	0.14	1,427
12	Cut Fruit	0.14	1,451
13	Apples	0.17	3,550
14	Mushroom	0.17	471
15	Mixed Vegetables	0.18	1,572
16	Carrots	0.20	874
17	Onions	0.20	2,502
18	Lettuce	0.20	1,638
19	Tomato	0.23	2,496
20	Pkg Salads	0.23	1,654
21	Bananas	0.24	6,928

Saving in total supply chain cycle time indicates that Firm A should decide to send products through a supply chain network with an FFC. However, we observed that Firm A could have significant savings in safety stock by adding a small amount of time in the supply chain.

For Avocadoes, Grapes, and Citrus, the supply chain with an FFC will add less than 0.15 days into the total supply chain cycle time, but it provides a significant reduction in safety stock. These products have high enough demand to generate a significant reduction in safety stock since saving in safety stock also depends on average store daily demand ($\overline{D}_{store}$) as shown in the equation below.

$$SS - SS' = n \times \overline{D}_{store} \times T_{ss} - n \times \overline{D}_{store} \times T'_{ss}$$

$$= n \times \overline{D}_{store} \times (T_{ss} - T'_{ss}) \quad (40)$$

By comparing the increment in total supply chain cycle time with the reduction in safety stock, Firm A has another criterion to use when make decisions about which supply chain a product should go through.

4.1.4 Demand Volatility

As shown in Table 10, the value of the average demand ($\overline{D}$) and demand standard deviation (σ) are various across 21 product categories. The category with a high standard deviation (σ) does not necessarily mean that category is more volatile than the others with low standard deviations (σ). For example, the Berries category has 29.87 lbs standard deviation and the Bananas category has 237.67 lbs standard deviation since daily demand of these two products are not equal.

In order to quantify the demand volatility across all 21 product categories, we introduced the concept of enhanced coefficient of variation (ECV). Table 10 shows ECV and change in total supply chain cycle time by product category.

Table 10: Enhanced coefficient of variation and changes of the total supply chain cycle time

	Product Category	Store average daily demand (POS) (lbs)	Store standard deviation of daily demand (lbs)	Enhanced Coefficient of Variation (ECV)	Incremental / (Saving) in total supply chain cycle time (days)
1	Berries	15.15	29.87	1.97	(0.47)
2	Watermelons	57.00	62.49	1.10	(0.24)
3	Cherries	64.45	60.20	0.93	(0.07)
4	Mixed Melons	56.86	48.70	0.86	(0.04)
5	Stone Fruit	164.94	132.76	0.80	(0.02)
6	Strawberries	175.95	112.67	0.64	(0.01)
7	Citrus	195.15	87.92	0.45	0.08
8	Nuts-Snacks-Dried Fruits	34.95	15.30	0.44	0.09
9	Grapes	317.19	117.43	0.37	0.12
10	Avocadoes	340.37	125.40	0.37	0.12
11	Potatoes	106.59	34.61	0.32	0.14
12	Cut Fruit	108.76	35.20	0.32	0.14
13	Apples	331.30	105.46	0.32	0.17
14	Mushroom	44.46	11.42	0.26	0.17
15	Mixed Vegetables	151.26	46.71	0.31	0.18
16	Carrots	103.74	25.97	0.25	0.20
17	Onions	297.30	74.33	0.25	0.20
18	Lettuce	202.99	48.66	0.24	0.20
19	Tomato	434.49	85.62	0.20	0.23
20	Pkg Salads	292.49	56.75	0.19	0.23
21	Bananas	1,427.05	237.67	0.17	0.24

We observed that products with high ECVs have large reductions in total supply chain cycle time. For example, the Berries category has the highest ECV (1.97) and has the highest saving in total supply chain cycle time (0.47 days). Figure 5 shows the relationship between the ECV and total supply chain cycle time. When the ECV increases, the total supply chain cycle time will decrease.

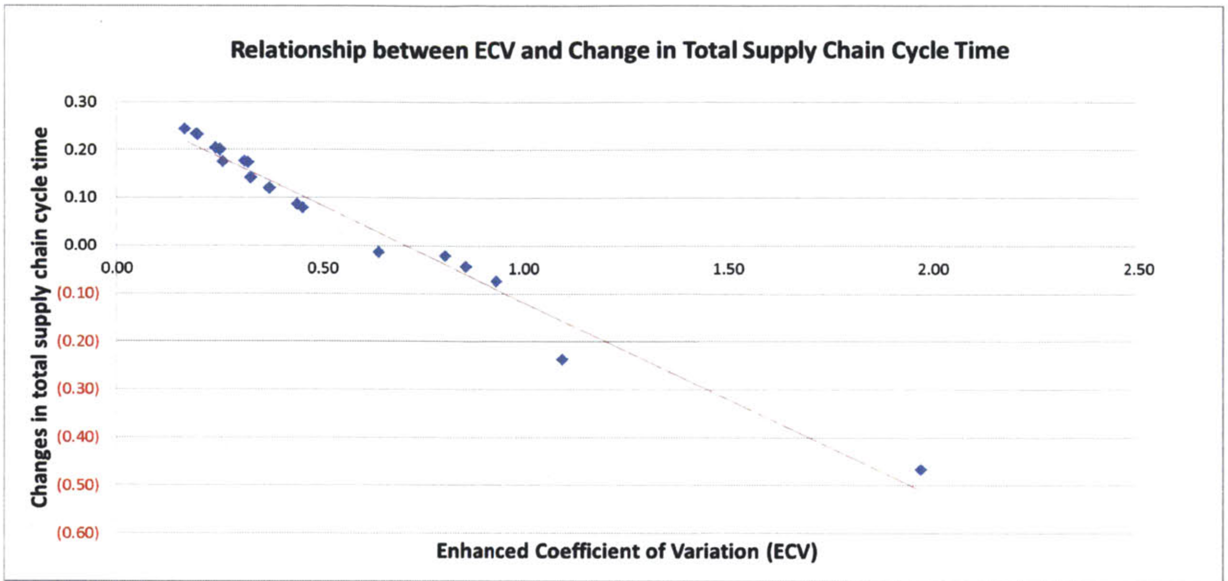


Figure 9: Relationships between the ECV and the change in the total supply chain cycle time (Unit: Dimensionless)

4.1.5. Sensitivity Analysis on Vendor Replenishment Frequencies

Then, we tested the model with Sensitivity Analysis on Vendor replenishment frequency. We fixed the order frequency from the Retail Stores to the GDCs at 7 times a week. We changed the order frequency from the GDCs and the FFC to the vendors and determined the ECV break-event point. For example, for those categories ordered 3 times a week from the FFC to the vendors, if the ECVs are below 0.76, the FFC will not improve the freshness. However, if the ECVs are above 0.76, the FFC will help to improve the freshness of those categories. Table 11 shows the ECV break event for each Vendor replenishment frequency.

Table 11: Enhanced coefficient of variation break-event point

Vendor replenishment frequency.	ECV Break-event point
1 time a week	0.45
2 times a week	0.63
3 times a week	0.76
4 times a week	0.88
5 times a week	0.99
6 times a week	1.08
7 times a week	1.18

4.2 Step II: Simulations of the Inventory Level in the Supply Chain

While we focus on time products spend in the supply chain in Step I, we focus on inventory level at each inventory facility in Step II. We relaxed the assumptions that Firm A adopted continuous inventory policy (Q, R). In Step II, the analysis is based on current Firm A' inventory policy which is periodic inventory policy. We built an inventory model to follow the inventory policy (R, s, S).

