VMI vs. Order Based Fulfillment

by

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ABSTRACT

In this thesis, two inventory fulfillment methods are compared by evaluating the vendor managed inventory (VMI) fulfillment against the current order based fulfillment. Several forms of adaptation to VMI are described. The costs and benefits of VMI are quantified. The difference between the current process and the proposed VMI process is measured by the monetary amount in total inventory storage, routing, management cost, and payment terms in one distribution center. A conclusion is drawn to determine whether VMI is a beneficial alternative to the current process, and possible future research is discussed.

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1 Introduction

Vendor managed inventory (VMI) fulfillment has become an important alternative method in inventory management in recent years. When implemented, VMI provides improved customer service to retailers and increased visibility and control of the inventory to the vendor, which in turn, offers further improvement and optimization opportunities. In a typical supply chain, the cost of management and transport of the products is a large expense, which is ultimately paid by the end user. But it is a concern for the vendor since reduction in transportation and inventory management makes products cheaper and therefore more competitive. This thesis investigates the potential of VMI with a large chemical manufacturer and its customers.

1.1 Vendor Managed Inventory (VMI)

VMI is the practice where vendors are responsible for determining the order size and timing for customers, usually based on receipt of retail point of sale and inventory data (Richardson, 2004). The vendor makes the replenishment decision for its customers based on shared information and inventory policies (Angulo, Nachtmann, & Waller, 2004). As a planning and management system, VMI is not directly tied to inventory ownership (Fox, 1996). When VMI is in practice, the vendor gains access to its customers’ inventory information and receives withdrawal and current balance information. The vendor, instead of the customer, assumes responsibility of monitoring its sales and inventory for the purpose of triggering replenishment orders and decides when and how much inventory should be replenished at each customer.

Under conventional inventory management, orders are controlled by customers and arrive randomly without regard to the actual cost of fulfillment. Consequently, the vendor's resources, such as the transportation and storage facilities cannot be well planned ahead (Kleywegt, Nori, &
Really urgent orders may be delayed because of a lack of information and a high demand on the vendor’s resources (Kleywegt et al., 2002).

VMI has evolved over the past few decades. Initially, many vendor-stocking programs operated by a vendor’s representative visiting a customer a few times a month and restocking the supplies to an agreed upon level (Fox, 1996). Later the VMI practice was adopted and popularized by War-Mart (Fox, 1996). Those visits by vendors were replaced with information gathered from customers and transmitted directly to a vendor’s computer system via EDI. Both customers and vendors need to make investments in new systems, software and employee training (Fox, 1996).

VMI can have a high impact on operational efficiency without completely reinventing the supply chain. What VMI really does is to serve as a set up to other possibilities of optimization and improvements. Jaillet, Bard, Huang, & Dror (2002) stated that vendors try to “develop ‘optimal’ a priori strategies based on expected consumption of customers, as opposed to reactive strategies based on accurate current knowledge of all local inventories.” (p. 293). Vendors gain valuable information that improves vehicle routing, inventory distribution and production planning.

To retailers, VMI offers benefits such as improved customer service and reduced management costs. The benefits of VMI to vendors include reduced demand uncertainty, reduced inventory requirements and reduced costs (Fox, 1996). By receiving timely information directly from customers, vendors can better respond to customers’ inventory needs in both quantity and location. By constantly monitoring customers’ inventory and demand patterns, the number of large and unexpected orders will decrease or even disappear. By knowing exactly how much inventory the customer is carrying, a vendor’s own inventory requirements can reduce as the need for excess stock to buffer against uncertainty is reduced or eliminated. By reorganizing and consolidating order fulfillment and distribution center replenishment activities, vendors are able to achieve cost reduction (Fox, 1996). Consolidations in transportation that would not be available with traditional method would become possible under VMI because the vendor controls the order timing (Kleywegt, Nori, & Savelsbergh, 2004). A practical benefit is reduced reliance on forecasting. With information sharing, the need for forecasting accuracy is
reduced. In addition, an important potential benefit is improved customer retention (Ross, 1996). Once a VMI system is developed and installed, a customer has effectively outsourced its material management function to its vendor and it becomes extremely difficult and costly for the customer to change vendors.

Furthermore, in the last decade the expression supply chain management, which emphasizes the view of the entire company as part of the supply chain, has become common (Bertazzi, Paletta, & Speranza, 2002). VMI in practice eliminates customers’ needs to manage inventory and takes off one duplicate process in the supply chain. As a result, VMI brings focus on cost effectiveness over the entire supply chain, from manufacturing, inventory storage to transportation, and attempts to coordinate inventory replenishment and transportation in such a way that the cost is minimized over the long run (Campbell, & Savelsbergh, 2004).

1.2 Consignment

Consignment occurs in some VMI programs. Generally, the change of ownership of goods happens at the same time as the change of inventory location. The ownership of the inventory is transferred from the vendor to the customer on receipt of goods by the customer. For example, this can be when the goods are delivered to a customer’s store from a vendor’s distribution center. In consignment, however, inventory is in the possession of the customer, but is still owned by the vendor (Piasecki, 2004). Ownership changes at the time of use by the end customer. In other words, some of the vendor’s inventory is in the customer’s possession (in customer’s store or warehouse), and it allows the customer to sell or consume directly from the vendor’s stock. The customer purchases the inventory only after it has been resold or consumed. Different practices that involve consignment are developing and gaining popularity among VMI relationships (Adel, 1996). Corbett (2001) identified a few types of consignment that are in common practice:

- Pay as sold in real time. In this type of arrangement, the ownership and payment are exchanged at the moment when the goods are consumed by the customer. Devices and facilities are set up to make the real time transactions feasible.
- Pay as sold during a pre defined period. In this type of arrangement, the ownership of the goods are transferred from the vendor to the customer at the moment of consumption; however the payment for the goods by the customer to the vendors come within a pre defined grace period after the transfer of ownership.

- Buy back after a pre defined period. In this type of arrangement, if the goods stored at the customer’s site are not consumed by the customer within a pre defined period of time, the customer has to face a choice to either take the ownership of the goods and make the payment or let the vendor take the goods back.

- Order to order consignment. In this type of arrangement, the exchange of ownership occurs when the next consignment order is placed and the customer is billed by the amount of goods in the previous consignment.

The benefits of consignment to customers include reduced or eliminated inventory costs and improved service level by making products immediately available to the customers, decreasing the risk of stock outs and last minute emergency orders. On the other hand, as a policy, consignment tends to highlight inefficiency caused by information disparities between the vendor and the customer. In such cases, vendors have to assume additional overhead and deal with discrepancies between customer’s reported usage and the vendor’s invoice (Greene, 2000). In addition, vendors tend to over compensate the buyer for stock outs (Corbett, 2001).

One of consignment’s most classic benefits to vendors comes when the vendor is trying to sell new and unproven products. Piasecki (2004) notes that by storing the stock in the retailer’s location it creates a scenario of shared risk, because while the vendor owns the inventory, the retailer provides the shelf space. This way, retailers are more likely to put the new and unproven products on their shelves. Consignment is based on immediate, and sometimes real time, communication of inventory changes between vendors and customers. In case of the ‘pay as sold in real time’ option, the level of information exchange and customer-vendor collaboration is usually high because vendors now have instant information at all times instead of the information from customers’ planning. Also, with consignment, customers effectively take responsibility of the storage of inventory and vendors are able to reduce warehousing costs. Furthermore, customers are now responsible for damages and disappearances of goods on their
properties and vendors are able to transfer insurance costs to customers. Finally, by closely tracking the use of product and acting swiftly on slow-moving items, vendors can minimize or completely eliminate product obsolescence (Ross, 1996).

In summary, VMI is the practice where vendors take over the inventory ordering management for its customers by gaining access of customers’ inventory information to monitor customers’ inventory balance and demand and decides when and how much to replenish each customer. Consignment inventory is inventory in possession of the customer but owned by the vendor and it becomes the customer’s property after it is consumed or resold by the customer.

1.3 Company Background

Company A is an international specialty chemical company that manufactures and distributes chemical products. The division in the US accounts for 15.5% of its global business. Specialty chemicals are high value added products used as intermediates, components or additives in a wide variety of products and processes. They are produced in relatively small volumes and must satisfy well defined performance requirements and specifications. Products are tailored to customer needs and rapid responses to changing customer needs are important competitive factors.

