Using SCM to Make Wind Plant and Energy Storage Operation More Profitable

Utilizing results from 51 million Monte Carlo simulation runs, we demonstrate that wind plant-plus-energy storage (WP+ES) operation becomes more profitable by applying supply chain management techniques such as network design and inventory management. Our business case shows that emerging, utility-scale battery storage can be economically viable even today under certain scenarios.

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

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

Forecasting Consumer Products Using Prediction Markets

We examined the use and the overall quality of forecasting using prediction markets. A total of 20 prediction markets involving over 150 participants were run for General Mills. It was found that predictive markets are a good tool to synthesize information from multiple sources and that the accuracy is close to traditional methods.

Analysis of an International Distribution Hub for Fast-Moving Consumer Goods

This project developed an optimization model to assess the benefits of hub capability in an international distribution network. Our model shows that a hub in this setting can provide savings of both holding and transportation costs. Hub capability can also provide companies with the flexibility to take advantage of potential savings in fluctuating environments.

Inventory Positioning for a Multi-Echelon Distribution Network

In a multi-echelon distribution network, managers may need to decide whether to centralize or decentralize inventory. We develop an optimization model to determine the inventory positioning strategy that minimizes total costs for a leading engineering services provider. Our research suggests that for high-volume commodity products, lane consolidation drives centralization; whereas for low-volume, specialty products inventory aggregation is the main driver.

Measuring the Value of a Responsive Supply Network

Using an analytical framework, this research project establishes that initiatives to improve responsiveness contribute to growth in sales. The framework uses an econometric model and a causal model to verify and explain relationships between measures of responsiveness and sales. The research also identifies measures that drive sales and measures that are driven by sales.

Humanitarian Aid in Less Secure Regions: An Analysis of the WFP-Ethiopia

Political instability, rebel activity, ethnic tensions, and poor infrastructure plague the Somali region of Ethiopia and consequently endanger and delay the World Food Programme’s (WFP’s) food-aid supply chain. Our study quantifies the risk in the region and proposes methods by which the WFP and other humanitarian organizations can enhance the security of their supply chains.

Complete List of MLOG 2009 Theses
Introduction


The seven papers included in this journal were selected from the 23 theses submitted by the MLOG Class of 2009 at the Massachusetts Institute of Technology. These articles are written as executive summaries and are intended for a business, rather than academic, audience. The purpose of the executive summaries is to give the reader a sense of the business problem being addressed, the methods used to analyze the problem, the relevant results, and the insights gained. Of course, the complete theses are much more detailed. At the end of this journal, we have also included a complete list of this year’s MLOG theses with short descriptions at the end of this journal.

The articles included in this publication cover a wide selection of interests, approaches, and industries. They explore how companies should assess the option to set up a hub for distribution in a Latin American region; balance various costs with service responsiveness when designing a multi-echelon distribution network; link supply chain key performance indicators (KPIs) with top-line sales impact; and evaluate a novel approach to forecasting using prediction markets. Other articles address supply chains within sectors that have not traditionally been explored – determining how to deploy and operate storage in the electric grid to increase the penetration of renewable energy; revealing hidden costs in the Washington State apple industry; and characterizing the impact of security risks on the distribution of food aid in the Somali region of Ethiopia. This variety of topics illustrates one of the hallmarks of the MIT MLOG Program: the ability for students to focus their coursework and research on the topics that most interest them.

The MLOG Program is designed for early to mid-career professionals who want a more in-depth and focused education in supply chain management, transportation, and logistics. Class size is limited each year to 30–40 students from around the globe and across all industries. The projects highlighted in this journal reflect the variety of opportunities available to MLOG students. Most are conducted in conjunction with a sponsoring company through the Supply Chain Education Partners Program at the MIT Center for Transportation & Logistics (CTL).

I hope you enjoy the articles. If you want access to the entire thesis, just let me know. Also, if you wish to discuss any other aspect of the MLOG Program or wish to find out how your company can interact with MLOG students, please contact me directly.

Sincerely,

Dr. Jarrod Goentzel
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Using SCm to Make Wind Plant and Energy Storage Operation More Profitable

By Prashant Saran and Clayton W. Siegert
Thesis Advisor: Dr. Jarrod Goentzel

Summary: Using results from 51 million Monte Carlo simulation runs, we demonstrate that wind plant-plus-energy storage (WP+ES) operation becomes more profitable by applying supply chain management techniques such as network design and inventory management. Our business case shows that emerging, utility-scale battery storage can be economically viable even today under certain scenarios.

Prashant Saran will be joining Amazon.com in the Operations Leadership Program. Prior to MLOG, Prashant worked as a Lean Six Sigma Black Belt and consultant for IBM Business Consulting, Tata Group, and Alghanim Industries.

Clayton Siegert is joining XL Hybrids as vice president of Supply Chain. Prior to MLOG, Clayton was a co-founder of two successful startups, most recently working as vice president of Supply Chain at Start Space Games.

KEY INSIGHTS
1. Applying concepts from inventory control policies and the "newsvendor" problem to charging/discharging of energy storage units improved profitability of the WP+ES operation.
2. Utility-scale battery storage units located in densely populated areas can realize significant profit by capitalizing on energy price arbitrage.
3. WP+ES operation can generate a pre-tax profit under certain scenarios if policymakers allot the same "installed capacity payments" to battery storage as pumped hydroelectric storage.

Introduction

Wind power is among the fastest-growing energy sources globally, but it has several shortcomings that can limit profitability. First, wind plants are often located in remote areas that have high wind speeds, but relatively low wholesale electricity prices. Second, since electricity is an absolutely perishable resource (meaning it needs to be consumed the moment it is produced, or be lost), wind plants are forced to sell at whatever wholesale price is prevailing in the market at the time of generation – even if that price is unprofitable for the wind plant. Third, wind power is classified as an intermittent resource due to the unpredictability of wind speed and direction. This prevents wind power from participating in some wholesale electricity markets (e.g., Day-Ahead market) where average prices are higher.

These constraints cause wind plants to get a lower price for electricity than other forms of generation. For example, while the U.S. national average wholesale price in 2007 ranged from approximately $0.040 to $0.070 per KWh, the cumulative capacity-weighted-average price paid for wind electricity was under $0.040 per KWh (Wiser & Bolinger, May 2008).

Energy storage technology has been proposed as a possible solution for overcoming the above-mentioned issues faced by wind plants. Storage can give wind-generated electricity a longer ‘shelf life’ to capitalize on price arbitrage opportunities and improve predictability. Despite the promise of energy storage as a useful application for wind plants, relatively few storage installations exist. Almost all are pumped hydroelectric storage facilities, which require special geographic considerations such as mountains near usable water sources. More appropriate storage technologies for wind plants – such as modular, utility-scale batteries – are still evolving and are not considered economically viable in existing research studies.
Being familiar with supply chain management techniques – which are used to reduce costs and improve financial performance for physical products – we hypothesized that they could have the same effect if applied to wind plant-plus-energy storage (WP+ES) operations. Our literature review did not reveal any study of WP+ES operation that has approached the problem with this perspective.

To test our hypothesis, we built a simulation model that creates a realistic environment for a WP+ES operation in New England. The model gives the opportunity to test the impact of various supply chain management techniques on incremental financial performance above our 'Base Case.' The Base Case is defined as a wind plant in Maine selling electricity into New England in the Real-Time or spot market without storage.

Simulation Model – Inputs

As shown in Figure 1 above, there are five inputs to our model:

1. **Wind Plant Electricity Output**: Since wind plants in the New England region were unwilling to share actual generation data, we synthesized wind plant output by applying wind turbine power curves and established industry techniques to wind speed data from a location in Maine. We generated hourly output data for 95 winter days and 95 summer days. Then we validated our synthesized output using the power duration curve and capacity factor comparisons.