4.2.1 Input Parameters

Inputs to our inventory model are the same as in Step I except transit times, because our focus in Step II is the inventory in supply chain. Inputs for the model include:

- Network configuration (same as section 4.1.1.1)
- Inventory Policy: Due to the complexity in running Microsoft Excel Model, we use the same inventory policy for all product categories.
    - The replenishment schedule of the Retail Stores: 7 times/ week
    - The replenishment schedule of the GDCs and the FFC: 3 times/week
    - Lead time from the GDCs to the retail stores : 1 day

- Lead time from the FFC to the retail stores : 2 days
- Lead time from the vendors to the GDCs and the FFC : 4 days

- Demand Characteristics (same as section 4.1.1.4)

4.2.2 Days of Supply (DOS)

Days of Supply (DOS) represents how many days of demand are covered by the current inventory level. Table 12 shows DOS at retail stores, GDC, and FFC by comparing Scenario 1 and Scenario 2.

Table 12: Days of supply (DOS) at inventory facilities

Product Category		Scenario 1	Scenario 2	Scenario 1	Scenario 2
		Average DOS at Retail store (days)	Average DOS at Retail store (days)	Average DOS at GDC (days)	Average DOS at FFC (days)
1	Berries	4.54	7.61	11.23	7.50
2	Watermelons	3.58	6.17	9.67	6.23
3	Cherries	3.41	5.79	9.70	6.24
4	Mixed Melons	3.35	5.73	9.66	6.25
5	Stone Fruit	3.12	5.43	8.98	5.60
6	Strawberries	2.84	5.00	8.81	5.63
7	Citrus	2.51	4.56	8.83	5.69
8	Nuts-Snacks-Dried Fruits	2.77	4.96	9.57	6.53
9	Grapes	2.32	4.29	8.50	5.90
10	Avocadoes	2.30	4.26	8.64	5.80
11	Potatoes	2.29	4.26	8.68	6.08
12	Cut Fruit	2.28	4.24	8.76	6.12
13	Apples	2.20	4.12	8.49	5.91
14	Mushroom	2.30	4.31	9.34	6.92
15	Mixed Vegetables	2.22	4.16	8.72	6.02
16	Carrots	2.12	4.03	8.70	6.32
17	Onions	2.05	3.94	8.54	6.45
18	Lettuce	2.04	3.94	8.56	6.49
19	Tomato	1.92	3.75	8.55	6.70
20	Pkg Salads	1.93	3.77	8.54	6.48
21	Bananas	2.84	3.65	8.47	6.96

For retail store inventories, Days of Supply (DOS) in Scenario 2 is more than in Scenario 1 since lead time for order replenishment at the retail stores changes. In a supply chain network with an FFC, retail stores will be replenished by the FFC, and the lead time will increases from 1 day to 2 days. However, DOS for inventories at the GDC in Scenario 1 is more than DOS for inventories at FFC in Scenario 2. the FFC aggregates demand from GDCs resulting in the reduction in demand variation and safety stock, which is same as the result in 4.1.2.3. Lower DOS implies that, with the same demand, average inventory level at the FFC is lower than the sum of the average inventory level at the GDCs.

4.2.3 Average Inventory

Average inventory measures inventory level at each inventory facility. This inventory level includes both cycle stock and safety stock. Table 13 shows the average inventory level at the retail stores, the GDC, and the FFC.

Table 13: Average inventory level at inventory facilities

	Product Category	Scenario 1	Scenario 2	Scenario 1	Scenario 2
		Total Average Inventory at all retail stores (lbs)	**Total Average Inventory at all retail stores (lbs)**	**Total Average Inventory at all GDC (lbs)**	**Average Inventory at FFC (lbs)**
1	**Berries**	5,778	9,684	18,992	12,581
2	**Watermelons**	17,141	29,542	48,640	31,417
3	**Cherries**	18,461	31,346	52,992	34,353
4	**Mixed Melons**	16,000	27,368	45,672	30,008
5	**Stone Fruit**	43,227	75,232	123,768	77,527
6	**Strawberries**	41,975	73,899	125,616	80,747
7	**Citrus**	41,145	74,750	138,176	89,711
8	**Nuts-Snacks-Dried Fruits**	8,132	14,562	26,768	18,392
9	**Grapes**	61,814	114,303	215,928	150,424
10	**Avocadoes**	65,759	121,798	235,568	158,624
11	**Potatoes**	20,504	38,142	74,104	52,090
12	**Cut Fruit**	20,830	38,736	76,264	53,413
13	**Apples**	61,224	114,656	225,568	157,657
14	**Mushroom**	8,590	16,096	33,192	24,777
15	**Mixed Vegetables**	28,207	52,856	105,200	73,345
16	**Carrots**	18,474	35,118	72,256	52,823
17	**Onions**	51,195	98,394	202,904	154,317

18	**Lettuce**	34,784	67,182	139,120	106,287
19	**Tomato**	70,075	136,864	296,296	23,478
20	**Pkg Salads**	47,418	92,626	199,904	152,605
21	**Bananas**	340,437	437,534	965,224	799,506

The total average inventory level at all retail stores is the sum of the average inventory at a retail store. As same as the DOS, total average inventory level in Scenario 2 is more than the one in Scenario 1. Since the lead-time from a fulfillment center in Scenario 2 is longer than the lead time from GDC in Scenario 1, retail stores in Scenario 2 have to carry more inventories to mitigate risk of stock-out due to demand variation over the longer lead time. Since the FFC has a risk pooling effect from aggregating demands from the GDC, the average inventory level at the FFC in Scenario 2 is less than the sum of the average inventory level from eight GDCs in Scenario 1.

4.2.4 Total Inventory of the Supply Chain

Supply chain inventory comprises of the pipeline inventory and the inventory at each echelon. Pipeline inventory is the inventory in transit. We exclude inventory in transit in our analysis for the purpose of comparison between Scenario 1 and Scenario 2. Table 14 shows total inventory in the supply chain for Scenario 1 and 2, and the comparison between those two scenarios.

Table 14: Total inventory in supply chain

Product Category		Scenario 1: Total Inventory in Supply Chain (lbs)	Scenario 2: Total Inventory in Supply Chain (lbs)	Increment / (Saving) in Total Inventory in Supply Chain (lbs)	Percentage change in Total Inventory in Supply Chain (lbs)
1	Berries	24,770	22,265	(2,504)	-10.11%
2	Watermelons	65,781	60,959	(4,822)	-7.33%
3	Cherries	71,453	65,699	(5,754)	-8.05%
4	Mixed Melons	61,672	57,376	(4,297)	-6.97%
5	Stone Fruit	166,995	152,759	(14,236)	-8.52%

6	Strawberries	167,591	154,646	(12,945)	-7.72%
7	Citrus	179,321	164,461	(14,860)	-8.29%
8	Nuts-Snacks-Dried Fruits	34,900	32,954	(1,947)	-5.58%
9	Grapes	277,742	264,727	(13,015)	-4.69%
10	Avocadoes	301,327	280,422	(20,905)	-6.94%
11	Potatoes	94,608	90,232	(4,375)	-4.62%
12	Cut Fruit	97,094	92,149	(4,945)	-5.09%
13	Apples	286,792	272,313	(14,479)	-5.05%
14	Mushroom	41,782	40,873	(908)	-2.17%
15	Mixed Vegetables	133,407	126,201	(7,206)	-5.40%
16	Carrots	90,730	87,941	(2,789)	-3.07%
17	Onions	254,099	252,711	(1,388)	-0.55%
18	Lettuce	173,904	173,469	(436)	-0.25%
19	Tomato	366,371	370,612	4,242	1.16%
20	Pkg Salads	247,322	245,231	(2,092)	-0.85%
21	Bananas	1,305,661	1,237,040	(68,622)	-5.26%

All twenty-one product categories, except *Tomato,* have less total inventory in the supply chain of Scenario 2 (the supply chain with an FFC). In this case, the increase in the inventory at retail stores due to longer lead time is less than the decrease in the inventory at the FFC due to the risk pooling effect, resulting in a net saving in total inventory in the supply chain. However, only *Tomato* increases the total inventory in the supply chain of Scenario 2.