Within the US market, company A is currently one of the 3 largest companies in the specialty chemical industry. With 5 plants, 35 distribution centers, and more than 4,000 customers, they offer over 100 different products that are categorized into 9 groups. Company A had an annual sale of approximately $2 billion in 2004. The sales from the first quarter of 2005 shows a 17.8% increase, primarily as a result of increased sales volumes from refining technology products and increased prices due to energy costs. The annual average delivery volume of one distribution center is 1.11 million gallons.

Company A serves over 30 service regions in US and each region has its own distribution center (DC). In the central US, services regions are usually large with high customer density and sales volume. In the northeast, service regions are small to medium sized and while customer density is still high, sales volume is medium. In the west and the southwest and along the west
coast, service regions have very large service areas, with sparsely located customers and medium to low sales volume.

Company A employees a private fleet of roughly 70 tanker trucks. Each truck has a total capacity of 3,000 to 4,000 gallons which is divided into 4 to 5 compartments ranging from 400 gallons to 1,500 gallons. Each compartment has a list of compatible products and those products outside this list cannot be loaded into this compartment.

Distribution center DCW resides in a service region located in New England. It provides service to 164 customers, covering 961 different tanks at 235 locations. The service area of DCW is over 26 thousand square miles. DCW is seriously considering adopting VMI program for some of its customers. DCW currently operates 3 trucks on a regular basis. DCW has an annual delivery volume of 1.53 million gallons, ranking 8th out of company A’s 35 distribution centers in the US.

Company A’s supply chain includes raw material purchasing, manufacturing and distribution. Company A utilizes a centralized SAP server for transaction data and processing. Its current fulfillment process begins when the orders come in. Ninety percent of orders are initiated by the customers and entered into the database by sales personnel, and the rest are entered by customers themselves. Those customers have permission to the system and may enter orders on a weekly, biweekly or monthly basis.

Company A’s dispatch team is centralized and in charge of determining trucking routes for the entire company. Order data are submitted a week in advance, and dispatchers plan the daily trucking routes from each DC. According to company A, the majority of orders, around 97 to 98%, have a window of a week to fulfill. The remainder are orders entered with emergency status and need to be fulfilled by the end of the second day. Emergency orders usually do not come with any additional charges to the customer. Trucking routes are organized to maximize trucking utilization and routing efficiency, which are both important indicators of transportation efficiency (Gallego, & Simchi-Levi, 1990). Whenever possible, emergency orders are worked into the next day’s regular trucking routes. When an order (emergency or not) cannot be fit into a trucking route before it reaches its fulfillment time window, a delivery routing failure occurs (Dror, & Trudeau, 1988). This situation is dealt with by sending an extra truck.
Once the orders are fulfilled, the driver relays the delivery confirmation to the DC manager who enters the sale amount into the central transaction database. The system sends the customer the bill for all products delivered in that particular delivery. The customer pays the bill within the payment terms. Presently, payment terms of customers range from 45 days to 120 days with an average of 52 days.

In recent years, in the marketplace of chemical products industry, VMI has been gaining popularity as an emerging practice. As company A’s customers are looking for improved customer service and reduced inventory and capital costs, some of them have expressed strong interest in entering VMI and consignment deals with company A. In response, company A is considering offering such deals to selected customers in an effort to keep up customer satisfaction and, ultimately, market share. From the perspective of an entire supply chain, VMI cuts down some redundant processes, which will lead to cost savings and improved service levels. However, from company A’s perspective, VMI first and foremost will fundamentally alter its ordering and fulfillment process. Prior to officially offering VMI deals, in order to take advantage of potential benefits of VMI, company A needs to analyze its current fulfillment process and quantitatively evaluate the potential costs and savings by studying and assessing the impact of this strategy in terms of additional costs, potential savings and implementation feasibility.

1.4 Objective

The objectives of this thesis are a) to evaluate the financial and operational impact of VMI and consignment to company A, in particular, at DCW and determine whether VMI, or consignment, or the combination of both, is a potentially beneficial alternative or complement to the current process, b) to identify the best candidates among company A’s customers to enter VMI and consignment deals with company A, c) to discover potential obstacles in the implementation of VMI and consignment.
1.5 **Scope**

The scope of the thesis is to evaluate the VMI model versus the current model from distribution center level down to the customer level and assess the impact of different payment term lengths. It includes inventory management at DCW as well as its customers’ sites, distribution and transportation planning and management and payment terms. It does not include manufacturing or raw material purchasing and it is not in a position to contemplate adding or eliminating distribution centers.

The remainder of the thesis is organized as follows. Chapter 2 discusses the motivation and the relevance of the research. Chapter 3 starts by discussing the basic methodology used in the research, followed by the ‘As is’ analysis of the current process, followed by the analysis of impact of VMI and consignment, followed by the possibility offered by different payment terms, Chapter 4 presents the conclusion of the research and Chapter 5 looks into potential future research directions.
2 Motivation

The motivation of this research is to determine if VMI fulfillment is a beneficial alternative or complement to company A’s current order based fulfillment. While VMI obviously brings savings to customers through improved customer service and reduced inventory storage and management cost, the cost and saving tradeoffs to vendors are much more complicated and not as straightforward to decide. Customers, looking to reduce inventory storage and management costs, are eager to make VMI and consignment deals with vendors. But VMI does not necessarily become a cost effective practice to the vendors’ operation. Consignment, in particular, does not always lead to financial benefit for vendors and is not a policy that is recommended unconditionally.

2.1 Potential Costs

If company A adopts VMI, the potential costs consist of implementation costs and operational costs. Implementation costs include investments in new transaction processes, new software systems, and personnel training. Operational costs include costs of new equipment at customer sites, costs of possible increase of fulfillment frequencies and transportation, and overhead for collaboration exchange and information sharing. In addition, if consignment is part of the deal, further cost also includes inventory carrying cost for customers.

Large customers may rely on their leverage to pressure the vendor into consignment deals. Those customers currently own inventory at their own sites. Once a consignment deal is in place, customers still have inventory on their sites but the capital of the inventory is freed up. By entering into consignment deals with company A, customers are effectively transferring their inventory carrying cost and capital opportunity cost to company A.
2.2 Potential Benefits

Besides potential costs, there are opportunities associated with VMI for savings and process improvements. Company A is concerned for its market share and profitability and looks for potentials in VMI business operation. There are two potential areas for improvement.

First, with VMI, customers’ inventory allocation comes under company A’s controls. Ordering size and ordering frequency can affect the efficiency of fulfillment. Under the current traditional order based fulfillment, orders are made by customers to suit their convenience, and company A has no control over order sizes and frequencies. There may exist inefficiency in customers’ inventory management, and thus opportunities for improvement. For example, some customers place several very small orders a month instead of one large monthly order. This leads to a large transportation cost to company A. Other customers make emergency orders when there is not a real emergency. According to company A’s drivers, it is common for an emergency to be placed when the customer’s tank is only half empty. Some customers order large quantities at long intervals, making it difficult to forecast by company A. Company A needs to keep a high safety stock to buffer against such a situation. When company A enters into a VMI or consignment deal with a client, company A installs a measuring device in each tank that contains its stock and the device constantly monitors the usage of the chemical inside the tank. Once VMI is implemented and company A takes over inventory management for its customers, the number of occurrences of the scenarios described above will decrease.

Second, there is potential improvement through more efficient vehicle routing. Currently in the order based fulfillment process, company A reacts to customers orders with a week’s window for planning. The opportunity to group and cluster customers according to geographic location is limited within fulfillment trips made during the same week. With VMI, company A controls when to replenish each customer and is able to organize transportation routes and adjust trucking resources according its own best interests while maintaining an agreed upon service level.

In addition to the two potential benefits, VMI offers an opportunity to negotiate customers’ payment cycles. Payment cycle is defined as the number of days it takes for a
customer to pay Company A after the customer receives the delivered products. The payment cycle runs on a rolling basis, which means that for each customer, each delivery is billed separately and the bills are not consolidated every month. Therefore, the customer receives a separate bill for every delivery. Currently company A’s customers have payment cycles that range from 45 days to as many as 120 days. Large customers have the leverage to stretch payment cycles. Because of long payment cycles, company A does not get paid as fast and, as a result, working capital is tied up. Therefore, reducing payment cycle represents enormous benefit for company A. With consignment deals, in exchange for VMI and consignment service, many customers may be willing to renegotiate payment cycles. As a result, payment cycles are frequently renegotiated, thus provides company A an opportunity to reduce payment cycles, especially with large customers.
3 Analysis

3.1 Methodology and Data

The fundamental methodology is to quantify the possible costs and benefits and then transform the benefits into monetary values for evaluation. Some of the costs and benefits from VMI are not readily measured in dollars and need to be translated by functions.