2. **Electricity Market Prices**: We obtained hourly price data for both the Day-Ahead (DA) and Real-Time (RT) electricity markets in summer and winter from the New England Independent System Operator (ISO-NE). A curve-fitting research exercise established that the 'Lognormal' probability distribution curve was the best fit for simulating prices based on hourly historical data. This approach captured the extreme variability and temporal trends of New England electricity prices.

3. **Storage Technology Characteristics**: To identify appropriate storage technologies for our model, we used existing research and industry interviews. We short-listed two battery technologies: Zinc Bromine (ZnBr) and Sodium Sulfur (NaS). Using technical characteristics and costs provided by two actual battery companies, we synthesized Alpha Battery and Beta Battery storage facilities (pseudonyms to preserve confidentiality) for use in the model.

4. **Supply Chain Network Design**: Supply chain literature (Chopra & Meindl, 2004) identifies five network design decisions:
   a. **Facility Role**: Our model uses the WP+ES system for 'Time Shifting' (price arbitrage), which involves charging the storage unit when demand and prices are low, and discharging (selling) the stored energy when prices are high.
   b. **Facility Location**: The storage unit in our model can be: i) 'Co-Located' with the wind plant in Maine, or ii) ‘Located’ afar in a densely populated area with high demand and high prices (such as Cos Cob, Connecticut).
   c. **Market Allocation**: Wind plants currently participate only in the RT market, which is equivalent to a 'spot' market. However, by using storage, the output becomes more predictable, making it possible to participate in the DA market (which requires commitment a day in advance, but has higher prices with lower volatility than the RT market).
   d. **Supply Allocation**: The supply of electricity into our battery can be: i) ‘Linked’ where the supply comes solely from wind plant output and thus can never exceed it, or ii) ‘Hybrid’ where supply is supplemented by grid electricity if wind plant output is too low.
   e. **Capacity Allocation**: The size of storage facility in our model can range from 10% to 100% of wind plant installed power capacity.

- 3 -
5. Supply Chain Inventory Management

To create daily operating policies for charging and discharging storage, we adapted concepts from the Newsvendor problem and Order-Up-To policies used in traditional inventory control systems.

We began with a naïve, ‘Simple’ policy that predetermines hours for charging/discharging based on historical price variation by hour of day. Next, we refined this policy and created our ‘Cost Based’ and ‘Max Peak’ policies. These policies dynamically discharge (sell) by comparing the prevailing market price with either the cost of buying or the historical maximum average peak-hour price, respectively. Both of these policies reduce the overage cost for stored electricity at the end of the day when prices are lower.

Finally, we created our ‘Rapid Arb’ policy, which dynamically buys and sells electricity throughout the day based on the prevailing market price. This policy addresses both the overage and underage costs of stored electricity to sell during the peak hours when prices are highest.

Figure 3 depicts the graphical differences among the four policies.

It should be noted that these policies are by no means exhaustive. Rather, they are meant to demonstrate the progressive improvement achieved by applying inventory management concepts.

Simulation Model – Configurations and Output

Based on all the options in our model, we could test over 121,000 possible configurations. We examined the convergence of the 95% confidence interval of results with increasing numbers of simulation runs and decided on 10,000 pricing simulations for each scenario. Since running 1.2 billion (121,600 scenarios * 10,000 runs) simulation runs was infeasible, we intelligently reduced the input configurations to 5,130 by sequentially testing and choosing options. Thus, we completed 10,000 runs for each of the 5,130 scenarios for a total of 51.3 million runs.

We evaluated the options based on Incremental Gross Profit over the Base Case, defined as follows:

$$\text{Incremental Gross Profit} = (\text{Revenue for WP+ES unit}) - (\text{Revenue in Base Case}) - (\text{Incremental costs of electricity})$$

Further, we incorporated cost estimates of storage to calculate the following:

$$\text{Incremental Operating Profit} = (\text{Incremental Gross Profit}) - (\text{Operating Cost of storage})$$

$$\text{Incremental Pre-tax Profit} = (\text{Incremental Operating Profit}) + [\text{Potential Incremental Installed Capacity Payment (IC Payments)}] - (\text{Depreciated capital cost of storage})$$

Results and Management Insights

We obtained Incremental Daily Gross profit for all the simulation runs. Then we compared results for statistical significance using 2-Sample t-Tests and ANOVA across winter and summer seasons. The summary of our findings is as follows:

1. Daily Operating Policies: The Rapid Arb policy that addressed both the costs of overage and underage yielded the best results. Figure 4 shows the results for Winter where the Rapid Arb policy yields an average incremental daily profit of $2,775 more than the base case of $78,975.

Management Insight: WP+ES operators should use policies based on inventory management concepts, and continually iterate by season, price trends, etc.

2. Network Design Decisions: As shown in Figure 5, certain network design decisions significantly improve profits. When determining facility location, it is more profitable to locate the storage unit in a high-demand area.

Figure 3: Graphical Depiction of Operating Policies

Figure 4: Comparison of Daily Operating Policies
area like Cos Cob, Connecticut. For market allocation, there is no significant advantage to participating in the DA market as compared to the RT market. However, if battery storage qualifies for IC Payments – like those paid to pumped hydro storage – that are contingent on selling in the DA market, then it is more profitable to participate in the DA market (see Result #4 for more details). In terms of supply allocation, it is more profitable to operate storage in a ‘Hybrid’ manner. For capacity allocation, there are diminishing returns for additional storage capacity beyond 20% of wind plant capacity under ‘Linked’ operation. However, in a ‘Hybrid’ scenario, supplemental energy from the grid makes larger capacity installations attractive.

**Management Insights:** WP+ES operators should consider locating storage in densely populated areas, participating in the Day-Ahead if IC Payments can be earned, operating storage with a ‘Hybrid’ supply, and sizing storage based on whether operations are ‘Linked’ or ‘Hybrid.’

3. Storage Technology: Our operating policies make WP+ES more profitable under certain scenarios. Yet, under current market conditions, Beta Battery and Alpha Battery are still too expensive to achieve year-round profitability. However, our research provides target cost estimates to these companies so their batteries can achieve year-round profitability. For example, without any subsidies, a target cost estimate for Alpha Battery is to reduce capital cost by approximately 64% and 89% based on summer and winter estimates, respectively.

**Management Insight:** Battery companies can use models like the one developed in this research to set target capital and operating costs.

4. IC Payments: Pumped hydroelectric storage receives IC Payments for being a predictable generation resource. Battery storage, which operates in the same way as pumped hydro, currently does not receive IC Payments. If it did, then battery storage could have a viable business case. For example, Figure 6 shows that Beta Battery with IC Payments generates a pre-tax profit with 14-year and 32-year paybacks using summer and winter numbers, respectively.

**Management Insight:** By qualifying batteries for IC Payments, policymakers can support economically viable business models to drive penetration of more profitable wind energy.
Reducing Shrinkage and Stock-Out Costs in the Washington State Tree Fruit Industry

By James Foreman
Thesis Advisor: Dr. Chris Caplice

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

**KEY INSIGHTS:**

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

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

3. The mixed integer linear program developed in this research can help sales managers quickly determine the lowest cost source to satisfy orders.

Introduction

Each year, $2 billion worth of apples, pears, and cherries, some 125–150 million boxes, move through the Washington State tree fruit supply chain. Historically, the most successful firms were the ones able to achieve low production costs and high sales volumes. Managers at these firms were accustomed to losing a certain percentage of fruit due to physical deterioration, as refrigeration technologies were less developed than they are today. Though technology has changed, the culture of focusing on production costs and sales volumes persists. While continuous improvements have been made in these areas, firms have only recently turned their attention to inventory management.