5. CONCLUSION

The objective of this thesis is to justify whether or not adding a fulfillment center to the existing supply chain can improve the supply chain performance by increasing products' freshness at the retail stores. To those ends, this thesis mainly focuses on the impacts from adding this facility. In this chapter, we present the challenges for the general fresh produce supply chain, the key insights drawn from our predictive model and inventory model, and the outline for further extensions of our predictive model.

5.1 Challenges for the General Fresh Produce Supply Chain

For fresh produce, value of products to customers significantly depends on the products' freshness. Fresh produce is a perishable product category in which freshness decreases with the increasing age of inventory in the supply chain. Therefore, retailers try to transfer fresh produce from the suppliers to their retail stores as fast as possible to maximize the level of freshness at the retail stores. However, it is not practical to move products directly from the suppliers to the retail stores, because demands at retailers are not stable. In addition, the cost of direct shipment is significantly higher than using intermediate inventory storage points to aggregate products from the suppliers before disaggregating into small shipments for each retail store. Besides saving in transportation costs, an intermediate inventory storage point also provides the benefit of risk pooling effect, which can reduce the demand variations in the supply chain, and results in the reduction of safety stock.

Adding a fulfillment center to the existing supply chain adds more "touches" to the system and increases the total transit time. However, a fulfillment center can lower safety stock by reducing demand variations. Utilizing our predictive model, the quantified benefits from the risk pooling effect and the increase in transit time can be determined. The output from the model is the comparison of the total supply chain cycle time between a supply chain network with and without the fulfillment center. Less total supply chain cycle time indicates that products stay a shorter time in the supply chain resulting in the improvement of product freshness.

5.2 Key Insights

5.2.1 Supply Chain Network with a Fulfillment Center

In the proposed supply chain network, an FFC is added to the existing supply chain between the vendors and the GDCs, as Figure 3 in section 3.2.2 shows. A fulfillment center will be a centralized warehouse to store inventories and fulfill orders from the retail stores. The function of those GDCs will be transformed from regional warehouses to regional cross-dockings, which means they will no longer carry inventories.

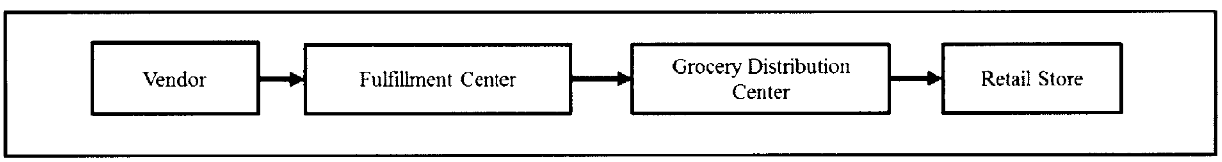


Figure 3: Multi-echelon supply chain with a fulfillment center

A fulfillment center will aggregate demands across assigned GDCs, making the possibility that high demand from one GDC will be offset by low demand from another one. Thus, the total demand variability of those GDCs will be reduced. The reduction in variability decreases safety stock and therefore reduces average inventory level. This phenomenon is called the risk-pooling effect. From the risk-pooling effect, an FFC will also reduce the safety time of each fresh produce category.

GDCs will function as a cross-dock to disaggregate products in a large shipment from the FFC to various smaller shipments for retail stores.

5.2.2 Total Supply Chain Cycle Time

We used the term "total supply chain cycle time" as a key metric to measure the product freshness. With a fulfillment center in the supply chain, safety time and transit time are changed. However, inventory dwell time does not change in this case because we will still use the same replenishment schedule. Total transit time will be increased because an FFC adds more "touches" of the inventories; transit time will be longer due to the extra processing activities. For the safety time, risk pooling at FFC reduces the safety time of the supply chain. Considering transit time and safety time, improvement in the upply chain from a fulfillment center depends on the magnitude of a decrease in safety time and the magnitude of an increase in transit time.

Using our predictive model with historical demand data and current parameters of network configurations and inventory policy, we found that six product categories out of twenty one product categories have shorter total supply chain cycle time in a supply chain network with a fulfillment center. These products are *Berries, Watermelons, Cherries, Mixed melons, Stone fruit, and Strawberries.*

5.2.3 Enhanced Coefficient of Variation (ECV)

We observed that product categories which had savings in the total supply chain cycle time generally had high demand volatility. We created a term "enhanced coefficient of variation (ECV)" to quantify demand volatility. From our predictive model, we found the minimum ECVs for different order frequencies in order for categories to reach the reduction of the total supply chain cycle time. (Table 11). This ECV break-event point is a key indicator to choose which supply chain network for products to go through. From our table in section 4.1.5, the increase in order frequency will increase the ECV break-event point.

5.2.4 Safety Stock

Different product categories with the same safety time reduction do not necessarily have the same saving in safety stock. Since reduction in safety stock saving depends on both reduction in the safety time and the average demand, there is a possibility that some product categories will have significant saving in safety stock while reduction in safety time is minimal.

For some fresh product categories, a supply chain network with a fulfillment center increases total supply chain cycle time but also provides a significant saving in safety stock. For example, *Avocadoes, Grapes, and Citrus* could have a significant reduction in safety stock by adding less than 0.15 days into the total supply chain cycle time. Therefore, it might be viable to flow these products through a supply chain network with a fulfillment center.

5.2.5 Total Inventory of the Supply Chain

Our inventory model focuses on inventory level in supply chain, which is a key concern for the supply chain management. Adding a fulfillment center to the supply chain will increase inventory at the retail stores. DOS at retail stores will increase because the lead time from the FFC to the retail stores is longer than the lead time from the GDCs to the retail stores. The increase of lead time makes the retail stores to carry more safety stock to mitigate stock-outs due to demand uncertainty over longer lead time. However, with risk pooling effect, an FFC carries less inventories than the sum of average inventories at the GDCs.

Our model revealed that all product categories, except *Tomato*, had lower total inventory in supply chain in a supply chain network with a fulfillment center. This means that the increase of inventories at the retail stores is less than the decrease of the inventories at the FFC.

5.3 Extension of the Model

Our thesis mainly focuses on the impacts and the benefits of an additional upstream facility to improve the products' freshness. Our predictive model is a prototype of the channeling decision tool based on changes in total supply chain cycle time when product go through a supply chain network with an FFC. The following variables can be added into our predictive model for extension;

- *Transit Time Variations:*

  The transit time variations can amplify the volatility of the order quantities of each echelon, which leads to changes in the safety time.

- *Demand Correlations Between Retail Stores:*

  This thesis assumed all retails store demands were independent, thus the demand correlations of those retails stores were zero. If we concern of the demand correlation in this prototype, the indication power of the enhanced coefficient of variation will be reduced.

- *Transportation and Administration Costs:*

  An FFC adds more transportation routes between the FFC and the GDCs and more administration cost into the current supply chain. Firm A needs to deduct this extra cost from the benefit of the inventory savings to determine the business viability of an FFC.