Therefore, the first step is to define cost functions of various operation procedures based on previous research and literature. They include inventory carrying costs at company A as well as at the customers’ sites, transportation costs, ordering costs, stock out costs and payment cycle capital opportunity costs.

The next step is data collection: gathering adequate and sufficient data. Company A has provided transactional data for the entire company. The data, covering 12 months, contains information about every transaction: the name of customer, the ID of distribution center, the time of delivery, the size of order, and the type of product delivered. From the data, further information can be obtained to determine the demand patterns of customers, the segmentation of products and customers, the average of each chemical’s yearly consumption, the seasonality of each chemical, the average order size, and the average order frequency. In this work, only the data for one distribution center (DCW) will be studied. Its current inventory data is collected directly from itself; the data and statistics of truck routing, inventory management, and finance are collected from various sources within company A.

Then, a benchmark should be set up for later analysis. The overall cost of the current fulfillment process is determined within the thesis scope using the cost functions defined in the previous step. The inputs into those functions are extracted from the data collected in the first step.
The following step is to determine the cost when VMI is implemented. Different customers, depending on their demand patterns and demand sizes, may encounter very different results. The VMI or consignment strategies adopted by company A may also vary to suit different customers. For example, to customers with mainly fast moving items with steady demand, a repetitive ordering amount can be set up and monitored by company A; to customers who currently have very long payment cycles, company A can negotiate for a shorter cycle to reduce tied up inventory capital. In order to take account of all possible outcomes, various scenarios are modeled and simulated. For daily distribution and transportation, in an effort to achieve more efficiency and convenience, a scenario which is enabled by the adoption of VMI is set up to calculate the new transportation cost. Transportation cost analysis is done at the distribution center level.

The results of all scenarios are compared against the as-is cost incurred by the current process to decide whether VMI and consignments are worthy alternatives to company A’s current process. In arriving at the decision, break even analysis is utilized, which indicates which scenario is able to at least compensate the operating cost of managing VMI. The results are also meant to be used as guidelines that will help determine future cases on an individual customer to customer basis.

3.2 Customer Segmentation Analysis

As stated earlier, DCW is a distribution center located in New England. It serves 164 customers at 235 locations for 961 tanks (one hundred and thirty customers have multiple locations). Most locations have multiple tanks for different products. Orders are taken at the tank level, deliveries are arranged at the location level, and VMI deals are made at the customer level.

Customers consume products at various rates depending on the location and product type. Some products are fast moving with steady flows, while other products are consumed in spikes, in which case they may be ordered only once a year and each time for a large amount. One way to segment customers is to identify different groups of customers by their demand.
Figure 1 shows the distribution of the annual total consumption of all 961 tanks served by DCW. Ten percent of the tanks have annual consumption of 5,000 gallons or more and are classified as fast moving tanks. On the other hand, over 30% of tanks have annual consumption of less than 500 gallons and they are classified as slow moving tanks.
Figure 2: Annual consumption of all customer locations served by DCW

Figure 2 is the annual total consumption level of all tanks at each location. Each location may demand more than one product. The pattern emerging from the Figure 2 shows that less than 10% of all locations have annual consumption is over 20,000 gallons. The majority consume in the range from 1,000 gallons to 20,000 gallons. At the lower end, a little over 20% of locations consume 1,000 gallons or less.
Figure 3  Annual consumption level of all customers served by DCW

Figure 3 gives a similar pattern of total consumption at the customer level. The difference between Figure 2 and Figure 3 shows that some large customers are likely to have more than one location within the service region of DCW. As a result, the pattern in Figure 3 shows a shift to the right compared with Figure 2.
In Figure 4, the distribution of number of different products required at each location is shown, assuming the number of tanks equals to the number of products at a location. The majority of location sites require less than 6. Large customers tend to require more types of products than smaller customers.
Figure 5  Number of deliveries per tank

Figure 5 shows the range of delivery frequencies during the year for all tanks served by DCW. More than 70% of all tanks are filled less than quarterly and more than 30% of tanks have only 1 delivery during the year. Only 5% of tanks are filled more than once a month.
Since transportation is arranged at each location, not each tank, the delivery frequency to each location is also relevant. Figure 6 shows the number of deliveries to each location during the year. With the aggregation of all products at the same location, the numbers to each site go up. There are 5.7% of customers' locations that require more than weekly fulfillment.
Figure 7 Location segmentation by demand

Figure 7 shows the segmentation of customer locations served by DCW. The top 8 locations with highest demand account for 30% of the total demand served by DCW and are classified as AA locations. These 8 locations belong to 5 different customers and include 55 tanks. In this thesis, these 5 customers are considered the prime candidates for VMI deals. The next 41 locations out of the 235 locations with highest demand take 41% of all sale volume and are classified as A locations. The B locations account for 70 out of the 235 locations and they take 22% of the total sales volume. The locations with lowest demand are C locations and they account for the remaining 116 locations out of 235 and they take the remaining 5% of the sale volume.
Figure 8  Large customer's products profile

Figure 8 compares the specific product demand of the AA locations to that of smaller A-B-C locations. In both figures, there are many products that are ordered by small sizes. The diamond dots in Figure 10 show the 8 AA locations out of 235 and these AA locations' yearly demand counts for 30% of total demand, and the square dots show the rest of the 227 customer locations.

One thing that emerges from Figure 10 is that there are a few products with very high demand volume. The top 6 products account for 85% of the total demand of the AA locations. Since the AA locations account for 30% of the total demand, those 6 products' demand by the top locations in fact accounts for 25% of the total demand. This means if VMI can be done by product, these 6 products are prime candidates.
Figure 9  Number of fulfillment in one trip and number of tanks at one location

Figure 9 shows that although many locations have multiple tanks, on average only less than 2 tanks are fulfilled at one location in each trip. Interestingly, as the number of tanks at a location increases, the number of tanks served stays at slightly less than 2. For locations with more than 2 tanks, if the number of tanks fulfilled in each trip increases, the number of trips can decrease.

Overall, the analysis of customer segmentation suggests that there are three areas with opportunities for improvement.

The first opportunity is to make VMI deals according to tanks instead of to customers. From Figure 5, tanks can be differentiated into fast moving tanks, slow moving tanks, and the others. The difference in demand can be very wide. Fulfillment frequencies within one year range from 6 to 26 times. If company A separates the fast moving tanks from the rest, these fast moving tanks can become good VMI candidate. Company A has decided that if a deal is made between a customer and company A, all tanks at that location have be done through VMI. The
analysis suggests that it may be beneficial and worth consideration to have a VMI policy according to tanks’ demand.

The second opportunity comes from the segmentation of 6 particular products. Figure 10 shows that the top 6 products account for 85% of total demand of the top 8 locations, which, in turn, account 30% of total demand volume served by DCW. If a VMI deal can be made with the top 8 locations (5 different customers) on only those 6 top products, it in effect accounts for 25.5% of the total demand. Compared with managing 28 different products that go into the 55 tanks of the top 8 locations, it is easier to manage 6 products for the same locations.

The last opportunity comes from fulfillment trip efficiency. Figure 11 shows that even if there are up to 10 tanks at one location, each trip on average only fulfills two tanks. A truck has 5 compartments; therefore, each fulfillment trip is capable of fulfilling 5 tanks at the same location. Company A may be able to increase the number of tanks fulfilled at one location in one trip with VMI.

### 3.3 Basic Cost Functions

A fulfillment process consists of four basic costs: inventory carrying cost, transportation cost, ordering cost and stock out cost. Each of these costs can be represented by a function.