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

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

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

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

**High Levels of Inventory Lead to Shrinkage**

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

1. **Sales managers begin to discount the price of inventory as it gets older because they know it is deteriorating.**

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

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

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

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

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

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

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

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

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

4. Shape customer demand through pricing, which should be done based on the Adjusted Revenue Curve developed in Figure 2.

Low Levels of Inventory Lead to Stock-Outs

Most sales organizations sell fruit on behalf of multiple packing sheds spread throughout Washington State. When a retailer places an order for a SKU that is not in stock at one of these warehouses, the sales manager has four ways to solve the problem: intra-shed transfer, inter-shed purchase, emergency production, or order cancellation.

In other words, the sales manager can move, buy, make, or cancel the order. In reality, sales managers never cancel orders because they are paid on commission, and packing managers refuse to conduct emergency production cycles because they are paid on packing line efficiency. Thus, sales managers essentially have only two choices: whether to consolidate fruit within their network of warehouses or buy it from an outside firm.
To make this move or buy decision, sales managers need a tool to quickly calculate the costs of each option in a dynamic environment.

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

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

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

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

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

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**Sales Organization Interface**

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

![Click Here When Done](image)

**Instructions**

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

**Figure 6: Sales Organization Interface**

paid for fruit from an external organization, sales managers can make a clear cost comparison and make the most efficient move or buy decision.
Introduction

Companies look for forecasting to drive supply chain efficiency. With new promotions being run every day, customer account teams spread all over the globe and distributed manufacturing, compiling a forecast has become a monumental task leading to inaccurate forecasts. As a result of the complexity of developing accurate collaborative forecasts, companies have begun evaluating a new approach for forecasting: Prediction Markets. Prediction Markets provide the ability for participants to buy and sell shares in a question using play money; for example, will the Bears or the Patriots win the Super Bowl? The stock prices reflect aggregate participant opinions and probability of the forecast. Thus, a Prediction Market is able to compile information from a large number of participants to derive a forecast with an associated distribution.

Research with public Prediction Markets, such as the Iowa Election Markets, has shown that they can be more accurate than experts and polls. We were asked to answer the following question: How accurate are Prediction Markets compared to collaborative forecasting processes? Our conclusion is that the accuracy of Prediction Market forecasts is comparable to traditional collaborative forecasts.

Our research was conducted in conjunction with General Mills and involved setting up 20 Prediction Markets open to 169 participants from 10 departments. The winner of each Prediction Market was given a gift card as an incentive to encourage participation. The Prediction Markets were grouped using the three types of forecasts, that General Mills develops as part of its Operational Forecasting process: Volume Forecasts, Category Forecasts and Promotional Forecasts.

Our aim in examining these forecasts was to determine how Prediction Markets performed under “normal” business conditions. This executive summary will present how we configured our Prediction Markets, how Prediction Market forecast accuracy compared with General Mills’ Operations Forecasting, how we identified irrational exuberance as a cause for inaccurate Promotional Forecasts, and how information flow determined winners while process determined forecast accuracy.

KEY INSIGHTS:

1. Prediction Market forecast accuracy is comparable to collaborative forecasting processes.
2. Information Flow determines the winners of Prediction Markets, while maturity of processes determine forecast accuracy.
3. Prediction Markets are overrun by irrational exuberance leading to poor forecast accuracy.
Prediction Market Configuration

We wanted to be certain that our Prediction Markets were immune to manipulation and participants felt comfortable buying and selling stocks. To test this, we ran a pilot Prediction Market with 18 participants selected from the Sales and Demand Planning departments. In our pilot, we discovered that participants will manipulate the price of Prediction Market stocks. Based on feedback from participants in the pilot, we learned how to prevent manipulation and encourage participation by setting investment caps and framing questions using forecast ranges.

In configuring our Prediction Markets, we concentrated on four components:

1. The question; e.g., “What will third-quarter shipments be?”
2. A set of stocks representing forecast ranges; e.g., “Third-quarter shipments will be between 145 and 155 cases.”
3. Prices representing the probability that actual shipments will fall into a stock’s forecast range; e.g., if the price of a stock was $50, then the Prediction Market is saying that there is a 50% chance that the actual shipments will fall within that range.
4. Play money and investment caps; e.g., $100,000 of play money was given to each participant and an investment limit of $15,000 was set per Prediction Market to encourage participation in multiple markets and to discourage manipulation.

We configured our Prediction Markets starting with a Central Point representing General Mills’ Operations Forecast with ranges radiating out to capture a reasonable set of outcomes. The forecast ranges were chosen by balancing the participants’ ability to differentiate between adjacent forecast ranges and the accuracy needed by Demand Planning. We then normalized prices around the Operations Forecast so that participants could not short-sell the outermost ranges or buy the current Operations Forecast to lock in easy profits. The stock price configuration coupled with the trading caps prevented participants from manipulating the Prediction Markets and invalidating our results.

Analyzing Prediction Market Results

General Mills was interested in exploring Prediction Market forecasts as a supplement or substitute to its current forecasting process. To a large extent, General Mills’ decision to move forward with Prediction Market Forecasts for operational planning depended on forecast accuracy. In addition to forecast accuracy, we examined information flow between departments and the ability of Prediction Markets to converge on the actual result.

Forecast accuracy was tracked using Mean Absolute Percent Error (MAPE), which measures the absolute difference between the forecast and actual as a percentage. Table 1 shows the comparison between Prediction Market MAPE and Operations Forecast MAPE for Volume, Category, and Promotional Prediction Markets.

<table>
<thead>
<tr>
<th>Forecast Type</th>
<th>Prediction Market MAPE</th>
<th>Operations Forecast MAPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>1.33%</td>
<td>1.38%</td>
</tr>
<tr>
<td>Category</td>
<td>1.96%</td>
<td>1.79%</td>
</tr>
<tr>
<td>Promotion</td>
<td>11.24%</td>
<td>11.89%</td>
</tr>
</tbody>
</table>

Table 1 – Comparison of Prediction Market and Operations Forecast Accuracy

From Table 1, we can see that Promotional Forecasts in general are the least accurate. The very low MAPE for the Volume and Category markets indicates the role of business strategy in driving forecast accuracy. The Volume forecasts are aggregate forecasts of many product categories, while the Category forecasts are for flagship product categories. Both these forecasts are across all retailers. In contrast, Promotional Forecasts concentrate on highly promoted product categories. The high MAPE for Promotional Markets indicates that participants are either misinformed or misinterpreting information about promotions that drive the poor forecast performance.

A more detailed analysis of the Promotional Prediction Markets using a measure of confidence is shown in Figure 1.

Confidence is a measure of probability in a forecast range as expressed by the prices in the Prediction Market. This graph shows that the Promotional Prediction Markets are 60% confident throughout the trading period. Because the percentage remains constant, we can see that participants did not become more confident over time. In contrast, the Volume and Category Prediction Markets increased in confidence with each passing week.

The lack of information and the varied interpretation of information for Promotional Prediction Markets by the participants are shown in Figure 2.
The convergence chart plots the MAPE of the Prediction Market Forecast and Coefficient of Variation (COV) of the Prediction Market Forecast. If better information were available, we would expect the MAPE and COV to decrease each week indicating a consensus among participants. The above plot indicates that participants differ in their opinions and are not able to arrive at a consensus because both MAPE and COV increase over time.