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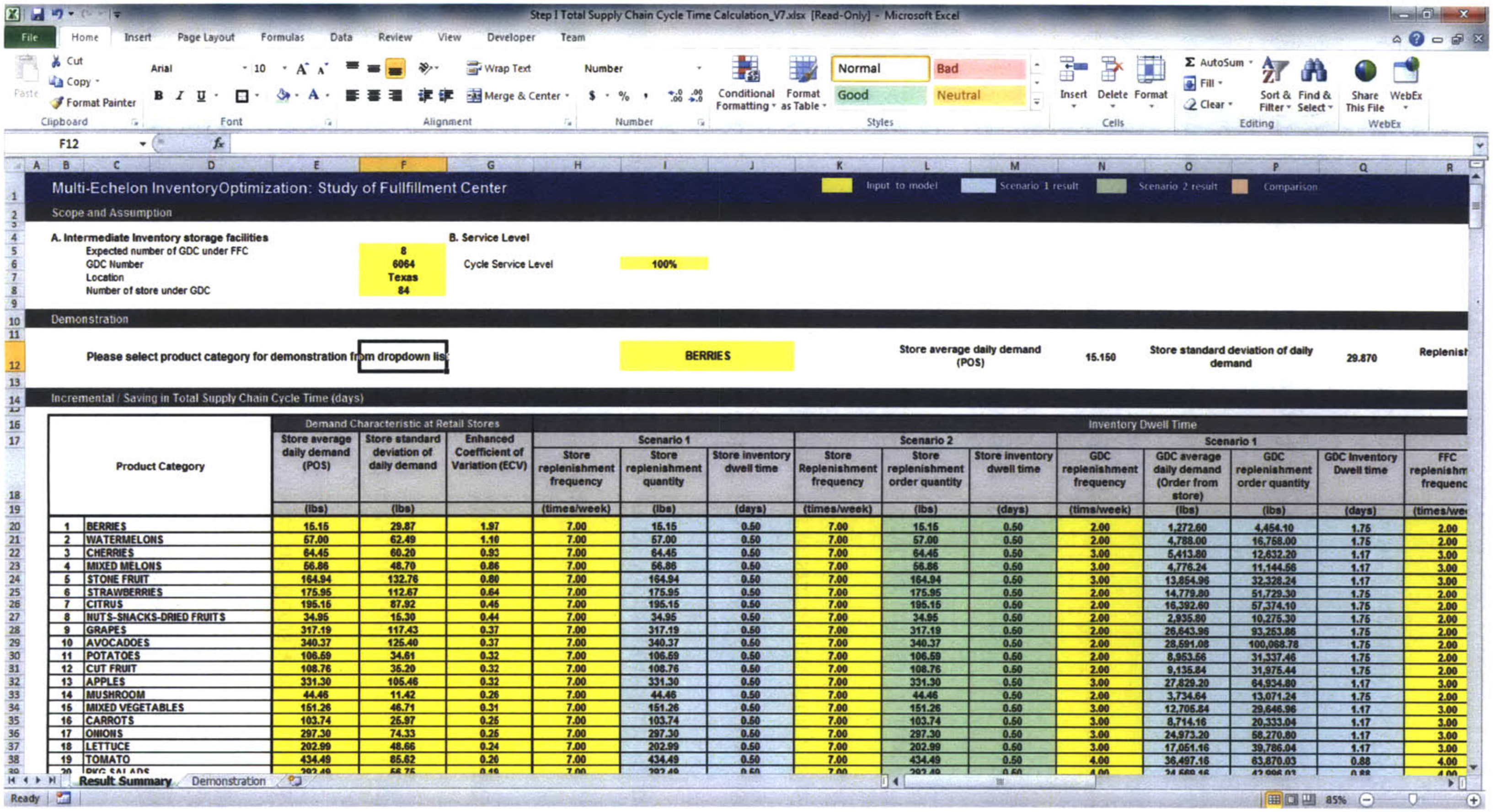
Appendix A.1: The Predictive Model



Step I Total Supply Chain Cycle Time Calculation_V7.xlsx [Read-Only] - Microsoft Excel

Multi-Echelon InventoryOptimization: Study of Fullfillment Center

Input to model | Scenario 1 result | Scenario 2 result | Comparison

Scope and Assumption

A. Intermediate Inventory storage facilities

Expected number of GDC under FFC	8
GDC Number	6064
Location	Texas
Number of store under GDC	84

B. Service Level

Cycle Service Level	100%

Demonstration

Please select product category for demonstration from dropdown list: **BERRIES**

Store average daily demand (POS): 15.150 | Store standard deviation of daily demand: 29.870 | Replenish

Incremental / Saving in Total Supply Chain Cycle Time (days)

	Product Category	Demand Characteristic at Retail Stores: Store average daily demand (POS) (lbs)	Store standard deviation of daily demand (lbs)	Enhanced Coefficient of Variation (ECV)	Inventory Dwell Time: Scenario 1: Store replenishment frequency (times/week)	Store replenishment quantity (lbs)	Store inventory dwell time (days)	Scenario 2: Store Replenishment frequency (times/week)	Store replenishment order quantity (lbs)	Store inventory dwell time (days)	Scenario 1: GDC replenishment frequency (tims/week)	GDC average daily demand (Order from store) (lbs)	GDC replenishment order quantity (lbs)	GDC Inventory Dwell time (days)	FFC replenishm frequenc (times/we
1	BERRIES	15.15	29.87	1.97	7.00	15.15	0.50	7.00	15.15	0.50	2.00	1,272.60	4,454.10	1.75	2.00
2	WATERMELONS	57.00	62.49	1.10	7.00	57.00	0.50	7.00	57.00	0.50	2.00	4,788.00	16,758.00	1.75	2.00
3	CHERRIES	64.45	60.20	0.93	7.00	64.45	0.50	7.00	64.45	0.50	3.00	5,413.80	12,632.20	1.17	3.00
4	MIXED MELONS	56.86	48.70	0.86	7.00	56.86	0.50	7.00	56.86	0.50	3.00	4,776.24	11,144.56	1.17	3.00
5	STONE FRUIT	164.94	132.76	0.80	7.00	164.94	0.50	7.00	164.94	0.50	3.00	13,854.96	32,328.24	1.17	3.00
6	STRAWBERRIES	175.95	112.67	0.64	7.00	175.95	0.50	7.00	175.95	0.50	2.00	14,779.80	51,729.30	1.75	2.00
7	CITRUS	195.15	87.92	0.45	7.00	195.15	0.50	7.00	195.15	0.50	2.00	16,392.60	57,374.10	1.75	2.00
8	NUTS-SNACKS-DRIED FRUITS	34.95	15.30	0.44	7.00	34.95	0.50	7.00	34.95	0.50	2.00	2,935.80	10,275.30	1.75	2.00
9	GRAPES	317.19	117.43	0.37	7.00	317.19	0.50	7.00	317.19	0.50	2.00	26,643.96	93,253.86	1.75	2.00
10	AVOCADOES	340.37	125.40	0.37	7.00	340.37	0.50	7.00	340.37	0.50	2.00	28,591.08	100,068.78	1.75	2.00
11	POTATOES	106.59	34.61	0.32	7.00	106.59	0.50	7.00	106.59	0.50	2.00	8,953.56	31,337.46	1.75	2.00
12	CUT FRUIT	108.76	35.20	0.32	7.00	108.76	0.50	7.00	108.76	0.50	2.00	9,135.84	31,975.44	1.75	2.00
13	APPLES	331.30	105.46	0.32	7.00	331.30	0.50	7.00	331.30	0.50	3.00	27,829.20	64,934.80	1.17	3.00
14	MUSHROOM	44.46	11.42	0.26	7.00	44.46	0.50	7.00	44.46	0.50	2.00	3,734.64	13,071.24	1.75	2.00
15	MIXED VEGETABLES	151.26	46.71	0.31	7.00	151.26	0.50	7.00	151.26	0.50	3.00	12,705.84	29,646.96	1.17	3.00
16	CARROTS	103.74	25.97	0.25	7.00	103.74	0.50	7.00	103.74	0.50	3.00	8,714.16	20,333.04	1.17	3.00
17	ONIONS	297.30	74.33	0.25	7.00	297.30	0.50	7.00	297.30	0.50	3.00	24,973.20	58,270.80	1.17	3.00
18	LETTUCE	202.99	48.66	0.24	7.00	202.99	0.50	7.00	202.99	0.50	3.00	17,051.16	39,786.04	1.17	3.00
19	TOMATO	434.49	85.62	0.20	7.00	434.49	0.50	7.00	434.49	0.50	4.00	36,497.16	63,870.03	0.88	4.00