The total relevant cost is represented by:

\[
C_{\text{Total} \; / \; \text{year}} = C_{\text{Carrying} \; / \; \text{year}} + C_{\text{Transportation} \; / \; \text{year}} + n_{\text{order}} C_{\text{order}} + n_{\text{stockout}} C_{\text{stockout}} \tag{1}
\]

The cost of carrying inventory includes the opportunity cost of the money invested, the expenses incurred in managing the tanks, handling and measuring costs, the costs of special storage equipments, insurance, and taxes:

\[
C_{\text{Carrying} \; / \; \text{year}} = I v r , \tag{2}
\]

where \(I\) is the average inventory level at DCW in gallons, \(v\) is the unit cost of product, and \(r\) is the carrying charge which is the cost in dollars of carrying one dollar of inventory for one year.
Transportation costs consist of a fixed and variable element. Vehicle depreciation and driver wages are fixed costs. Variable costs include the trucks’ repairs and fuel costs that are based on driving distance. The function of one vehicle’s annual cost is:

\[ C_{\text{transportation/ year}} = C_{\text{fixed}} + C_{\text{var}} d_{\text{trip}}, \]  

where \( d_{\text{trip}} \) is the yearly driving distance of all deliveries.

The stock out cost is estimated as the cost of one additional trip because in these cases the remedy is an emergency shipment. The function for one stock out event is:

\[ C_{\text{stockout}} = C_{\text{var}} d_{\text{shipment}}, \]

where \( d_{\text{shipment}} \) is the driving distance of a round trip of a shipment to one location.

The total ordering cost, the cost of maintaining customer service representatives (CSR), is given by company A as following:

\[ C_{\text{order}} = C_{\text{CSR}} n_{\text{CSR}}, \]

where \( C_{\text{CSR}} \) is the cost of keeping one customer service representative, and \( n_{\text{CSR}} \) is the number of customer service representatives employed by company A. Since the total order cost is decided only by the number of customer service representatives \( (n_{\text{CSR}}) \), it remains constant.

### 3.4 Total Cost Analysis for Current Process

The current ordering and shipping process is explained in chapter one. The total operational cost consists of four major components: inventory carrying cost, transportation cost, order cost, and stock out cost.
3.4.1 Inventory Carrying Cost

Carrying cost means the opportunity cost of capital that is tied up in cycle stock and safety stock. Company A’s safety stock resides at their DC. Customer safety stock resides in the tanks at each location. It is calculated as a fraction of the cost of the goods. Company A uses 10% as its standard annual inventory carrying cost.

3.4.1.1 Company A’s Safety Stock at DCW

Safety stock that resides in DCW is decided by the DC manager. The information is available from the DC manager and shown in Figure 10. The diamonds are the safety stock levels for each product kept at DCW, and the squares show the daily demand from all customers served by DCW. The daily demand data is extracted from the transaction database and covers one year.

![Safety stock vs. daily demand](image)

Figure 10 Safety stock and daily demand for all 28 products carried by DCW
Figure 11  Safety stock over daily demand ratio for all 28 products carried by DCW

Figure 11 shows the numbers of days of supply (DOS) covered by the safety stock of each of the 28 products served by DCW. The lowest DOS is 15 days, and for the majority of the products, the DOS is between 2 weeks and 3 months. One certain product has DOS as high as 690 days, almost 2 years. However, it could be regarded as an exception because this product is particularly slow moving.
Figure 12 Coefficient of variation for all 28 products carried by DCW

Figure 12 shows the coefficient of variation (defined as $\sigma/\mu$) of each product’s order sizes during one year. It is calculated with the average order size of each product and the standard deviation of the order sizes of each product. Some products have very low coefficient of variation ($< 0.2$), which means that these products have relatively uniform order sizes and should have low safety stock. On the other hand, some products have very high coefficient of variation ($> 0.5$), which means that those products’ order sizes can vary in a wide range and they require higher safety stock levels.

In addition, products with low coefficients of variation are better candidates for VMI than ones with high coefficients of variation. Company A can forecast with higher accuracy for products with stable order sizes than for those with random order sizes.

The actual data of every product’s total consumption and safety stock set by the DC manager are shown in Table 1, as well as the average daily demand of each product. When using the safety stock of each product as the stock on hand, there are 65,400 gallons of stock on hand.
Since the unit cost is about $1/gallon, it means that there is $65,400 worth of safety stock. With 10% as the standard annual inventory carrying cost, the annual carrying cost is:

\[ \$65400 \times 10\% = \$6540/\text{year} \]

Since the lead time to replenish the DC is estimated to be around 5 days, \( k \) is calculated by formula:

\[ k = \frac{SS}{(\sigma \sqrt{L})}, \]  

(6)

where \( SS \) is the current level of safety stock in each tank, \( \sigma \) is the standard deviation of demand, \( L \) is the lead time, and \( \sigma \sqrt{L} \) is the standard deviation of lead time demand. The lead time is the time required to fulfill a customer’s order after the order is placed.

According to company A, the desired service level is 99.9%, and the corresponding \( k \) is 3. The \( k \) values of the products have large deviation from the desired value. When the value is greater than 3, it indicates excessive safety stock level and in turn, unnecessary safety stock carrying cost. When the \( k \) value is less than 3, it indicates the service level is compromised. Assume the demand follows a normal distribution; the implied service level for each product is calculated and shown in Table 1.
<table>
<thead>
<tr>
<th>Product ID</th>
<th>Safety Stock at the DC (gal)</th>
<th>k</th>
<th>Implied Service Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,100</td>
<td>1.114</td>
<td>1.0000</td>
</tr>
<tr>
<td>2</td>
<td>1,650</td>
<td>21.98</td>
<td>1.0000</td>
</tr>
<tr>
<td>3</td>
<td>4,400</td>
<td>29.60</td>
<td>1.0000</td>
</tr>
<tr>
<td>4</td>
<td>2,475</td>
<td>5.77</td>
<td>1.0000</td>
</tr>
<tr>
<td>5</td>
<td>825</td>
<td>5.73</td>
<td>1.0000</td>
</tr>
<tr>
<td>6</td>
<td>2,200</td>
<td>5.71</td>
<td>1.0000</td>
</tr>
<tr>
<td>7</td>
<td>3,850</td>
<td>4.92</td>
<td>1.0000</td>
</tr>
<tr>
<td>8</td>
<td>2,475</td>
<td>4.38</td>
<td>1.0000</td>
</tr>
<tr>
<td>9</td>
<td>2,475</td>
<td>4.11</td>
<td>1.0000</td>
</tr>
<tr>
<td>10</td>
<td>1,100</td>
<td>3.96</td>
<td>1.0000</td>
</tr>
<tr>
<td>11</td>
<td>1,100</td>
<td>3.64</td>
<td>0.9999</td>
</tr>
<tr>
<td>12</td>
<td>7,975</td>
<td>3.45</td>
<td>0.9997</td>
</tr>
<tr>
<td>13</td>
<td>550</td>
<td>3.42</td>
<td>0.9997</td>
</tr>
<tr>
<td>14</td>
<td>1,375</td>
<td>2.85</td>
<td>0.9978</td>
</tr>
<tr>
<td>15</td>
<td>825</td>
<td>2.84</td>
<td>0.9978</td>
</tr>
<tr>
<td>16</td>
<td>2,475</td>
<td>2.76</td>
<td>0.9971</td>
</tr>
<tr>
<td>17</td>
<td>1,325</td>
<td>2.74</td>
<td>0.9969</td>
</tr>
<tr>
<td>18</td>
<td>1,375</td>
<td>2.72</td>
<td>0.9967</td>
</tr>
<tr>
<td>19</td>
<td>3,850</td>
<td>2.54</td>
<td>0.9945</td>
</tr>
<tr>
<td>20</td>
<td>1,375</td>
<td>2.50</td>
<td>0.9938</td>
</tr>
<tr>
<td>21</td>
<td>550</td>
<td>2.45</td>
<td>0.9929</td>
</tr>
<tr>
<td>22</td>
<td>1,100</td>
<td>2.43</td>
<td>0.9924</td>
</tr>
<tr>
<td>23</td>
<td>7,975</td>
<td>2.39</td>
<td>0.9915</td>
</tr>
<tr>
<td>24</td>
<td>2,200</td>
<td>2.17</td>
<td>0.9848</td>
</tr>
<tr>
<td>25</td>
<td>1,650</td>
<td>1.48</td>
<td>0.9306</td>
</tr>
<tr>
<td>26</td>
<td>550</td>
<td>1.37</td>
<td>0.9147</td>
</tr>
<tr>
<td>27</td>
<td>550</td>
<td>1.37</td>
<td>0.9147</td>
</tr>
<tr>
<td>28</td>
<td>6,050</td>
<td>1.00</td>
<td>0.8420</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>65,400</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Total consumption, safety stock and daily consumption of all 28 products carried by DCW

3.4.1.2 Safety Stock in Customers' Tanks

The AA customer locations have 55 different tanks, which are the prime candidates for VMI deals. Therefore, only these 55 tanks are analyzed. The inventory that resides in the customers’ tanks consists of safety stock and cycle stock. The optimal level of safety stock is estimated by the tank size minus the maximum delivery quantity, and the cycle stock is estimated to be the half of the average order size. The current safety stock level is calculated by the equation:
\[ SS = \text{Capacity}_{\text{tank}} - \text{Order}_{\text{max}}, \]

where \( \text{Capacity}_{\text{tank}} \) is the capacity of the tank and \( \text{Order}_{\text{max}} \) is the max order size. This is a conservative estimation of the current safety stock level.