A startling contrast came to light during the analysis when we compared the number of winners from each department with the overall MAPE for their department. The results are shown in Table 2.

Table 2 shows that individuals from the Sales department won the most markets. However, Demand Planning had the most accurate forecasts. This result when combined with interviews of participants led to two important conclusions. First, Sales, through their interaction with the customers has precise information about promotions; however, this knowledge is limited to a handful of salespeople and not the group as a whole. Second, the current process followed by Demand Planning is able to process information and generate more accurate forecasts. Thus, we see that access to information determines winners, while processes determine forecast accuracy.

We wrapped up our analysis using surveys of all participants and in-depth interviews of key participants selected based on their trading behavior. The surveys indicated that 73% of the participants spent less than 20 minutes per week indicating that larger rollouts of Prediction Markets within corporations are possible without taking too much time away from other work. Participants were almost unanimous in their opinion that knowledge about the Prediction Markets was the most important factor in determining their participation, indicating Participants will self-select into markets where they have knowledge. The surveys and interviews confirmed the willingness of participants to use Prediction Markets on a regular basis.

**Conclusion**

From the analysis, we see that Prediction Markets generate forecasts that are comparable to forecasts developed by collaborative forecasting processes. Prediction Markets have powerful information aggregation and self-selection properties, making them ideal for capturing opinions from a large number of participants. Our research indicates Prediction Markets can play an important role in new product forecasting, long-range planning, and consumer preference measurement by gathering opinions from a disparate group of participants and distilling them into an intelligible result when there is no established process in place.
Analysis of an International Distribution Hub for Fast-Moving Consumer Goods

By Rich Hawks and Sebastian Ortiz Duran
Thesis Advisor: Stephen Graves

Summary: This project developed an optimization model to assess the benefits of hub capability in an international distribution network. Our model shows that a hub in this setting can provide savings of both holding and transportation costs. Hub capability can also provide companies with the flexibility to take advantage of potential savings in fluctuating environments.

KEY INSIGHTS:
1. Hub capability in an international supply chain may provide higher flexibility and lower cost.
2. Logistics infrastructure and economies of scale often impact international transportation costs more than total distance traveled.
3. Postponing final allocation to regional distribution centers until containers reach a hub enables the use of more accurate forecasts.

Introduction
A growing homogeneity in consumer products tastes across countries has many consumer packaged goods (CPG) companies analyzing the cost tradeoffs between consolidated production economies of scale and increased distribution costs. Our research, performed in partnership with a CPG company referred to throughout as Consumer Co., analyzed the potential benefits that could be achieved by introducing an international distribution hub into their supply chain.

Consumer Co. is a large multinational manufacturer of consumer packaged goods. As a well-established global company, Consumer Co. consists of multiple operating divisions throughout the world organized geographically. Our research focused on their distribution to their Northwest Latin American (NWLA) division in Central America and northern South America. Within this region, Consumer Co. maintains regional distribution centers (RDCs) in 11 countries that receive products from international and local production sources and ship to local retailers who are Consumer Co.’s customers. Those products with wide geographic reach were typically produced at one of three manufacturing plants that the company owned in Argentina, Brazil, and Mexico in order to consolidate volume and create economies of scale.

Current practices require each RDC to hold high levels of inventory. Containers are shipped directly to RDCs at full capacity to minimize transportation costs. Lead times from the production facility to the RDC average 35 days and are highly volatile. Forecast errors at the time of shipment are approximately 40%. These factors result in high holding costs at the RDCs in order to maintain desired fill rates.

Duties and tariffs also play an important role in an international distribution network. Taxes are applied to the accumulated value of the imported product up to the port of arrival. The added cost of taxes and transportation to the cost of the product itself results in a higher opportunity cost of holding inventory. Consumer Co.’s imported product lines must pay duties of up to 30%, making this an important consideration of their network design.
Mixed Integer Program Modeling

To assess whether cost savings could be achieved by introducing an international distribution hub into Consumer Co.’s supply chain, we developed a mixed integer programming model to evaluate transportation, holding, and hub handling costs.

Capability was added to the model to assess whether holding safety stock at the hub could provide savings as compared to strictly cross-docking product at the hub. While both options must account for the variability during the lead time from the hub to the RDC in their safety stock, the cross-dock option must also account for the variability during the lead time from the production facility to the hub. Due to the risk pooling and postponement benefits, only a fraction of this variability from production facility to the hub must be accounted for.

We also considered that the mean absolute percentage error (MAPE) between forecasts and actual demand decreases as the days between shipment and actual sales decrease. As shown in Figure 1, postponing allocation until containers reach a hub enables products to be shipped to RDCs with more accurate forecasts.

Comparing Hub Scenarios to the Baseline

To replicate the current state of operations, we ran a scenario with no product flowing through a hub, which is used as the baseline for cost, saving assessment. Figure 2 shows the results of the different scenarios we compared to the baseline.

The first Hub scenario we modeled was Total Hub Panama, in which all imported product flowed through a hub located in the Free Trade Zone in Colon, Panama. In such a scenario, total supply chain costs for Consumer Co. would actually increase by 19.4%.

We then performed optimization to determine a minimized cost using a Hybrid approach of shipping some production to destination combinations direct and the others through a hub. This scenario proved to be the best, providing 4.4% total cost savings. While savings in this scenario can be achieved using a cross-dock hub, we found greater savings with safety stock holding capability at the hub.

Another scenario, Total Hub Colombia, was run to test if Colombia’s close proximity to high-demand points would reduce overall cost. However, due to Colombia’s lack of quality infrastructure, cost per mile and lead times were highest. Total costs were actually 56.9% higher than the baseline. No Hybrid configuration for Colombia provided lower cost than the baseline.

Reduced Shipping Cost with Layover at Panama

Although containers shipped through the Panama hub would travel increased distances, transportation costs were actually reduced for some routes. As seen in Figure 3, the cost per mile was lower with a Hybrid or Total Hub in Panama than in the current network.

This can be explained by the economies of scale available in shipments to and from Panama. Given the country’s unique infrastructure, there is a considerable volume of traffic flowing through these lanes. Panama also stimulates volume growth by providing low duties and tariffs, access to Free Trade Zones, and efficient customs clearance times. Consumer Co. can generate savings simply by cross-docking some of its more expensive shipping lanes through the Colon Free Trade Zone for a layover and then shipping to the final destination country.
Sensitivity Analysis

With so many dynamic variables in the analysis, it is important to test the sensitivity to fluctuations in each. The sensitivity analysis that we conducted involved running optimizations altering each input variable to -20%, -10%, +10%, and +20% of its current actual value and measuring the savings projected by our model. Figure 4 displays key variables which, when increased, lead to increased savings from implementation of an international distribution hub.

This data tells us that the most sensitive variables are customer fill rate, lead time, and hub handling cost. As desired fill rates approach 100%, required safety stock increases exponentially. This dramatically raises the potential savings that centralization can offer. Lead time reduction is an alternative solution Consumer Co. can undertake to achieve savings. Finally, if Consumer Co. can decrease handling costs at the hub, its benefits could be significantly larger.

Conclusion

Increasing customer expectations, long lead times, and forecast inaccuracies have a profound effect on supply chain costs. Centralization can offer lower transportation and holding costs, but companies must assess correctly which links in their supply chain may benefit from it.