Result Summary | Demonstration

Appendix A.2: Model Input

Multi-Echelon InventoryOptimization: Study of Fullfillment Center

Input to model | Scenario 1 result | Scenario 2 result | Comparison

Scope and Assumption

A. Intermediate Inventory storage facilities

Expected number of GDC under FFC	8
GDC Number	6064
Location	Texas
Number of store under GDC	84

B. Service Level

Cycle Service Level	100%

Demonstration

Please select product category for demonstration from dropdown list: **BERRIES**

Store average daily demand (POS): 15.150 — Store standard deviation of daily demand: 29.870 — Replenish

Incremental / Saving in Total Supply Chain Cycle Time (days)

	Product Category	Demand Characteristic at Retail Stores: Store average daily demand (POS) (lbs)	Store standard deviation of daily demand (lbs)	Enhanced Coefficient of Variation (ECV)	Store replenishment frequency (times/week)	Store Replenishment frequency (times/week)	Transit Time: Scenario 1: From Supplier to GDC (days)	Scenario 2: From Supplier to FFC (days)	FCC Processing Time (days)	From FFC to GDC (days)	From GDC to Store (days)
1	BERRIES	15.15	29.87	1.97	7.00	7.00	4.00	3.00	0.30	1.00	1.00
2	WATERMELONS	57.00	62.49	1.10	7.00	7.00	5.00	4.00	0.30	1.00	1.00
3	CHERRIES	64.45	60.20	0.93	7.00	7.00	6.00	5.00	0.30	1.00	1.00
4	MIXED MELONS	56.86	48.70	0.86	7.00	7.00	5.00	4.00	0.30	1.00	1.00
5	STONE FRUIT	164.94	132.76	0.80	7.00	7.00	4.00	3.00	0.30	1.00	1.00
6	STRAWBERRIES	175.95	112.67	0.64	7.00	7.00	5.00	4.00	0.30	1.00	1.00
7	CITRUS	195.15	87.92	0.45	7.00	7.00	4.00	3.00	0.30	1.00	1.00
8	NUTS-SNACKS-DRIED FRUITS	34.95	15.30	0.44	7.00	7.00	5.00	4.00	0.30	1.00	1.00
9	GRAPES	317.19	117.43	0.37	7.00	7.00	5.00	4.00	0.30	1.00	1.00
10	AVOCADOES	340.37	125.40	0.37	7.00	7.00	4.00	3.00	0.30	1.00	1.00
11	POTATOES	106.59	34.61	0.32	7.00	7.00	5.00	4.00	0.30	1.00	1.00
12	CUT FRUIT	108.76	35.20	0.32	7.00	7.00	4.00	3.00	0.30	1.00	1.00
13	APPLES	331.30	105.46	0.32	7.00	7.00	5.00	4.00	0.30	1.00	1.00
14	MUSHROOM	44.46	11.42	0.26	7.00	7.00	6.00	5.00	0.30	1.00	1.00
15	MIXED VEGETABLES	151.26	46.71	0.31	7.00	7.00	6.00	5.00	0.30	1.00	1.00
16	CARROTS	103.74	25.97	0.25	7.00	7.00	5.00	4.00	0.30	1.00	1.00
17	ONIONS	297.30	74.33	0.25	7.00	7.00	4.00	3.00	0.30	1.00	1.00
18	LETTUCE	202.99	48.66	0.24	7.00	7.00	4.00	3.00	0.30	1.00	1.00
19	TOMATO	434.49	85.62	0.20	7.00	7.00	2.00	1.00	0.30	1.00	1.00
20	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.00	2.00	0.30	1.00	1.00
							5.00	4.00	0.30	1.00	1.00

Appendix A.3: Inventory Dwell Time, Transit Time, and Safety Time

Incremental / Saving in Total Supply Chain Cycle Time (days)

Inventory Dwell Time

	Product Category	Scenario 1 Store replenishment frequency (times/week)	Scenario 1 Store replenishment quantity (lbs)	Scenario 1 Store inventory dwell time (days)	Scenario 2 Store Replenishment frequency (times/week)	Scenario 2 Store replenishment order quantity (lbs)	Scenario 2 Store inventory dwell time (days)
1	BERRIES	7.00	15.15	0.50	7.00	15.15	0.50
2	WATERMELONS	7.00	57.00	0.50	7.00	57.00	0.50
3	CHERRIES	7.00	64.45	0.50	7.00	64.45	0.50
4	MIXED MELONS	7.00	56.86	0.50	7.00	56.86	0.50
5	STONE FRUIT	7.00	164.94	0.50	7.00	164.94	0.50
6	STRAWBERRIES	7.00	175.95	0.50	7.00	175.95	0.50
7	CITRUS	7.00	195.15	0.50	7.00	195.15	0.50
8	NUTS-SNACKS-DRIED FRUITS	7.00	34.95	0.50	7.00	34.95	0.50
9	GRAPES	7.00	317.19	0.50	7.00	317.19	0.50
10	AVOCADOES	7.00	340.37	0.50	7.00	340.37	0.50
11	POTATOES	7.00	106.59	0.50	7.00	106.59	0.50
12	CUT FRUIT	7.00	108.76	0.50	7.00	108.76	0.50
13	APPLES	7.00	331.30	0.50	7.00	331.30	0.50
14	MUSHROOM	7.00	44.46	0.50	7.00	44.46	0.50
15	MIXED VEGETABLES	7.00	151.26	0.50	7.00	151.26	0.50
16	CARROTS	7.00	103.74	0.50	7.00	103.74	0.50
17	ONIONS	7.00	297.30	0.50	7.00	297.30	0.50
18	LETTUCE	7.00	202.99	0.50	7.00	202.99	0.50
19	TOMATO	7.00	434.49	0.50	7.00	434.49	0.50
20	PKG SALADS	7.00	292.49	0.50	7.00	292.49	0.50
21	BANANAS	7.00	1,427.05	0.50	7.00	1,427.05	0.50

	Product Category	Scenario 1 GDC replenishment frequency (tims/week)	Scenario 1 GDC average daily demand (Order from store) (lbs)	Scenario 1 GDC replenishment order quantity (lbs)	Scenario 1 GDC Inventory Dwell time (days)	Scenario 2 FFC replenishment frequency (times/week)	Scenario 2 FFC average daily demand (Order from store) (lbs)	Scenario 2 FFC replenishment order quantity (lbs)	Scenario 2 FFC Inventory Dwell time (days)
1	BERRIES	2.00	1,272.60	4,454.10	1.75	2.00	10,180.80	35,632.80	1.75
2	WATERMELONS	2.00	4,788.00	16,758.00	1.75	2.00	38,304.00	134,064.00	1.75
3	CHERRIES	3.00	5,413.80	12,632.20	1.17	3.00	43,310.40	101,057.60	1.17
4	MIXED MELONS	3.00	4,776.24	11,144.56	1.17	3.00	38,209.92	89,156.48	1.17
5	STONE FRUIT	3.00	13,854.96	32,328.24	1.17	3.00	110,839.68	258,625.92	1.17
6	STRAWBERRIES	2.00	14,779.80	51,729.30	1.75	2.00	118,238.40	413,834.40	1.75
7	CITRUS	2.00	16,392.60	57,374.10	1.75	2.00	131,140.80	458,992.80	1.75
8	NUTS-SNACKS-DRIED FRUITS	2.00	2,935.80	10,275.30	1.75	2.00	23,486.40	82,202.40	1.75
9	GRAPES	2.00	26,643.96	93,253.86	1.75	2.00	213,151.68	746,030.88	1.75
10	AVOCADOES	2.00	28,591.08	100,068.78	1.75	2.00	228,728.64	800,550.24	1.75
11	POTATOES	2.00	8,963.56	31,337.46	1.75	2.00	71,628.48	250,699.68	1.75
12	CUT FRUIT	2.00	9,135.84	31,975.44	1.75	2.00	73,086.72	255,803.52	1.75
13	APPLES	3.00	27,829.20	64,934.80	1.17	3.00	222,633.60	519,478.40	1.17
14	MUSHROOM	2.00	3,734.64	13,071.24	1.75	2.00	29,877.12	104,569.92	1.75
15	MIXED VEGETABLES	3.00	12,705.84	29,646.96	1.17	3.00	101,646.72	237,175.68	1.17
16	CARROTS	3.00	8,714.16	20,333.04	1.17	3.00	69,713.28	162,664.32	1.17
17	ONIONS	3.00	24,973.20	58,270.80	1.17	3.00	199,785.60	466,166.40	1.17
18	LETTUCE	3.00	17,051.16	39,786.04	1.17	3.00	136,409.28	318,288.32	1.17
19	TOMATO	4.00	36,497.16	63,870.03	0.88	4.00	291,977.28	510,960.24	0.88
20	PKG SALADS	4.00	24,569.16	42,996.03	0.88	4.00	196,553.28	343,968.24	0.88
21	BANANAS	4.00	119,872.20	209,776.35	0.88	4.00	958,977.60	1,678,210.80	0.88