Figure 13 shows the safety stock stored in each of the 55 tanks and the daily estimated stock on hand. The total safety stock level is 41,154 gallons. The current cycle stock \( CC \) for each tank is shown in diamonds in the figure and is determined to be half of the average order size:

\[ CC = \frac{Q}{2}, \]  

(7)
where $Q$ is the average order size. Current average order sizes are found from transaction data of one year.

Besides, Figure 13 shows the current estimated inventory level ($E[I]$), also known as the daily stock on hand, which can be calculated as the sum of the safety stock and the current cycle stock:

$$E[I] = SS + CS.$$  \hspace{1cm} (8)

The total current estimated inventory level of all 55 tanks at the concerned 8 locations is 58,602 gallons. When applied with the 10\% , the current carrying cost incurred in the 55 tanks is:

$$58,602 \times 10\% = 5,860.$$

![Figure 14 Current service level by tank](image)

Figure 14 shows the implied service level, which is calculated from the function (6). For some tanks it is very low, less than 60\%. With VMI, the service level can benefit from better managed safety stock levels and replenishment processes. On average, the lead time is 10 days,
from the date that the order is received to the date that the order is fulfilled. The actual process is
described in chapter one. The lead time has an important bearing to the optimal level of safety
stock left in each tank, which will be discuss later. In the current process, the safety stock at the
customers’ location is owned and managed by the customers, and therefore, not a concern to
Company A.

3.4.2 Transportation Cost

Berman and Larson (2001) noted that a trip is associated with a fixed time-related charge
and a variable distance-related charge. Annual fixed cost is known to be around $94,000 for a
truck (Hernandez Lopez, 2003). Daily fixed cost is $94,000 / 250 working days = $376. The
other part of the cost is the variable cost, including repairs which are $0.19 per mile (Hernandez
Lopez, 2003) and the gas cost which depends on gas price. According to the dispatch team
manager, while the upper limit of a trip is set to be 250 miles, a trip is on average 210 miles. The
current fuel price is around $2 per gallon for diesel, and the truck mileage is 6 miles/ gallon, so
the total variable cost per trip on average is ($2 / 6 + $0.19) * 210 = $110. Therefore, the total
cost per trip is the fixed cost per trip $376 + the variable cost per trip $110 = $486.

<table>
<thead>
<tr>
<th>Fixed cost</th>
<th>$/truck/vehicle</th>
<th>$94,000.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable cost</td>
<td>$/mile</td>
<td>$0.52</td>
</tr>
<tr>
<td>Fuel ($/per gallon)</td>
<td>2.00</td>
<td></td>
</tr>
<tr>
<td>Mileage (miles/gallon)</td>
<td>6.00</td>
<td></td>
</tr>
<tr>
<td>Repairs ($/mile)</td>
<td>0.19</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Transportation cost per vehicle

According to the driver and confirmed by the DC manager and the dispatch team
manager, there are 2 to 4 trips coming out of the DCW each day and the average is 3. This
information is supported by the given transaction data. Therefore, since one trip’s variable cost
is $110, 3 trips will bring the total up to $330 / day. On an annual basis with 250 working days,
the transportation variable cost adds up to be $82,500 / year. The fixed cost depends on how
many trucks there are in the DC. Currently there are 3 trucks operating regularly at DCW, which
means the total fixed cost is $282,000, so the total annual transportation cost is $364,500.
It is obvious that the transportation cost is a major cost. However, most of that cost comes from the fixed cost of owning a truck: depreciation, maintenance, and etc. Therefore, it cannot be decreased unless there are fewer trucks needed. In the scope of this thesis, the goal is to lower the miles driven and improve routing efficiency.

### 3.4.3 Ordering Cost

The current order cost is directly proportional to the number of orders. At DCW, there are 2,710 orders in 2004. According to company A, there are 15 customer service representatives company wide (CSR’s) at full loaded cost of $75,000 each. These 15 CSR’s cover all DC’s. It is estimated by company A that there are 100,000 orders company wide annually. Therefore, each order costs:

\[
\frac{75,000 \times 15}{100,000} = 11.25, 
\]

and the 2710 orders fulfilled by DCW in a year have a total cost of:

\[
11.25 \times 2,710 = 30,487.50. 
\]

The current order cost per order is quite high at $11.25. Annual order cost for DCW is around $30,487.50. However, the order cost is based solely on the number of CSRs employed. Changing the number of CSRs is outside of the scope of this thesis.

### 3.4.4 Stock Out Cost

Stock out costs occur when the customer requests an emergency fulfillment. These constitute 2% are the emergency orders. According to the dispatch manager, 10% of the emergency orders require an extra trip. The stock out cost within a year is:

\[
2,710 \times 2\% \times 10\% \times $330 = 1,789, 
\]

where 2710 is the number of total orders in one year, and $330 is the variable cost of one trip.
3.4.5 Total Relevant Cost Function

The total relevant cost of the current process at DCW is the sum of total annual inventory carrying cost, total annual transportation cost, total annual ordering cost, and annual stock out cost. All the specific numbers are shown in Table 3.

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory holding cost (DCW)</td>
<td>$6,540</td>
</tr>
<tr>
<td>Inventory holding cost (tanks)</td>
<td>$5,860</td>
</tr>
<tr>
<td>Transportation variable cost</td>
<td>$82,500</td>
</tr>
<tr>
<td>Transportation fixed cost</td>
<td>$282,000</td>
</tr>
<tr>
<td>Order cost</td>
<td>$30,487</td>
</tr>
<tr>
<td>Stock out cost</td>
<td>$1,789</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$409,136</td>
</tr>
</tbody>
</table>

Table 3 Annual total relevant cost incurred by DCW

The current process at DCW has a total cost of $409,136. The fixed transportation cost accounts for a major portion of the total cost. However, the fixed transportation cost is associated with the number of trucks at DCW and is not affected by adopting VMI. Among the rest, inventory carrying cost and transportation variable cost have potential to be reduced by VMI.

3.5 Total Cost Analysis for VMI

A VMI deal should be mutually beneficial for both the customer and the vendor. Under VMI, the inventory carrying cost and the transportation cost all have potentials to decrease. The total cost model for VMI is the same as in the current process. What is different is the information that goes into the decision. With VMI, information is directly exchanged between customers and company A, instead of company A trying to predict what the customers will do. Company A gains access to customers’ demands and planning information, which can aid forecasting accuracy.
### 3.5.1 Inventory Carrying Cost

As in the current process, there are two locations where inventory incurs cost. One is at company A’s own DC’s, and the calculations has been shown in last section. The other is in the customers’ tanks. The analysis of the current process gives a rough estimation of the current safety stock in customers’ tanks. Now, with VMI, company A can reset the safety stock at both DCW and customers’ tanks.

#### 3.5.1.1 Inventory at DCW

As shown in Table 1, currently the safety stock at DCW is set with implied service level in the range from 84% to 100%. To achieve the desirable service level of 99.9% set by company A, many of the current safety stock levels are not enough. The desirable levels of safety stock at DCW can be set according to equation (6). The current lead time to replenish DCW is 5 days. However, current levels are not optimal. In the process of setting up VMI, company A can look to reset the safety stock level to achieve higher service level. VMI is not necessary for this change to occur, but this change can be easier to make if company A decides to adopt VMI, because if DCW goes into VMI, its safety stocks are likely to change and there won’t be any additional cost necessary for the change of DC safety stock levels.