In emerging markets like Latin America, demand, exchange rates, inflation, trade agreements, and infrastructure investments can be highly volatile. Hub capability provides Consumer Co. with the flexibility to adapt to potential changes in the environment. Our model will allow the company to periodically assess the profitability of a hub and to tailor its network accordingly.
Inventory Positioning for a Multi-Echelon Distribution Network

By Deepak Avari and Naman Dayal
Thesis Advisor: Dr. Amanda Schmitt

Summary: In a multi-echelon distribution network, managers may need to decide whether to centralize or decentralize inventory. We develop an optimization model to determine the inventory positioning strategy that minimizes total costs for a leading engineering services provider. Our research suggests that for high-volume commodity products, lane consolidation drives centralization; whereas for low-volume specialty products, inventory aggregation is the main driver.

KEY INSIGHTS:

1. For high-volume bulk products, large gains in service levels may be achieved with a relatively small increase in total costs.
2. For low-volume specialty products, centralization may reduce total costs with a minimal impact on supply chain responsiveness.
3. Lane consolidation drives centralization of bulk products, whereas inventory aggregation drives centralization of specialty products.

Introduction

Our sponsor company is a leading engineering services provider across the United States and Europe, with a predominantly decentralized distribution network in North America (NA). The company's services in NA require large volumes of bulk products along with small volumes of specialty products. With a large number of district DCs close to customer sites, the company has been able to meet demand and sustain high service levels. The company's management wants to improve operational efficiency by centralizing inventory at regional distribution centers (RDCs), each of which will serve the aggregate demand arising out of several distribution centers (DCs). Figure 1 shows the flow of products from suppliers through the RDC or the district DC to the customer site.

Figure 1: Product Flow

Products have diverse characteristics, in terms of demand patterns, lead times, product costs, service-level requirements, transportation modes, and supplier locations. In Figure 2, we can see that the annual demand is highly variable across products. Figure 3 shows the annual cost for a representative set of products across seven different product families.
In this thesis, we address the key question that our sponsor company is facing. How should management decide which products should be centralized at the RDC, and which ones should remain decentralized at the district DC?

Cost and Service Tradeoffs

The decision to centralize a product can have a significant impact on total cost and supply chain responsiveness. For some products, holding inventory in a central facility can achieve a reduction in total costs through:

1) Reduction in safety stock requirements due to the aggregation of demand variability (the risk pooling effect).

2) Reduction in inbound (from supplier) transportation costs, through a consolidation of replenishment orders across several district DCs.

This cost reduction has to be weighed against the effect on service levels and responsiveness to fluctuating demand. Choosing the optimal combination of RDCs, products, and district DCs requires an understanding of the tradeoffs among inventory costs, transportation costs, and supply chain responsiveness.

Our research quantifies the tradeoffs above and develops a decision-making framework to help management decide which products should be centralized to the RDC.

Optimization Model

We develop a non-linear integer program that evaluates the total cost, which includes inventory holding and transportation cost, for each product in both centralized and decentralized scenarios. Our model incorporates the following cost elements:

a) Inventory (Safety Stock) Holding Cost.

b) Outbound (from RDC) Transportation Cost.

c) Inbound (from Supplier) Transportation Cost.

The network configuration is composed of all suppliers and all facilities where the product is stocked. End customers are mostly clustered around each district DC. The inventory is stocked at the district DC in a decentralized system and at the RDC in a centralized system.

The total cost function is minimized, subject to the constraint that a district DC may be served by at most one RDC. An optimization model is run for each product and its corresponding distribution network. The output gives a set of district DCs to RDCs assignment, which denotes centralization for those district DCs. Thus, the centralization decision is made separately for each product at each district DC.

Model Outputs and Results

Model’s output is an optimal configuration that represents the best possible placement of inventory in the given network, minimizing total costs. The results include the total costs of the optimized network along with a measure of supply chain responsiveness.

As discussed earlier, the total cost is the sum of the expected inventory holding and transportation costs. Responsiveness is measured in terms of product miles, which is the product of annual volume and distance traveled for any product. Higher product miles indicate lower responsiveness, and vice versa.

As an example, the solution for product B1 is explained. Table 1 shows the result of the optimization, in which five district DCs have been centralized out of a total of eight. The cost and responsiveness metric of the optimal configuration are quantified in this table. Table 2 compares the optimized network with the baseline configuration, in which all district DCs are completely decentralized. We see that the optimal inventory placement can reduce total safety stock cost by 27% and total transportation cost by 5% for product B1. However, the cost reduction comes at the expense of supply chain responsiveness. The optimal configuration increases product miles for product B1 by 6%, which translates to lower responsiveness as compared to the fully decentralized baseline network.
Quantifying cost and responsiveness in this way enables managers to make the tradeoff among inventory costs, transportation costs, and supply chain responsiveness for each product based on individual business requirements.

**Lane Consolidation**

Centralization can result in significant savings in inbound transportation costs between the supplier and the RDC due to lane consolidation. In our model, we use a reduction factor, \( M \), to denote a percentage reduction in inbound transportation costs. \( M \) depends on the consolidation of replenishment orders placed per year to the supplier after centralization. We estimate the percentage of lane consolidation using the annual demand and lane capacities to compute the expected number of replenishment orders.

### Table 1: Optimization Run Results for Product B1

<table>
<thead>
<tr>
<th>No</th>
<th>Description</th>
<th>Units</th>
<th>Centralized</th>
<th>De-Centralized</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Number of District DCs Centralized</td>
<td>#</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Aggregate Safety Stock Cost</td>
<td>$/year</td>
<td>$1,087</td>
<td>$1,051</td>
</tr>
<tr>
<td>3</td>
<td>Aggregate Transportation Cost</td>
<td>$/year</td>
<td>$26,182</td>
<td>$14,506</td>
</tr>
<tr>
<td>4</td>
<td>Total Product Miles Travelled</td>
<td>lbs-miles</td>
<td>1,611,361</td>
<td>1,611,361</td>
</tr>
</tbody>
</table>

### Table 2: Baseline Comparison for Product B1

<table>
<thead>
<tr>
<th>No</th>
<th>Description</th>
<th>Units</th>
<th>Baseline</th>
<th>Optimized</th>
<th>% change</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Aggregate Safety Stock Cost</td>
<td>$/year</td>
<td>$45,750</td>
<td>$45,422</td>
<td>-0.6%</td>
</tr>
<tr>
<td>3</td>
<td>Aggregate Transportation Cost</td>
<td>$/year</td>
<td>$1,507,800</td>
<td>$1,611,361</td>
<td>6%</td>
</tr>
<tr>
<td>4</td>
<td>Product Miles Travelled</td>
<td>lbs-miles</td>
<td>1,517,633</td>
<td>1,611,361</td>
<td></td>
</tr>
</tbody>
</table>

### Sensitivity Analysis

We perform a sensitivity analysis to test the optimal solution over a range of input values for different variables. The graphs shown are for product B1. The vertical “Base Input” line shows the input value for which we get the outputs in Tables 1 and 2.

Figure 4 shows the sensitivity analysis for lane consolidation. We see that the degree of centralization increases with higher lane consolidation. This is because lane consolidation reduces the inbound transportation costs to the RDC. With an increase in centralization, the total costs reduce and the product miles increase.

Figure 5 shows sensitivity analysis for the transportation multiplier (transportation cost per unit volume, per unit distance) between the RDC and district DC. With an increase in transportation cost on this leg, centralization leads to higher cost.

### Managerial Recommendations

Based on the insights gained from our work, we offer the following three managerial recommendations:

1) Centralize high-volume bulk products to an RDC with rail shipments instead of by truck, because lane consolidation can reduce total costs by up to 30%.

2) Identify and centralize low-volume specialty products for which suppliers are geographically close to the RDC. This can deliver immediate reduction in total costs (5% to 10%), with minimal impact on responsiveness.

3) Negotiate better contracts with vendors and transportation providers using the greater leverage provided by lane consolidation.