Transit Time

	Product Category	Scenario 1 From Supplier to GDC (days)	Scenario 2 From Supplier to FFC (days)	Scenario 2 FCC Processing Time (days)	Scenario 2 From FFC to GDC (days)	From GDC to Store (days)
1	BERRIES	4.00	3.00	0.30	1.00	1.00
2	WATERMELONS	5.00	4.00	0.30	1.00	1.00
3	CHERRIES	6.00	5.00	0.30	1.00	1.00
4	MIXED MELONS	5.00	4.00	0.30	1.00	1.00
5	STONE FRUIT	4.00	3.00	0.30	1.00	1.00
6	STRAWBERRIES	5.00	4.00	0.30	1.00	1.00
7	CITRUS	4.00	3.00	0.30	1.00	1.00
8	NUTS-SNACKS-DRIED FRUITS	5.00	4.00	0.30	1.00	1.00
9	GRAPES	5.00	4.00	0.30	1.00	1.00
10	AVOCADOES	4.00	3.00	0.30	1.00	1.00
11	POTATOES	5.00	4.00	0.30	1.00	1.00
12	CUT FRUIT	4.00	3.00	0.30	1.00	1.00
13	APPLES	5.00	4.00	0.30	1.00	1.00
14	MUSHROOM	6.00	5.00	0.30	1.00	1.00
15	MIXED VEGETABLES	6.00	5.00	0.30	1.00	1.00
16	CARROTS	5.00	4.00	0.30	1.00	1.00
17	ONIONS	4.00	3.00	0.30	1.00	1.00
18	LETTUCE	4.00	3.00	0.30	1.00	1.00
19	TOMATO	2.00	1.00	0.30	1.00	1.00
20	PKG SALADS	3.00	2.00	0.30	1.00	1.00
21	BANANAS	5.00	4.00	0.30	1.00	1.00

Safety Time

	Product Category	Scenario 1 Existing Supply Chain Network (days)	Scenario 2 Supply chain network with FFC (days)	Incremental / (Saving) in Variation in total supply chain cycle time (days)
1	BERRIES	1.50	0.53	(0.97)
2	WATERMELONS	0.83	0.29	(0.54)
3	CHERRIES	0.58	0.20	(0.37)
4	MIXED MELONS	0.53	0.19	(0.34)
5	STONE FRUIT	0.50	0.18	(0.32)
6	STRAWBERRIES	0.49	0.17	(0.31)
7	CITRUS	0.34	0.12	(0.22)
8	NUTS-SNACKS-DRIED FRUITS	0.33	0.12	(0.21)
9	GRAPES	0.28	0.10	(0.18)
10	AVOCADOES	0.28	0.10	(0.18)
11	POTATOES	0.25	0.09	(0.16)
12	CUT FRUIT	0.25	0.09	(0.16)
13	APPLES	0.20	0.07	(0.13)
14	MUSHROOM	0.19	0.07	(0.13)
15	MIXED VEGETABLES	0.19	0.07	(0.12)
16	CARROTS	0.16	0.05	(0.10)
17	ONIONS	0.15	0.05	(0.10)
18	LETTUCE	0.15	0.05	(0.10)
19	TOMATO	0.11	0.04	(0.07)
20	PKG SALADS	0.10	0.04	(0.07)
21	BANANAS	0.09	0.03	(0.06)

Appendix A.4: Total Supply Chain Cycle Time

	Product Category	Total Supply Chain Cycle Time			Safety Stock		
		Scenario 1 Existing Supply Chain Network	Scenario 2 Supply chain network with FFC	Incremental / (Saving) in Average total supply chain cycle time	Scenario 1 Existing Supply Chain Network	Scenario 2 Supply Chain network with FFC	Reduction in Safety Stock
		(days)	(days)	(days)	(lbs)	(lbs)	(lbs)
1	BERRIES	8.75	8.08	(0.67)	1,905	673	1,231
2	WATERMELONS	9.08	8.84	(0.24)	3,985	1,409	2,576
3	CHERRIES	9.25	9.17	(0.07)	3,134	1,108	2,026
4	MIXED MELONS	8.20	8.15	(0.04)	2,536	896	1,639
5	STONE FRUIT	7.17	7.14	(0.02)	6,912	2,444	4,468
6	STRAWBERRIES	8.74	8.72	(0.01)	7,185	2,540	4,645
7	CITRUS	7.59	7.67	0.08	5,606	1,982	3,624
8	NUTS-SNACKS-DRIED FRUITS	8.58	8.67	0.09	976	345	631
9	GRAPES	8.53	8.65	0.12	7,488	2,647	4,841
10	AVOCADOES	7.53	7.65	0.12	7,996	2,827	5,169
11	POTATOES	8.50	8.64	0.14	2,207	780	1,427
12	CUT FRUIT	7.50	7.64	0.14	2,245	794	1,451
13	APPLES	7.86	8.04	0.17	5,491	1,941	3,550
14	MUSHROOM	9.44	9.62	0.17	728	257	471
15	MIXED VEGETABLES	8.86	9.03	0.18	2,432	860	1,572
16	CARROTS	7.82	8.02	0.20	1,352	478	874
17	ONIONS	6.82	7.02	0.20	3,870	1,368	2,502
18	LETTUCE	6.82	7.02	0.20	2,534	896	1,638
19	TOMATO	4.48	4.71	0.23	3,861	1,365	2,496
20	PKG SALADS	5.48	5.71	0.23	2,559	905	1,654
21	BANANAS	7.46	7.71	0.24	10,717	3,789	6,928

Appendix B1: Simulations of the Inventory Level in Supply Chain

Inventory Model at Store

Demand Simulation Parameter

Average daily demand	1427.1	lb
STD of daily demand	237.7	lb

Replenishment Parameter

Lead time (LT)	1	day
Review Time (RT)	1	day
Cycle Service Level	98%	Percentage
Safety Factor	2.1	

Supplier Order Schedule

Mon	X
Tue	X
Wed	X
Thu	X
Fri	X
Sat	X
Sun	X

Summary Data (Annual)

Data: One Representative Store

	Forecast	Actual Demand		Forecast Error	Inventory On Hand	DOS	Replenishment Order
Averag	1,438	1,432	8	212	2,705	1.89	1,429
STD	101	247	2%	170			