Table 4 shows the comparison between the current safety stock and the improved safety stock level. The current safety stock levels show various $k$ values for different products, indicating over stocking and under stocking in safety stocks, while the new safety stock for every product is calculated to guarantee service level.

The result also shows that the new safety stock level not only guarantees the service level, but also reduces the total safety stock because the current safety stock levels are very often unnecessarily high. The new safety stock has a carrying cost of:

$$58,537 \times 10\% = 5,854.$$  

Compared with the current safety stock level of 65400 gallons and the associated carrying cost of:
$65,400 \times 10\% = $6,540.

The new safety stock level provides consistent service level to the customers and occurs less carrying cost by:

$$6,540 - 5,854 = 686.$$  

Therefore, the new safety stock levels improve service level and reduce cost.

<table>
<thead>
<tr>
<th>Product ID</th>
<th>Safety Stock at the DC (gal)</th>
<th>Implied Service Level</th>
<th>New safety stock with ( k = 3 )</th>
<th>Changes in gallons</th>
<th>Changes in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.100</td>
<td>1.000000000</td>
<td>77</td>
<td>-1023</td>
<td>-93%</td>
</tr>
<tr>
<td>2</td>
<td>1.650</td>
<td>1.000000000</td>
<td>328</td>
<td>-1322</td>
<td>-80%</td>
</tr>
<tr>
<td>3</td>
<td>4.400</td>
<td>1.000000000</td>
<td>214</td>
<td>-4186</td>
<td>-95%</td>
</tr>
<tr>
<td>4</td>
<td>2.475</td>
<td>0.999999996</td>
<td>3552</td>
<td>1077</td>
<td>44%</td>
</tr>
<tr>
<td>5</td>
<td>825</td>
<td>0.999999995</td>
<td>561</td>
<td>-264</td>
<td>-32%</td>
</tr>
<tr>
<td>6</td>
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<td>0.999999994</td>
<td>1544</td>
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</tr>
<tr>
<td>7</td>
<td>3.850</td>
<td>0.999999575</td>
<td>3705</td>
<td>-145</td>
<td>-4%</td>
</tr>
<tr>
<td>8</td>
<td>2.475</td>
<td>0.999993937</td>
<td>1727</td>
<td>-748</td>
<td>-30%</td>
</tr>
<tr>
<td>9</td>
<td>2.475</td>
<td>0.999980214</td>
<td>3416</td>
<td>941</td>
<td>38%</td>
</tr>
<tr>
<td>10</td>
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<td>652</td>
<td>-448</td>
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</tr>
<tr>
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</tr>
<tr>
<td>12</td>
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<td>0.999718695</td>
<td>5108</td>
<td>-2867</td>
<td>-36%</td>
</tr>
<tr>
<td>13</td>
<td>2.200</td>
<td>0.999684513</td>
<td>603</td>
<td>53</td>
<td>10%</td>
</tr>
<tr>
<td>14</td>
<td>1.375</td>
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</tr>
<tr>
<td>15</td>
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<td>0.997773265</td>
<td>1592</td>
<td>767</td>
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</tr>
<tr>
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</tr>
<tr>
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<td>1906</td>
<td>581</td>
<td>44%</td>
</tr>
<tr>
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<td>1001</td>
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<td>-27%</td>
</tr>
<tr>
<td>19</td>
<td>3.850</td>
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<td>-8%</td>
</tr>
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</tr>
<tr>
<td>21</td>
<td>550</td>
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<td>51%</td>
</tr>
<tr>
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<td>1.100</td>
<td>0.992409010</td>
<td>1474</td>
<td>374</td>
<td>34%</td>
</tr>
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<td>7.975</td>
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<td>6153</td>
<td>-1822</td>
<td>-23%</td>
</tr>
<tr>
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<td>2.200</td>
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<td>2768</td>
<td>568</td>
<td>26%</td>
</tr>
<tr>
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<td>0.930609014</td>
<td>3239</td>
<td>1589</td>
<td>96%</td>
</tr>
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<td>550</td>
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<td>475</td>
<td>-75</td>
<td>-14%</td>
</tr>
<tr>
<td>27</td>
<td>550</td>
<td>0.914687475</td>
<td>1526</td>
<td>976</td>
<td>178%</td>
</tr>
<tr>
<td>28</td>
<td>6.050</td>
<td>0.842029434</td>
<td>4895</td>
<td>-1155</td>
<td>-19%</td>
</tr>
</tbody>
</table>

Table 4 Improved safety stock at DCW
3.5.1.2 Safety Stock in Customers' Tanks

The safety stock levels in customers' tanks of the top 8 locations were discussed earlier. Under VMI, instead of customer makes replenishment decisions, company A controls when and how much to replenish at each tank.

When service level = 99.9%, the new safety stock level can be calculated by equation (6). The safety stock levels are reset now under VMI. The current lead time to replenish a tank is 10 days. With VMI, an assumption is made that the lead time will decrease and it is roughly estimated that the lead time can be reduced to 5 days. Customer service level is 99.9%. Just to illustrate how lead time may impact the result of VMI, Table 5 shows an example of how one tank's average inventory carrying cost decreases when the lead time is reduced. Currently, company A waits for customers to place orders and then fulfill the orders in an average of 10 days. With VMI, company A knows exactly when to place an order and the lead time will effectively be 1 day. Therefore, 5 days is in reality a conservative estimation.

<table>
<thead>
<tr>
<th>Lead time (day)</th>
<th>Lead time demand (gal)</th>
<th>Safety stock (gal)</th>
<th>Average inventory on hand (gal)</th>
<th>Carrying cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>527.1</td>
<td>3390.6</td>
<td>3814.9</td>
<td>381.5</td>
</tr>
<tr>
<td>9</td>
<td>474.4</td>
<td>3051.5</td>
<td>3475.8</td>
<td>347.6</td>
</tr>
<tr>
<td>8</td>
<td>421.7</td>
<td>2712.5</td>
<td>3136.8</td>
<td>313.7</td>
</tr>
<tr>
<td>7</td>
<td>369.0</td>
<td>2373.4</td>
<td>2797.7</td>
<td>279.8</td>
</tr>
<tr>
<td>6</td>
<td>316.3</td>
<td>2034.3</td>
<td>2458.7</td>
<td>245.9</td>
</tr>
<tr>
<td>5</td>
<td>263.6</td>
<td>1695.3</td>
<td>2119.6</td>
<td>212.0</td>
</tr>
<tr>
<td>4</td>
<td>210.8</td>
<td>1356.2</td>
<td>1780.6</td>
<td>178.1</td>
</tr>
<tr>
<td>3</td>
<td>158.1</td>
<td>1017.2</td>
<td>1441.5</td>
<td>144.2</td>
</tr>
</tbody>
</table>

**Table 5 Lead time sensitivity analysis**

And the cycle stock can be calculated by equation (7). In this calculation, the cycle stock remains unchanged from the current process.
Figure 15 shows the demand pattern of a fast moving tank and it appears random. Under VMI, the order pattern is likely to be smoother, which can further decrease the stress on safety stock and also can help with transportation planning.
The estimated daily inventory level on hand in each tank is the sum of safety stock and cycle stock. Both the current and the new estimated inventory levels for the 55 tanks carried by the AA locations are shown in Figure 16. For every tank, the diamond shaped dotted line shows the current inventory level and the square shaped dotted line shows the inventory level under VMI. For the majority of the tanks, the new inventory levels are lower than the current inventory levels because of the decrease in safety stock levels. Consequently, the total carrying cost of inventory in customers’ tanks go down.

The resulted new total estimated inventory for the 55 tanks is 40,248 gallons. The carrying cost associated with total inventory is:

$$40,248 \times $1 \times 10\% = $4,024.8$$

This cost shows a $1,796 decrease from the current cost, a saving of 31%. When VMI is done without consignment, this saving is recorded by customers.
3.5.2 Transportation Cost

Figure 17 Map of all customers' locations served by DCW
Figure 17 shows a map of where all the customers served by DCW are located, in which DCW is at the point \((0, 0)\) of the figure. The map is calculated from the latitude and longitude of each location. The triangles are the 8 AA locations and they have an average distance of 26 miles to DCW. The map also indicates that all AA locations are relatively close to DCW.