Our optimization model is able to quantify tradeoffs among transportation costs, inventory costs, and supply chain responsiveness, thus enabling managers to make more effective decisions.
Measuring the Value of a Responsive Supply Network

By Jaime Garza and Subramanian Suryanarayanan
Thesis Advisor: Dr. Chris Caplice

Summary: Using an analytical framework, this research project suggests that initiatives to improve responsiveness contribute to growth in sales. The framework uses econometric and causal models to verify and explain relationships between measures of responsiveness and sales. Our research also identifies measures that drive sales and measures that are driven by sales.

KEY INSIGHTS:
1. Using econometric and causal models, it is possible to establish relationships between sales and KPIs.
2. LargeCo’s initiatives to reduce Supply Chain Cycle Time and Time Between Production Runs have an effect on Sales, but with a time lag.
3. Due to already high fill rates, a marginal increase in high fill rates does not contribute to measurable growth in sales.

Introduction

LargeCo is a large manufacturer and distributor of a wide variety of consumer products. The markets for these products are characterized by low growth rates, high product variety, and demand uncertainty. LargeCo focuses on high service levels to maximize sales. Therefore, it relies on a responsive supply chain to be successful in the markets where it competes. The company executes initiatives to improve the responsiveness of its supply chain and uses various Key Performance Indicators (KPIs) to track the performance of its supply chain. LargeCo believes that initiatives to improve responsiveness in its supply chain have had the desired effects. It also believes that improvement in responsiveness is reflected by improvements in the various KPIs it used to track the performance of its supply chain.

Organizations that have invested in initiatives to improve the responsiveness of their supply chains have done so with the belief that improvement in responsiveness reduces lost sales and contributes to growth in sales. However, our literature review did not reveal a model to verify this belief. LargeCo is interested in determining whether improvements in KPIs, driven by improvement in responsiveness of its supply network, contribute to improvements in sales. This research project develops an analytical framework to answer this research question.

Approach

Our research work analyzed the sales impact of changes in the following five KPIs:
1. Days of Inventory: Days of sales held as inventory.
2. Fill Rate: Percent of demand fulfilled.
3. Logistics Cost: Inbound and outbound transportation cost.
4. Supply Chain Cycle Time: Sum of procurement, manufacturing, and distribution cycle times.
5. Time Between Production Runs: Period between two production runs of a product.
LargeCo uses a proxy measure for sales known as Sales Net Effects. This measure eliminates from sales the impact of discounts, marketing, and promotions, thereby providing a measure of sales devoid of these effects. The scope of research was limited to LargeCo’s sales in the United States for five of its product lines for a period of nearly three years, and used monthly data for this period. The five product lines are referred to as ProductLine1 to ProductLine5.

The analytical framework includes an econometric model and a causal model. Our econometric model uses correlation analysis, regression analysis, and tests of statistical significance to examine if relationships exist between sales and the KPIs. The causal model uses causal diagrams and mathematical formulations to explain these relationships.

**Analytical Framework**

Figure 1 is an illustration of the analytical framework with a summary of the steps involved.

1. **Define Hypothesis**
   - Define KPIs to be analyzed
   - Identify instrumental/dummy variables related to KPIs
   - Gather related data (weekly/monthly data for 5 years at a minimum is recommended)

2. **Identify Variables**
   - Remove unrelated effects (i.e., discounts, marketing and promotional)
   - Remove seasonality and outliers
   - Standardize data if required
   - Perform trend analysis to validate data

3. **Remove Effects**
   - Add instrumental or dummy variables
   - Build correlation matrix and verify significance
   - Build regression models and verify significance
   - p-value from t-test and F-test
   - Check for multicollinearity and heteroscedasticity
   - Include time lag to improve model (if required)
   - Determine causality to explain relationship using
     - Causal diagrams
     - Mathematical formulations

4. **Assess Relationship**
   - Finalize conclusions on relationships between dependent variable and KPIs

5. **Finalize Inferences**
   - Using the econometric and causal models, we obtained quantitative and qualitative inferences about the relationships between sales and KPIs.

**Findings**

**Econometric Model**

Correlation analysis, regression analysis, and statistical tests helped identify statistically significant relationships between sales and KPIs. Table 1 summarizes these inferences.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Product Line</th>
<th>Correlation</th>
<th>Confidence Level</th>
<th>Lag</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days of Inventory</td>
<td>ProductLine1</td>
<td>-0.49</td>
<td>96%</td>
<td>None</td>
</tr>
<tr>
<td>Supply Chain Cycle Time</td>
<td>ProductLine2</td>
<td>-0.52</td>
<td>100%</td>
<td>None</td>
</tr>
<tr>
<td>Days of Inventory</td>
<td>ProductLine3</td>
<td>-0.42</td>
<td>96%</td>
<td>None</td>
</tr>
<tr>
<td>Days of Inventory</td>
<td>ProductLine4</td>
<td>-0.63</td>
<td>100%</td>
<td>3 Months</td>
</tr>
<tr>
<td>Supply Chain Cycle Time</td>
<td>ProductLine4</td>
<td>0.59</td>
<td>95%</td>
<td>3 Months</td>
</tr>
<tr>
<td>Time Betw. Prod. Runs</td>
<td></td>
<td>0.45</td>
<td>96%</td>
<td>1 Months</td>
</tr>
</tbody>
</table>

Table 1. Summary of Econometric Analysis

Three of five KPIs – Days of Inventory, Supply Chain Cycle Time, and Time Between Production Runs — appear to have a relationship (with or without time lag) with sales. Relationships between sales and KPIs for ProductLine4 were reviewed and rejected because the direct nature of the relationship revealed by correlation analysis was in contrast to generally accepted linkages in the supply chain function between sales and these KPIs.

**Causal Model**

A causal diagram for a supply network was developed to explain relationships between sales and the KPIs in a supply network. In addition, mathematical formula-
tions were developed to link each of the KPIs to sales. Causal analysis showed that improvements in sales drove a reduction in Days of Inventory and Logistics Cost. The analysis also confirmed the original hypothesis that improvements in Fill Rate, Supply Chain Cycle Time, and Time Between Production Runs drove improvements in sales.

The econometric and causal models show that for LargeCo, two of five KPIs – Days of Inventory and Supply Chain Cycle Time, have a relationship (with or without time lag) with sales. The general inferences from the causal model are that:

- Changes in sales drive Days of Inventory and Logistics Cost.
- Fill Rate, Supply Chain Cycle Time, and Time Between Production Runs drive sales.

Caveats

A few key caveats to consider while using the inferences drawn from the research work are:

- Addition of instrumental and dummy variables could help draw more meaningful conclusions.
- Aggregated monthly data for product families was used in the analysis; disaggregated data could help draw better inferences.
- Only 24 to 32 months of data were available for analysis.

- The link between initiatives to improve responsiveness and improvements in KPIs is assumed as given.

Conclusion

Applying the analytical framework to the research hypothesis helps draw the following conclusions from our research work:

1. Using econometric and causal models it is possible to establish relationships between sales and KPIs.
2. Econometric and causal models show that while sales and Days of Inventory are linked, improvements in sales drive improvements in Days of Inventory. Therefore, LargeCo’s initiatives to improve Days of Inventory cannot be shown as improving sales.
3. Causal models show that improvements in Fill Rate have a relationship with improvements in sales. Analysis also showed that LargeCo may not obtain noticeable benefits in sales by trying to improve its Fill Rates because current Fill Rates are quite high and the improvements are marginal.
4. Contrary to the initial hypothesis, improvements in sales drive a reduction in Logistics Cost. Therefore, LargeCo’s initiatives to improve Logistics Cost cannot be shown as improving sales.
5. LargeCo’s initiatives to reduce Supply Chain Cycle Time and Time Between Production Runs have an effect on sales, but with a time lag.
Humanitarian Aid in Less Secure Regions: An Analysis of the WFP-Ethiopia

By Vidya Chander and Lauren Shear
Thesis Advisor: Dr. Jarrod Goentzel

Summary: Political instability, rebel activity, ethnic tensions, and poor infrastructure plague the Somali region of Ethiopia and consequently endanger and delay the World Food Programme’s (WFP’s) food-aid supply chain. Our study quantifies the risk in the region and proposes methods by which the WFP and other humanitarian organizations can enhance the security of their supply chains.