Data: All store under

Average DOS	Average Replenishment
1.85	1422.40

Transaction Data (Daily)

	Forecast	Actual Demand	Forecast Error	Inventory: Beginning	Inventory: Ending Inventory (before replenishment)	Inventory: Shipment from GDC	Inventory: Ending Inventory (after replenishment)	DOS	Order Date	Replenishment Quantity	Safety Stock	Buffer Order Point (BOP)	Order Up to Level (OUTL)
Day -15		16											
Day -14		14											
Day -13		17											
Day -12		22											
Day -11	13	26		3,370	3,370		3,370						
Day -10	24	1,028	1,004	3,370	2,342		2,342	1.39	Yes	1,028	494	3,226	3,370
Day -9	227	1,287	1,060	2,342	1,055	1,028	2,083	1.19	Yes	2,315	494	3,226	3,370
Day -8	481	1,724	1,243	2,083	359	2,315	2,674	0.85	Yes	3,011	494	3,226	3,370
Day -7	823	1,245	423	2,674	1,428	3,011	4,440	1.43	Yes	1,942	494	3,226	3,370
Day -6	1,067	1,409	341	4,440	3,031	1,942	4,973	2.61	Yes	339	494	3,226	3,370
Day -5	1,344	1,550	206	4,973	3,423	339	3,762	2.93	Yes	0	494	3,226	3,370
Day -4	1,448	1,474	26	3,762	2,288	0	2,288	2.11	Yes	1,082	494	3,226	3,370
Day -3	1,486	1,843	358	2,288	445	1,082	1,527	0.95	Yes	2,925	494	3,226	3,370
Day -2	1,509	1,622	112	1,527	-95	2,925	2,830	0.50	Yes	3,465	494	3,226	3,370
Day -1	1,585	1,300	285	2,830	1,530	3,465	4,995	1.52	Yes	1,840	494	3,226	3,370
Day 0	1,563	1,315	248	4,995	3,681	1,840	5,521	3.03	Yes	0	494	3,226	3,370
Day 1	1,516	1,545	29	5,521	3,975	0	3,975	3.32	Yes	0	494	3,226	3,370
Day 2	1,530	1,623	93	3,975	2,352	0	2,352	2.21	Yes	1,018	494	3,226	3,370
Day 3	1,486	1,592	106	2,352	760	1,018	1,778	1.09	Yes	2,610	494	3,226	3,370
Day 4	1,480	1,713	232	1,778	65	2,610	2,675	0.64	Yes	3,305	494	3,226	3,370
Day 5	1,563	1,370	193	2,675	1,305	3,305	4,611	1.39	Yes	2,065	494	3,226	3,370
Day 6	1,574	1,087	487	4,611	3,524	2,065	5,588	2.84	Yes	0	494	3,226	3,370
Day 7	1,482	1,415	68	5,588	4,174	0	4,174	3.41	Yes	0	494	3,226	3,370
Day 8	1,440	1,511	71	4,174	2,663	0	2,663	2.39	Yes	707	494	3,226	3,370
Day 9	1,424	1,749	325	2,663	913	707	1,621	1.25	Yes	2,457	494	3,226	3,370
Day 10	1,432	1,557	125	1,621	64	2,457	2,521	0.59	Yes	3,306	494	3,226	3,370
Day 11	1,469	1,304	165	2,521	1,217	3,306	4,523	1.30	Yes	2,153	494	3,226	3,370
Day 12	1,512	1,249	264	4,523	3,275	2,153	5,428	2.72	Yes	0	494	3,226	3,370
Day 13	1,479	1,445	34	5,428	3,982	0	3,982	3.29	Yes	0	494	3,226	3,370

Inventory Model at GDC

Re[illegible]nishment Parameter

Supplier Lead time (LT)	1	day
Review Time (RT)	1.0	day
Average DOS	3.13	day
Cycle Service Level	98%	
Safety Factor	2.0	

Supplier Order Schedule

Mon	X
Tue	X
Wed	X
Thu	X
Fri	X
Sat	X
Sun	X

Summary Data (Annual)

	Forecast	Actual Demand	Forecast Error
Average	14,305	14,240	2,970
STD	361	3543	1973

Inventory On Hand	DOS
29,312	2.06

Replenishment Quantity	Safety Stock	Buffer Order Point	Order Up to Level (OUTL)
14,172	5,468	32,648	34,078

Transaction Data (Daily)

		Forecast	Actual Demand	Forecast Error	Inventory					Order Date	Replenishment Quantity	Safety Stock	Buffer Order Point (BOP)	Order Up to Level (OUTL)
					Beginning	Ending Inventory (before replenis	Shipment from GDC	Ending Inventory (after replenis	DOS					
Sat	Day -15													
Sun	Day -14													
Mon	Day -13													
Tue	Day -12													
Wed	Day -11				34,078	34,078								
Thu	Day -10	242	12,706	12,464	50,000	37,294		37,294	1.95	Yes	0	5,468	32,648	34,078
Fri	Day -9	2,751	27,439	24,687	37,294	9,856	0	9,856	1.66	Yes	24,223	5,468	32,648	34,078
Sat	Day -8	5,670	28,887	23,217	9,856	-19,031	24,223	5,192	(0.32)	Yes	53,109	5,468	32,648	34,078
Sun	Day -7	8,466	16,750	8,283	5,192	-11,558	53,109	41,551	(0.22)	Yes	45,637	5,468	32,648	34,078
Mon	Day -6	11,483	3,044	8,439	41,551	38,507	45,637	84,144	2.81	Yes	0	5,468	32,648	34,078
Tue	Day -5	14,388	1,668	12,720	84,144	82,475	0	82,475	5.85	Yes	0	5,468	32,648	34,078
Wed	Day -4	14,640	11,324	3,316	82,475	71,151	0	71,151	5.39	Yes	0	5,468	32,648	34,078
Thu	Day -3	14,594	22,027	7,432	71,151	49,125	0	49,125	4.22	Yes	0	5,468	32,648	34,078
Fri	Day -2	14,237	25,885	11,648	49,125	23,240	0	23,240	2.54	Yes	10,839	5,468	32,648	34,078
Sat	Day -1	14,214	18,531	4,317	23,240	4,709	10,839	15,548	0.98	Yes	29,369	5,468	32,648	34,078
Sun	Day 0	14,191	8,194	5,996	15,548	7,354	29,369	36,723	0.80	Yes	26,725	5,468	32,648	34,078
Mon	Day 1	14,520	5,160	9,360	36,723	31,563	26,725	58,288	2.40	Yes	2,515	5,468	32,648	34,078
Tue	Day 2	14,563	11,142	3,420	58,288	47,145	2,515	49,661	3.70	Yes	0	5,468	32,648	34,078
Wed	Day 3	15,093	19,548	4,454	49,661	30,113	0	30,113	2.80	Yes	3,965	5,468	32,648	34,078
Thu	Day 4	14,744	20,254	5,510	30,113	9,859	3,965	13,824	1.40	Yes	24,219	5,468	32,648	34,078
Fri	Day 5	14,179	14,060	119	13,824	-236	24,219	23,984	0.48	Yes	34,314	5,468	32,648	34,078
Sat	Day 6	13,728	7,737	5,991	23,984	16,247	34,314	50,561	1.41	Yes	17,832	5,468	32,648	34,078
Sun	Day 7	13,533	8,155	5,378	50,561	42,406	17,832	60,238	3.26	Yes	0	5,468	32,648	34,078
Mon	Day 8	13,418	15,469	2,051	60,238	44,769	0	44,769	3.69	Yes	0	5,468	32,648	34,078
Tue	Day 9	13,697	21,238	7,541	44,769	23,531	0	23,531	2.40	Yes	10,548	5,468	32,648	34,078
Wed	Day 10	14,200	18,898	4,698	23,531	4,633	10,548	15,181	0.39	Yes	29,445	5,468	32,648	34,078
Thu	Day 11	14,154	11,574	2,581	15,181	3,607	29,445	33,052	0.66	Yes	30,472	5,468	32,648	34,078
Fri	Day 12	14,219	8,650	5,569	33,052	24,402	30,472	54,874	2.02	Yes	9,677	5,468	32,648	34,078
Sat	Day 13	14,458	10,519	3,939	54,874	44,355	9,677	54,032	3.48	Yes	0	5,468	32,648	34,078

