Introduction

Bulk chemicals manufacturers are considering the implementation of vendor managed inventory systems (VMI) as a way of offering improved customer service, building stronger customer relationships and obtaining the cost benefits that are possible under such systems. VMI is the practice under which the vendor is responsible for monitoring inventories at the customer’s sites and for determining when to replenish a product as well as what quantities to deliver.

Company A, an international specialty chemicals manufacturer, is considering the implementation of a VMI system for one of its major product lines. Products within this line are delivered in bulk, using compartmentalized tanker trucks. Under the current system, replenishments are triggered by customer orders that are placed under the discretion of the company’s customers and without any limitations on the order quantities. Storage tanks are installed at each customer site, each being dedicated to a specific product, with replenishments taking place at the tank level. Company A is considering the installation of telemetry devices at the storage tanks for remotely monitoring their levels.

Since under VMI, company A will be able to control the timing of replenishments, opportunities will exist for more efficient grouping of customer locations and design of highly utilized replenishment trips. Our goal has been to design a procedure for
identifying the products and customer locations for which implementation of VMI would make economic sense as well as to quantify the benefits that could be realized. We have chosen to focus on the possible improvements in transportation costs since these comprise the major part of company A’s cost of operations. However, reductions in inventory holding costs are also possible via the reduction in demand uncertainty and variability that is achieved through information sharing.

To limit the scope of our work we focused on a single facility located in southern California. This facility serves a large metropolitan area with high customer density and sales volumes and exhibits mild demand seasonality. For carrying out the analysis, we used data for a single year from the company’s ERP system. The data included the characteristics of the customer sites being served, as well as the order and delivery histories for the year.

We begin with an analysis of the current system, and from that determine two possible methods for improvement. Next, we discuss a strategy for reducing the total number of visits to each customer location. Then, we describe a three step approach for creating better vehicle routing and measure the results of this process. Finally, we discuss areas for future research that can improve upon our findings.

**Current System**

Our initial goal was to understand the operation of the current system. Towards this direction we tried to identify how each customer location contributes to the total sales volume as well as how this volume is distributed across the various products. Analysis of the order history revealed that out of the 289 customer sites served during the year under
study, 13.49% account for 50.74% of total sales and 31.14% account for 80.41% of total sales. It is important to note that the majority of the high volume customer sites are closely located to the facility despite the high overall dispersion of the total number of customer sites.

On the other hand, distribution of total sales volume across products is not as highly fragmented. From the 25 distinct products that were delivered from the facility, the top product accounts for 60% of the total sales volume and the top 4 products account for 81.11% of total sales.

The analysis of the order history also revealed that certain products at some locations are ordered very infrequently and possibly only once per year whereas others are ordered multiple times within a given week. In addition, the variability of the replenishment size varies widely across tanks. Tanks that are replenished infrequently usually exhibit high variability in the replenishment sizes whereas tanks that are frequently replenished have less variable replenishment quantities. On average, across all tanks, the replenishment size equals almost half the tank capacity.

In order to determine the effectiveness of the existing dispatching practice, our analysis subsequently turned to the delivery history. Truck utilization averaged 84.17%, indicating that there exists some room for improvement in this respect. In addition, 81.25% of all trips were two – three – or four – stop trips. In most trips, only one, two or three products were delivered with most stops on a trip entailing the replenishment of a single product.

The determination of which customer sites should be visited on the same trip is also a process in which VMI can offer improvement opportunities. To assess how
effectively this process is currently being carried out, we measured the average distance between stops on multi-stop trips and compared this number with the average distance between adjacent customer locations. It appears that the existing trip design process is effective in that only customer sites located close to each other are assigned on the same trip.

Based on the analysis of current practice we identified two methods for improving routing efficiency. First, the current system uses trips that visit many customers, and as a result each customer location receives more deliveries than necessary. We examine the possibility of using dedicated trucks that visit only one customer per trip, and attempt to minimize the total number of times each customer is visited. Next, current truck utilization averages about 85% of capacity. We create a procedure for reducing the total number of trips by planning routes that make full use of truck capacity.

**Replenishment Via Dedicated Trucks**

In an initial attempt to quantify what the potential benefits of implementing VMI would be and based on our observation that in most cases only one product was replenished at a stop and that several locations were being visited multiple times within a week, we considered the possibility of sending dedicated trucks to customer sites. Our goal was to quantify the potential reduction in the total number of visits at a customer site. For this reason, we designed a mixed-integer program that was solved for selected customer locations separately.

Results showed that significant reductions are possible in the total number of required visits. However, to achieve high truck utilization, most products stored at a
customer site should be relatively fast – moving. Instead, most customer sites served by the facility consume a single product in high rates and only order other products very infrequently. In such cases, the tank capacity of the high volume product becomes a binding constraint and leads to the generation of low utilization trips that only replenish this product. Hence, use of dedicated trips for replenishing customer sites is not a viable option.

Maximizing Truck Utilization Through VMI

As dedicated trucks are not an option we next turned our attention to maximizing capacity utilization during delivery trips, thus reducing the total number of trips required to service the customers. The capacitated vehicle routing problem is NP-hard, and the additional constraints of multiple products, compartmented vehicles, and tank capacities increase the complexity of the problem. Therefore, we developed a three step process to reduce the complexity and create a workable solution.