KEY INSIGHTS:

1. By increasing collaboration with the government and the military through weekly Joint Committee meetings, the WFP decentralized escort dispatching decisions and increased its monthly service from 20% to 80%.

2. Carriers charge almost 50% more per kilometer for routes that involve a security threat, even though incidents of loss account for only 0.1% of food. The WFP and other humanitarian organizations should quantify the risks of the environment in which they operate, in order to pinpoint problematic issues and negotiate with the proper authorities to find workarounds.

3. The WFP and other humanitarian organizations should use overt Global Positioning Systems (GPS) to increase the visibility of their distribution system and to deter corrupt individuals from cargo theft.

Introduction

Rebel forces, hijackers, and looters in the Somali region have a history of taking over government-sponsored aid vehicles. Because of this, the Ethiopian government requires military escorts and convoys for vehicles traveling on designated routes in the region. Traveling in this manner, however, can significantly slow down the delivery process – waiting at checkpoints and traveling at the speed of the slowest convoy member increases the transportation period by two to three times. While reducing the loss in aid that the WFP incurs, this escort process and its slowed travel times affect the WFP supply chain in ways we discuss below.

In an effort to improve this escort process, the WFP and the Ethiopian government have set up Joint Committees, composed of the WFP, the military, and government workers. These committees decentralize the dispatch and escort decisions from the capital, Addis Ababa, to the Extended Delivery Points/warehouses seen in Figure 1 to increase cooperation at local levels.

Figure 1: The Extended Delivery Points (EDPs) Servicing the Somali Region
This Joint Committee has two tangible benefits. Because the WFP and the military work together to schedule these deliveries from the ground, the military can send WFP-sponsored vehicles with escorts instead of waiting so long for full convoys at the Somali region border. Further, because of their now local, joint dispatching efforts, the military can more accurately predict WFP deliveries and thus deliver aid more frequently. For instance, in the past, only 20% of delivery points were being reached each month. However, due to the increased frequency of military escorts, 70%–80% of distribution points are now successfully receiving monthly deliveries. Additionally, since the dispatches are local, the drivers are also locals of Somali ethnicity. Non-Somalis are often mistrusted in the politically rebellious Somali region; therefore, transportation security increases with the addition of local drivers.

Analysis of Security Risks

The limitations on travel restrict the WFP to only servicing a beneficiary community once every month or two. Therefore, the WFP must send enough rations to fulfill a community’s entire monthly (or bi-monthly) needs. However, beneficiaries cannot pick up monthly or bi-monthly rations all at once, and therefore must leave some behind for later pick-up. Because the WFP has no responsibility for the food once it has reached the beneficiary community, it does not have the resources to ensure proper storage or warehousing of the excess food at the community site. Limited storage and excess aid at beneficiary communities often result in the creation of unofficial town distributors, who store and distribute the unpicked-up food from their homes. As “payment” for this position, the town distributors may take a portion of the food aid, resulting in smaller rations or food-aid stockouts. In our analysis, this loss could be up to 16% of the food aid. If the WFP could deliver rations more frequently in bi-weekly or weekly shipments, additional flexibility would be built into current operations by allowing shipments to be dispatched as needed rather than in one bulk shipment.

The limitations on travel not only impact the beneficiaries, but also the carrier rates charged to the WFP. As seen in Figure 2, on average, routes with escorts cost 50% more than routes without escorts. We can assume that the carrier rates charged reflect both the high risks that these contracted carriers face in transporting goods into the region and the slowed travel time that those risks cause. In analyzing the rates charged by carriers, we found that escorts bring serious cost impacts on route rates, probably because less secure paths require escorts and escorts cause longer waiting times.

Additionally, we found that road conditions and driving time also affect the cost of transportation. According to our regression, road conditions, escort need/security conditions, and drive time explain 64.6% of the variation on the price of transportation.

\[
\text{Price} = f (\text{road risk, escort risk, driving time})
\]

\[
y_1 = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + e
\]

Where:

\[y_1 = \text{cost of transportation}\]

\[b_0 = \text{baseline} \quad e = \text{noise}\]

\[b_1 = \text{coefficient for road risk} \quad x_1 = \text{road risk score (0–2)}\]

\[b_2 = \text{coefficient for escort risk} \quad x_2 = \text{escort risk score (0–2)}\]

\[b_3 = \text{coefficient for driving time} \quad x_3 = \text{driving time (hrs)}\]

Though escorts create significantly slower traveling times, their presence does defend the WFP’s food aid in a considerable manner. In 2008, the WFP data show only nine incidents of food loss. At first, the amount of food lost last year seems inconsequential compared to the total amount of aid that the WFP distributes to the Somali region, merely 0.1% of the goods. Additionally, as most of these incidents occur in “secure areas,” we might assume that the data correlates poorly to the perceived threat of the region. However, because the military requires escort services on roads considered medium and high security risks, this may mean that hijackers and looters target areas without military protection.

Figure 2: The Effect of Escort Risk on the Cost of Transportation

Additionaly, we found that road conditions and driving time also affect the cost of transportation. According to our regression, road conditions, escort need/security conditions, and drive time explain 64.6% of the variation on the price of transportation.

\[
\text{Price} = f (\text{road risk, escort risk, driving time})
\]

\[
y_1 = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + e
\]

Where:

\[y_1 = \text{cost of transportation}\]

\[b_0 = \text{baseline} \quad e = \text{noise}\]

\[b_1 = \text{coefficient for road risk} \quad x_1 = \text{road risk score (0–2)}\]

\[b_2 = \text{coefficient for escort risk} \quad x_2 = \text{escort risk score (0–2)}\]

\[b_3 = \text{coefficient for driving time} \quad x_3 = \text{driving time (hrs)}\]

Figure 3: The Impact of Road Conditions, Escort Need, and Driving Time on the Cost of Transportation

Though escorts create significantly slower traveling times, their presence does defend the WFP’s food aid in a considerable manner. In 2008, the WFP data show only nine incidents of food loss. At first, the amount of food lost last year seems inconsequential compared to the total amount of aid that the WFP distributes to the Somali region, merely 0.1% of the goods. Additionally, as most of these incidents occur in “secure areas,” we might assume that the data correlates poorly to the perceived threat of the region. However, because the military requires escort services on roads considered medium and high security risks, this may mean that hijackers and looters now target areas without military protection.
We found that the WFP uses its carrier contracts to ensure carrier honesty and responsibility to combat some of these security risks. Unlike commercial contracts, the language of the WFP contract anticipates the possibility of fraud, theft, and corruption. Given this potential danger, the contract urges carriers to take full responsibility for cargo and sets strict guidelines for beneficiary interaction, ensuring the safety of both aid and beneficiaries. The contract’s attitude of carrier responsibility may instill in drivers the responsibility to vehemently defend the food-aid cargo from rebel groups or even insider scams. Similarly, the documentation demands that all carriers and contractors act according to the highest standards of protection, as according to the United Nations’ protection agreement.