The following formula is used to calculate the distance between any two spots given their latitudes and longitudes:

\[
d = \frac{2\pi r}{360} \left\{ \arccos\left[\cos(a_1)\cos(b_1)\cos(a_2)\cos(b_2)\right.ight. \\
\left.\left. + \cos(a_1)\sin(b_1)\cos(a_2)\sin(b_2) + \sin(a_1)\sin(a_2) \right]\right\}, \tag{9}
\]

where \(r\) is the radius of the earth, \((a_1, b_1)\) is the latitude and longitude of point 1, and \((a_2, b_2)\) is the latitude and longitude of point 2. Using the above formula, the distance between DCW and every customer’s location is found, and the distribution is shown in Figure 18. The average distance was found out to be 65.6 miles, and the weighted (by volume) average distance is 39.6 miles.

![Figure 18 Distribution of distances from each customer to DCW](image)
Imagine a line sweeping through the service region clockwise, all locations will be touched one by one. The distances between every two adjacent locations can be found with the same formula. Figure 19 shows the distance distribution. The average is found to be 27.3 miles between adjacent locations.

Central planning provides an opportunity to better prepare vehicle routing. For AA locations, one way is to fulfill up to 5 different tanks to the same location. There are many locations, especially large locations, have multiple tanks, as shown in Figure 4. Figure 9 indicates that currently on average each trip only fulfills less than 2 tanks even when a location has 10 tanks. With VMI, company A can fulfill as many tanks as possible at the given location. As a result, the number of stops necessary in one trip decreases and the driving distance decreases. The weighted average (by volume) number of tanks per location is 5.97 and the weighted averaged number of tanks fulfilled at each location is 1.87. If this number doubles, the number of stops required per trip will be halved from 3 to 1.5. If the number increases by 50%, the number of stops required per trip will be reduced from 3 to 2.
Another way to improve transportation efficiency is to reduce the average length of the trip. Now, with VMI, company A has more flexibility to cluster locations in one trip by geographical proximity, shorten the distance between stops and fit in more stops in one trip, and ultimately reduces the number of trips necessary. The line haul can be regarded as the distance between a location and DCW and the weighted average is 39.6 miles. Distance between any 2 stops can be regarded as the distance between two adjacent locations and it is 27.3 miles. Overall driving miles will be able to decrease. Now if the new average number of stops required is 2, the trip length is:

\[39.6 \times 2 + 27.3 = 106.5 \text{ miles}.\]

Because of shorter driving distance, it also leaves ample time to fulfill more tanks at each location if needed. From Table 2, the current gas price is $2/gallon, the truck mileage is 6 miles/gallon and the variable repairs cost per mile is $0.19. Then the new transportation variable cost is:

\[\$(2/6 + 0.19) \times 106.5 = 55.5\]

And everyday there are 3 trips which makes it $166.5 per day. The annual cost is the daily cost times the annual business days = $41,625. The new annual transportation variable cost is reduced by:

\[\$82,500 - 41,625 = 40,875\]

Which shows a decrease of 50% and it is a marked improvement. This is the largest saving among all monetary benefits from VMI at DCW.

Furthermore, since the new average trip length is only 106 miles, it might be possible to fit two trips per truck in one day and the number of trucks required can go down from 3 to 2, which reduce the transportation fixed cost by 50%. Since the transportation fixed cost is the one single largest cost at DCW, reducing the fixed cost brings a huge cost reduction. Although reducing the number of trucks is outside of the scope of this thesis, company A can now be aware of this opportunity.

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3.5.3 Ordering Cost

Total ordering cost at DCW does not change under VMI. Ordering becomes company A’s internal process for customers enter VMI. While VMI customers do not order from outside anymore, internal orders incur costs as well. Furthermore, the rest of customers who are not in VMI deals still place orders and customer service representatives continue to be necessary. Even if the total number of orders is reduced at DCW, the only way to reduce total ordering cost is to reduce the number of CSR’s, which is outside the scope of this thesis. As a result, total ordering cost at DCW is not likely to change.

3.5.4 Stock Out cost

Stock out cost is proportional to the number of emergency fulfillment deliveries. Under VMI, stock out cost is likely to remain the same or decrease slightly. However, the decrease in cost is likely to be insignificant due to the fact that stock out cost accounts for a small proportion of the current total costs. Currently, the stock out cost comes from 4 to 5 emergency trips. While VMI may help lower the number, it cannot guarantee that emergency deliveries do not occur. Therefore, the same amount should still be included as part of the total cost.

3.5.5 Total Relevant Cost under VMI

The total relevant cost under VMI is the sum of inventory carrying cost, transportation cost, ordering cost and stock out cost. Table 6 shows the comparison of the total costs under current process as well as under VMI. Overall, VMI gives a significant decrease in total cost.

<table>
<thead>
<tr>
<th></th>
<th>Current</th>
<th>VMI</th>
<th>Changes in $</th>
<th>Changes in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inventory Carrying Cost (DCW)</td>
<td>$6,540</td>
<td>$5,854</td>
<td>($687.00)</td>
<td>-11%</td>
</tr>
<tr>
<td>Inventory carrying cost (customer location)</td>
<td>$5,820</td>
<td>$4,024</td>
<td>($1,796.00)</td>
<td>-31%</td>
</tr>
<tr>
<td>Transportation variable cost</td>
<td>$82,500</td>
<td>$41,625</td>
<td>($40,875.00)</td>
<td>-50%</td>
</tr>
<tr>
<td>Transportation fixed cost</td>
<td>282,000</td>
<td>$282,000</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td>Ordering cost</td>
<td>$30,487</td>
<td>$30,487</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td>Stock out cost</td>
<td>$1,789</td>
<td>$1,789</td>
<td>$0.00</td>
<td>0%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$409,136</strong></td>
<td><strong>$365,779</strong></td>
<td><strong>($43,357.00)</strong></td>
<td><strong>-11%</strong></td>
</tr>
</tbody>
</table>

Table 6 Annual total relevant cost under consignment
The inventory carrying cost decreases both at DCW and at customers’ sites. The transportation fixed cost remains unchanged because the number of vehicles is outside the scope of this thesis. However, with shorter driving distance, the new transportation variable cost has a 50% decrease. The ordering cost and the stock out cost are not likely to have changes. In total, the cost incurred at DCW reduces by $43,358 and 11%.

3.5.6 Impact of Consignment

Usually inventory becomes customers’ property once it reaches customers’ tanks, but when VMI is done with consignment, company A owns the inventory in customers’ tanks until it is consumed. Although the inventory carrying cost remains the same as it is in VMI without consignment, company A now shoulders the inventory carrying cost for its consignment customers instead of customers paying for the inventory in their tanks.

Thus, the most direct impact of consignment is that company A now has a higher inventory cost: the inventory carrying cost at customers’ locations in Table 6 becomes company A’s responsibility when consignment becomes part of the deal. While customers have savings from eliminated inventory carrying cost of $5,820, company A pays an expense of $4,024 to hold the inventory. Looking solely at inventory carrying cost, company A is at a loss to enter consignment deals. However, VMI (with or without consignment) also offers a saving from reduced transportation variable cost. The saving in transportation variable cost is larger than the extra inventory carrying cost. Overall, company A benefits from VMI without consignment.

Moreover, consignment puts company A in a position where it has its customers’ storing devices at its own disposal. On one hand, consignment customers are benefitting from company A’s inventory; on the other hand, company A is in charge of all inventory throughout vendor-customer supply chain, which provides more flexibility in company A’s VMI fulfillment operations. Under VMI without consignment, company A’s customers intend to keep their own inventory level low. If for any reason, company A decides to increase the inventory level of customers’ tanks, it is likely to encounter objection from customers. When consignment is in place, since customers do not pay for the product up front, they are less likely to interfere with
any fulfillment decisions company A makes. The end result is that company A has effectively more control over its customers’ fulfillment process.

Another option to consider with consignment is the buy back option. A buy back option specifies a period of time, and when the customer does not consume the product within this period of time, either company A may take the product back or the customer has to pay for it. Therefore, company A can avoid losses with a buy back option. Without this option, once company A ships the product to a customer’s tank, the product stays in the tank until it is used. However, if for any reason (for example, the customer’s production plan has changed), the customer does not consume the product for a long time or ever, company A will not get paid for a long time or ever. In this case, a buy back option can be a helpful addition to company A’s consignment policy.