1. Segment the tanks into those that will be served by VMI and those that will not
2. Separate customers into delivery clusters
3. Develop routes to serve the VMI tanks within each delivery cluster

In order to limit the number of tanks considered for VMI we examined the order history for all tanks. We sorted the tanks in decreasing order of total delivered volume and added them to the VMI group until 80% of total delivered volume was reached. This produced a set of 248 tanks at 163 separate customer locations. Though this represented only 26% of the total number of tanks they accounted for 80% of the volume and 67% of the orders.
Customer locations were placed into delivery clusters through the use of a K-means clustering algorithm. The K-means clustering algorithm works by assigning each location to a cluster such that the total sum of the distances between each customer location and the center of its cluster is minimized. We created a set of five delivery regions, consisting of as few as 22 and as many as 78 tanks. This reduced the complexity of the problem such that we were able to construct a mathematical program to create routes for the VMI tanks within each cluster.

The series of routes needed to service the VMI tanks was determined through the creation of a mixed integer program in the OPL Studio modeling environment. The objective of the program was to minimize the total number of delivery trips, subject to constraints on the number of stops per trip, the number of products per trip, the size of the tank at the customer site, and the volume capacity of the vehicle. The output of the model was a series of routes consisting of the customer tanks visited on the route, the quantity delivered to each tank, and the frequency the route is run. Given the specific customers visited on a route we were able to solve a Traveling Salesman Problem (TSP) to calculate the mileage required for a truck to leave the company facility, visit each customer, and return to the facility. This distance, combined with the frequency of the route, was used to determine a total annual mileage for servicing the tanks on the route. The sum of these distances then provided the total mileage necessary to serve all tanks considered candidates for VMI.

In order to measure the savings in total mileage of VMI compared with the order based fulfillment system it was necessary to estimate the mileage required to serve the non-VMI tanks. This was accomplished by estimating the total number of delivery trips
and customer visits required based on average truck utilization and order history in each
delivery region. The average length of a delivery trip was then calculated based on the
distance from the depot to the center of the delivery region, the customer density within
the region, and the estimated number of customer locations visited on a trip. Using the
expected number of trips and the estimated length of a trip within each delivery region
we calculated the estimated mileage for servicing the non-VMI tanks. Table 1 provides a
summary of the results of this method compared with the estimated mileage of serving all
tanks through the current order based fulfillment system.

<table>
<thead>
<tr>
<th>Method</th>
<th>Trips per Year</th>
<th>Mileage</th>
<th>Volume (gallons)</th>
<th>Avg Stops per Trip</th>
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</thead>
<tbody>
<tr>
<td>VMI</td>
<td>714</td>
<td>189755</td>
<td>2854796</td>
<td>3.52</td>
</tr>
<tr>
<td>non-VMI</td>
<td>210</td>
<td>76250</td>
<td>713320</td>
<td>5.15</td>
</tr>
<tr>
<td>Total</td>
<td>924</td>
<td>266005</td>
<td>3568116</td>
<td>3.89</td>
</tr>
<tr>
<td>Current</td>
<td>1049</td>
<td>282146</td>
<td>3568104</td>
<td>3.17</td>
</tr>
</tbody>
</table>

Table 1: Comparison of Systems

In order to test the method used to estimate mileage we compared its results with
that of two other quantities. First, we compared the estimated mileage for the current
order based fulfillment system with that of actual recorded mileage from Company A’s
delivery information, and the estimated total mileage was within 1.6% of the actual
recorded mileage. In the second scenario we compared the mileage estimate with that
calculated by solving the TSP for each of the VMI routes. In this case the estimated
mileage was within 0.6% of the calculated value.

**Conclusion**

Using the methodology we described the calculated reduction in vehicle mileage
achieved through VMI was 6%. Given the limitations of the model and the assumptions
we made it is difficult to determine how accurate this figure is, or how much it could be
improved. This research did produce several key findings, however. First, attempting to serve customers by sending dedicated trucks to each location does not appear to be a viable strategy given the high variation in demand rates between products. Next, by focusing on improved truck capacity utilization the total number of trips can be reduced, and this reduction in number of trips outweighs the increased mileage required to visit more customers on a single delivery. Finally, the major factor in many of the routing issues encountered was the size of the tank at the customer site, not the demand rate of the product usage. Many tanks were simply sized too small, requiring frequent deliveries and limiting opportunities for efficiently combining multiple products in one trip to the customer.

There are several areas of future research that could address the deficiencies of the approach used in this thesis. The most important assumption made in this model was the deterministic demand rate for products. In reality the products exhibit seasonality and fluctuations in usage, and a more complex model that incorporated stochastic demand would likely provide more accurate results. This research also focused on the improvements available in vehicle routing due to the high transportation costs, but a model that included the inventory component would provide better results for the actual savings available through such a VMI system. As the tank capacity at the customer site was often a limiting factor a model that considered tank size a decision variable rather than a constraint could show improved performance. Finally, in order to limit complexity of the model we attempted simply to minimize the total number of delivery trips. In order to truly minimize distance traveled a model would need to calculate the actual distance traveled on all routes and minimize that quantity.