Inventory Model at FFC

Replenishment Parameter

Supplier Lead time (LT)	4	day
Review Time (RT)	2.3	day
Average DOS	3.13	day
Cycle Service Level	98%	
Safety Factor	2.0	

Supplier Order Schedule

Mon	X
Tue	
Wed	X
Thu	
Fri	X
Sat	
Sun	

Summary Data (Annual)

	Forecast	Actual Demand	Forecast Error
Average	114,438	113,979	12,277
STD	962	18570	13967

Inventory On Hand	DOS
593,864	5.21

Replenishment Quantity	Safety Stock	Buffer Order Point	Order Up to Level (OUTL)
111,454	68,890	766,962	793,664

Transaction Data (Daily)

		Forecast	Actual Demand	Forecast Error	Inventory: Beginning	Ending Inventory (before replenis	Shipment from GDC	Ending Inventory (after replenishment)	DOS	Order Date	Replenishment Quantity	Safety Stock	Buffer Order Point (BOP)	Order Up to Level (OUTL)
Sat	Day -15													
Sun	Day -14													
Mon	Day -13													
Tue	Day -12													
Wed	Day -11				793,664	793,664								
Thu	Day -10	1,936	112,851	110,915	793,664	680,813		680,813	6.47	No	0	68,890	766,962	793,664
Fri	Day -9	24,250	228,885	204,635	680,813	451,929		451,929	4.97	Yes	341,736	68,890	766,962	793,664
Sat	Day -8	47,233	229,199	181,966	451,929	222,730		222,730	2.96	No	0	68,890	766,962	793,664
Sun	Day -7	69,594	119,898	50,304	222,730	102,832		102,832	1.43	No	0	68,890	766,962	793,664
Mon	Day -6	93,159	20,337	72,822	102,832	82,496	0	82,496	0.81	Yes	711,168	68,890	766,962	793,664
Tue	Day -5	115,965	16,213	99,752	82,496	66,282	341,736	408,018	0.65	No	0	68,890	766,962	793,664
Wed	Day -4	116,576	93,198	23,378	408,018	314,820	0	314,820	3.17	Yes	478,845	68,890	766,962	793,664
Thu	Day -3	115,512	192,831	77,318	314,820	121,989	0	121,989	1.92	No	0	68,890	766,962	793,664
Fri	Day -2	116,049	213,594	97,545	121,989	-91,605	711,168	619,564	0.13	Yes	885,269	68,890	766,962	793,664
Sat	Day -1	114,924	135,083	20,159	619,564	484,481	0	484,481	4.84	No	0	68,890	766,962	793,664
Sun	Day 0	114,566	42,024	72,542	484,481	442,457	478,845	921,301	4.07	No	0	68,890	766,962	793,664
Mon	Day 1	114,181	24,758	89,423	921,301	896,543	0	896,543	7.97	Yes	0	68,890	766,962	793,664
Tue	Day 2	114,730	85,194	29,536	896,543	811,350	885,269	1,696,619	7.49	No	0	68,890	766,962	793,664
Wed	Day 3	113,960	172,309	58,348	1,696,619	1,524,310	0	1,524,310	14.13	Yes	0	68,890	766,962	793,664
Thu	Day 4	113,817	198,159	84,342	1,524,310	1,326,151	0	1,326,151	12.50	No	0	68,890	766,962	793,664
Fri	Day 5	113,162	140,699	27,538	1,326,151	1,185,452	0	1,185,452	11.02	Yes	0	68,890	766,962	793,664
Sat	Day 6	113,290	59,336	53,954	1,185,452	1,126,116	0	1,126,116	10.14	No	0	68,890	766,962	793,664
Sun	Day 7	113,322	39,928	73,394	1,126,116	1,086,189	0	1,086,189	9.70	No	0	68,890	766,962	793,664
Mon	Day 8	114,558	92,467	22,091	1,086,189	993,722	0	993,722	9.12	Yes	0	68,890	766,962	793,664
Tue	Day 9	115,025	164,255	49,230	993,722	829,467	0	829,467	8.00	No	0	68,890	766,962	793,664
Wed	Day 10	115,721	188,932	73,211	829,467	640,535	0	640,535	6.45	Yes	153,129	68,890	766,962	793,664
Thu	Day 11	116,225	138,597	22,372	640,535	501,939	0	501,939	5.01	No	0	68,890	766,962	793,664
Fri	Day 12	116,234	66,284	49,950	501,939	435,654	0	435,654	4.11	Yes	358,010	68,890	766,962	793,664

Inventory Model at GDC 1

Replenishment Parameter

Supplier Lead time (LT)	1
Review Time (RT)	1.0
Average DOS	3.13
Cycle Service Level	98%
Safety Factor	2.0

Summary Data (Annual)

	Forecast	Actual Demand
Average	14,332	14,275
STD	313	3688

Transaction Data (Daily)

		Forecast	Actual Demand
Sat	Day -15		
Sun	Day -14		
Mon	Day -13		
Tue	Day -12		
Wed	Day -11		
Thu	Day -10	242	14,313
Fri	Day -9	3,073	28,346
Sat	Day -8	5,851	27,172
Sun	Day -7	8,445	14,452
Mon	Day -6	11,526	3,825
Tue	Day -5	14,432	3,746
Wed	Day -4	14,596	13,294
Thu	Day -3	14,663	24,507
Fri	Day -2	15,027	25,932
Sat	Day -1	14,846	14,768
Sun	Day 0	14,557	4,533
Mon	Day 1	14,646	4,423
Tue	Day 2	14,611	14,705
Wed	Day 3	14,698	25,131
Thu	Day 4	14,724	24,463
Fri	Day 5	14,863	12,872
Sat	Day 6	14,411	4,309
Sun	Day 7	14,494	4,173
Mon	Day 8	14,114	13,915
Tue	Day 9	14,105	24,839
Wed	Day 10	14,317	26,819
Thu	Day 11	14,833	16,191
Fri	Day 12	14,744	4,059

Inventory Model at GDC 2

Summary Data (Annual)

	Forecast	Actual Demand
Average	14,341	14,284
STD	368	3488

Transaction Data (Daily)

		Forecast	Actual Demand
Sat	Day -15		
Sun	Day -14		
Mon	Day -13		
Tue	Day -12		
Wed	Day -11		
Thu	Day -10	242	14,315
Fri	Day -9	3,073	28,409
Sat	Day -8	5,864	28,544
Sun	Day -7	8,720	14,032
Mon	Day -6	11,455	1,049
Tue	Day -5	14,116	1,711
Wed	Day -4	14,333	13,736
Thu	Day -3	14,387	27,220
Fri	Day -2	14,536	27,938
Sat	Day -1	14,648	15,218
Sun	Day 0	14,835	4,126
Mon	Day 1	14,766	3,294
Tue	Day 2	14,629	9,094
Wed	Day 3	13,916	19,859
Thu	Day 4	13,995	25,527
Fri	Day 5	14,048	21,196
Sat	Day 6	14,142	9,725
Sun	Day 7	14,186	4,569
Mon	Day 8	14,827	9,002
Tue	Day 9	14,566	16,853
Wed	Day 10	14,492	20,893
Thu	Day 11	13,995	19,147
Fri	Day 12	14,144	12,195