Overall, consignment inventory gives an additional facet to VMI. Customers generally benefit from consignment deals, but from company A’s point of view, it adds complexity to company A’s VMI operation. Alternatively, company A may use consignment as a selling point to attract or retain customers. Nevertheless, VMI with consignment has a higher cost compared with VMI without consignment; therefore, company A should not offer consignment deals unless it is necessary.

### 3.6 Impact of Reduced Payment Cycles

One of the benefits of VMI is the possibility to reduce payment terms. A payment term is the time between delivery of products and reception of payment from the customer. After the product is delivered or consumed, it takes a period of time for the customer to pay for the product. According to company A, the current average payment term of company A’s customers is 52 days. Large customers tend to have more leverage and push the term longer. In one case, the length is as long as 120 days.

The longer the payment term is, the more capital opportunity cost is incurred. It is to company A’s best interest to reduce payment terms and VMI provides an opportunity for it. When a VMI deal is made between company A and its customers, customers may be willing to
shorten payment terms to exchange for other incentives, which puts company A in a position to negotiate for better payment term deals.

The opportunity cost of capital during a payment term is:

\[ C_{\text{opportunity}} = I_{\text{daily}} vrX / 365, \]

where \( I_{\text{daily}} \) is the daily inventory level on hand, \( v \) is the unit price, \( r \) is the annual interest rate, and \( X \) is the number of days in the payment term.

Currently, it takes 52 days on average for a customer to pay for the product. Once again, consider the 55 tanks of the AA locations. From the data, on average, the customers order around 4000 gallons of product per day. Therefore, the daily and annual capital opportunity costs are:

\[
C_{\text{daily}} = 4000 \times \$1 \times 10\% \times 52 / 365 = \$57
\]
\[
C_{\text{year}} = 4000 \times \$1 \times 10\% \times 52 = \$20,800
\]

When unit price \( v \) is $1/gal, \( r \) is 10\% and \( X \) is 52 days. For each day the inventory is not paid for, it costs company A $57. The annual cost is $20,800.

Table 7 shows a sensitivity analysis of payment terms. As the number of days in the payment term decreases, the opportunity cost of the tied up capital decreases accordingly. The capital opportunity cost is proportional to the length of the payment term.

<table>
<thead>
<tr>
<th>Payment terms (days)</th>
<th>Capital tied up ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>$ 48,000</td>
</tr>
<tr>
<td>105</td>
<td>$ 42,000</td>
</tr>
<tr>
<td>90</td>
<td>$ 36,000</td>
</tr>
<tr>
<td>75</td>
<td>$ 30,000</td>
</tr>
<tr>
<td>60</td>
<td>$ 24,000</td>
</tr>
<tr>
<td>45</td>
<td>$ 18,000</td>
</tr>
<tr>
<td>30</td>
<td>$ 12,000</td>
</tr>
<tr>
<td>15</td>
<td>$  6,000</td>
</tr>
</tbody>
</table>

*Table 7 Payment terms vs. capital opportunity cost*
The result also shows that if the payment term can be reduced from 52 days to 30 days, the saving for the 55 tanks of the AA locations is:

\[
\text{Savings} = $20,800 - $12,000 = $8,800.
\]

The result indicates with VMI there is a saving of $8,800 or 42% for company A annually. This number is not a large amount by itself. But if a company is cash strapped, it can provide a welcome increase in the amount of cash on hand. Also, this is the savings from the 8 AA locations in one DC. If more customers are willing to shorten their payment terms and VMI can be done in more DC’s, the savings become more significant.
4 Conclusion

Overall, the analysis shows that VMI is a beneficial alternative and complement to company A’s current fulfillment process. The results from previous chapters indicate that both inventory cost and transportation cost are reduced under VMI.

With company A setting the safety stock and controlling replenishments, there is less customer demand fluctuation from company A’s point of view. Similarly, knowing the daily inventory balance in customers’ tanks, company A can foresee the best timing for replenishment and better allocate its resources and reduce the lead time. Less demand fluctuation and shorter lead time lead to lower safety stock and lower average stock on hand, and ultimately lower inventory carrying costs. From Table 6, for those 55 tanks at AA locations that are targeted for VMI deals, VMI reduces inventory carrying cost at both company A and the customers’ sites. At DCW, the cost is lowered by $687, or 11%. At the customers’ locations, VMI reduces inventory cost by $1,796, or 31%.

VMI also reduces transportation variable cost by improving transportation efficiency. A large proportion of the locations have multiple tanks and the transportation efficiency can benefit if each trip can fulfill multiple tanks. With more control and flexibility that comes with VMI over transportation routing, company A can arrange the daily trip to fulfill more tanks in the same location. In addition, company A can better arrange the routing according to the geographical locations of customers’ locations and group close locations in one trip. The end result of transportation routing is reduced driving distance and lower transportation variable cost. From Table 6, under VMI, the transportation variable cost is lowered by $40,875 from $82,500 to $41,625, which is a 50% reduction.

Total ordering cost at DCW is not changed because that the total ordering cost solely depends by the total number of CSR’s employed by company A, which is not within the scope of
this thesis. Stock out cost is not significantly affected either because emergency deliveries are not likely to be eliminated.

The payment cycles costs have potentials to be reduced if customers are willing to renegotiate and offer shorter payment terms to exchange for other incentives comes with VMI. If payment terms can be shortened from the current 52 days to 30 days, it can bring a $8,800 savings for the 55 tanks, which amounts to a reduction of 42%.

VMI also improves customer service level. Currently, the safety stocks in customers’ tanks and at DCW are both set inefficiently. Some products have overly high safety stock levels and some products’ safety stock levels are too low and not able to sustain the 99.9% service level desired by company A. In the process of setting up VMI, the safety stocks in both customer’s tanks and DCW can be reset. Overly high safety stocks can be reduced, which results in savings. Overly low safety stocks can be increased to meet the 99.9% service level.

Consignment inventory costs company A extra $4,024 because company A needs to pay for the inventory carrying cost at customers’ sites under consignment. However, the savings from VMI in transportation cost can cover that cost. Also, with consignment inventory, customers are more willing to reduce payment terms in exchange for the extra benefit. Besides, consignment deals are attractive to customers and can increase customer retention level. Overall, when consignment is added to VMI, it incurs an additional cost to company A; nevertheless, the benefits of VMI in transportation cost, the improved payment terms and the increased customer retention rate are still sufficient to make VMI with consignment a worthy option.

While AA customers with high demand provide the most inventory savings, VMI can reduce inventory carrying cost regardless of customer’s size. Although customers with low demand do not offer significant savings in inventory carrying cost, as they enter VMI the transportation efficiency benefits from a larger customer base. As more customers enter VMI deals, company A can better plan transportation routing and the transportation cost goes down. In fact, from the analysis, transportation variable cost provides the largest amount of savings. Therefore, smaller customers are welcome candidates for VMI.
In summary, based on the analysis, VMI is a recommended option for DCW. VMI brings savings in both inventory cost and transportation cost. In the meantime, it also offers higher service level to customers and helps to achieve higher customer retention.
5 Future Research

In addition to what this thesis has found out, there are a few additional areas to which further research can provide more insights.

One topic for possible further research is to determine the ideal order size and ordering frequency when operating under VMI. Large order size saves transportation cost but brings customers inventory level up as well as the inventory carrying cost. Small order size are able keep the customer’s inventory level low but requires frequent deliveries and brings up the transportation variable cost. Currently ordering is controlled by customers and ordering sizes and frequencies fluctuate randomly. When the orders are under company A’s control, to what extent can company A reduce the fluctuation is a question that is worth exploring. There is a trade off between inventory carrying cost and transportation cost. In order to minimize total cost, the optimal balance between inventory carrying cost and transportation cost should be found out. Linear programming may be a helpful method.

Another topic of further research is to quantify the benefit of shared information. An important advantage of being in a VMI program is information sharing. For example, some products are being ordered in large quantities infrequently. However, these products’ consumption may not be in spikes. There is a possibility that the products are being consumed in small steady flow. Identifying those products involve communication with the customers. If customers’ information such as production plan is open to company A, company A will be able to forecast customers’ demand with higher accuracy. How much would the shared information benefit company A and the customer is the question that waits to be answered.
Bibliography