Proposed Technology for the WFP

The WFP is currently looking into GPS technologies to implement onto its dedicated fleet of vehicles. By implementing GPS, the WFP will have a chance to not only track the progression of its contracted carriers, but also speculate upon potential hazards. If GPS is implemented, then we recommend that the WFP also consider geo-fencing applications. Geo-fencing would send a real-time alert if a vehicle moves outside the bounds or time schedule for its route, which could indicate a security event. The WFP should also overtly implement GPS within its vehicles. An insurgent group may be deterred when it comes upon an aid truck mounted with an overt GPS tracking unit. Further, drivers themselves would resist assisting insurgent groups if they know that the WFP will monitor their behavior. However, GPS or any new technology should be deployed in coordination with other security measures, such as the successful Joint Committees for escort planning.

Conclusion

The WFP and other humanitarian organizations can benefit from efforts to quantify the risks of the environment in which they operate. Through this quantification, humanitarian organizations will be able to pinpoint problematic issues and negotiate with the proper authorities to find workarounds. For instance, the WFP could use its new understanding of the 50% mark-up on escort-guided routes to re-negotiate some carrier rates. Documented improvements from the Joint Committee escort process, along with the low risk indicated by the 0.1% food-loss statistic, would assist in the negotiations.

To enhance the security of their distribution systems, the WFP and other humanitarian organizations should continue to explore technologies such as GPS. By placing a GPS unit in a truck, the WFP can track the whereabouts of the vehicle, and the unit’s presence will deter cargo theft.

Finally, humanitarian organizations should increase collaborative efforts with all stakeholders in their aid-supply chains. Government entities, carrier companies, and individuals, such as food monitors and truck drivers, all have a significant hand in the distribution of aid and act as security guarantors. Working closely with these groups and individuals will ensure the safety of aid and beneficiaries. In fact, a simple Joint Committee with the government and military increases the WFP’s monthly service rate from 20% to 80%.
Complete List of MLOG 2009 Theses

Use of Transportation Relays to Improve Private Fleet Management – By Mayank Agarwal and John Tsu
This project uses a linear program to examine the effectiveness of using transportation relays for private fleets. A transportation relay is a shipment that is divided into two legs. This linear programming model is run for a large retailer that we name LargeRetailerCo. The results for LargeRetailerCo show significant quantifiable benefits for private fleets to use relays. The results show a reduction in the overall transportation spend by 6%.

Supply Chain Management in the Cement Industry – By Isabel Agudelo
Supply chain management (SCM) has traditionally played an operational role within cement companies missing opportunities for cost reduction and value creation. These missed opportunities can be realized by introducing the strategic use of SCM as explained in this article.

A Classification of Carbon Footprint Methods Used by Companies – By Suzanne Andrews
The percent increase in greenhouse gas (GHG) concentration in the atmosphere may be harmful. There is no single preferred method for measuring GHG output. How can one classify and choose an appropriate method? This thesis offers a classification of current methods used by companies to measure their GHG output.

Strategies for Cost Reduction in Procuring Trucking Services – By Carlos G. Castro Izaguirre
This project compares planned truckload procurement to executed truckload procurement using shipment transactions from 2006 to 2008. The research suggests that matching between the two occurs in fewer than 10% of the lanes, and overspending occurs in more than 50% of the lanes. This article proposes strategies to reduce truckload procurement to help shippers avoid "planning to waste."

Measuring Performance of Transportation Carriers – By Weixia Cheng
We propose a carrier performance measurement framework for a specialty chemical manufacturer to assess and compare the performance of various carriers in a dynamic fashion.

Managing Multi-Tiered Suppliers in the High-Tech Industry – By Charles Frantz and Jimin Lee
This project explores high-tech manufacturers who outsource many of their components to various supplier tiers to reduce costs. However, disruptions in the supply chain occur due to poor quality and delays, therefore increasing costs. We created a five-step roadmap that companies can use to manage their suppliers and mitigate disruptions.

Predictive Metrics for Supply Chains – By Linda Haydamous
Many supply chain management decisions continue to be made as though driving with the rear-view mirror. This project offers a set of metrics that provide supply chain managers with a forward-looking approach to predict supply chain future performance and align their strategy with performance outcomes.

Multi-Echelon Multi-Product Inventory Strategy in a Steel Company – By Juan D. Iocco
Ternium is an integrated steel mill that faces customers’ requirements of short service times and high service levels. However, increasing safety stock is not a desired solution. This project addresses the problem of determining where to allocate inventories in a long lead-time multi-echelon system, and its impact on inventory costs and service level.

Including Costs of Supply Chain Risk in Strategic Sourcing Decisions – By Avani Jain
Cost evaluations during supplier selection do not always include the costs associated with risks inherent to the supplier, resulting in higher total costs than expected. This project uses Value-at-Risk methodology to develop a quantitative model for comparing total costs of sourcing from multiple suppliers with unique risk profiles. The model predicts the confidence of a supplier exceeding initial cost estimates and helps identify the lowest-cost supplier in the longterm.

Analyzing the Level of Service and Cost Tradeoffs in Cold Chain Transportation – By Saiqi (Cindy) Liu
This thesis discusses the tradeoff between transportation cost and the level of service in cold chain transportation. Regression models are built to quantify the additional cost of superior quality cold chain for both the shipper and its carriers, and analyze the relationship between such cost and customer service level. No correlation is found between transportation cost and the level of service in cold chain transportation. Therefore, carriers with the best cold chain management do not necessarily charge the highest.
Structuring Strategic Decisions Through the Analytical Hierarchy Process: A Case Study of the Selection of Warehouse Location for WFP in Ethiopia – By Gina Malaver and Colin Regnier
This thesis developed a multi-attribute model to help the World Food Programme in the optimization of its warehouse location in the Somali region of Ethiopia. The Analytic Hierarchy Process was used to facilitate the use of qualitative information for optimization purposes. The model can be scaled in order to be used, first, in other geographical regions and second, as a guide for as a guide for making strategic decisions with imperfect information.

Floating Offshore Wind Farms: Demand Planning and Logistical Challenges of Electricity Generation – By Christopher Dozie Nnadili
This paper examines the logistical challenges and inventory management issues a prospective operator of a floating offshore wind farm would encounter in generating electricity. The author studied economic distance from the shore to locate a wind for optimal electricity generation, and examined suitable inventory policies for a floating offshore wind farm based on failure rate data of wind turbine components.

Analysis of Global Channel Costs for the Pharmaceutical Industry – By Eric C. Rimling and Wontae Thomas Seoh
The pharmaceutical industry has become increasingly global with multiple supply chain channels available for each product. Determining the optimal channel is difficult due to cost variability caused by market forces. Our study accounts for this variability through a framework and decision-making process for analyzing multiple channel costs.

Costs of Multiplicity in Public Health Supply Chains in Burundi – By Jeet Shah and Trevor Thomas
This project performed an assessment of the costs of multiplicity in the public health supply chains in Burundi in the context of proposed structural reform from a province-based to a district-based system. The study demonstrated that significant cost savings and improved service levels can be realized with better transportation and inventory management practices.

An Analysis of Long-Term Agreements with Suppliers in Lockheed Martin’s Commercial Satellite Systems Division – By Hem Singh
Lockheed manufactures satellites using a combination of in-house manufacturing, purchasing, and subcontracting for subcontract parts, which constitute the majority of a satellite’s costs. Lockheed uses contracts and other supply management techniques to stay competitive and to keep satellite, specifically subcontract part, costs under control. The subcontract part contracts are called long-term agreements (LTAs). This study found that LTAs, when feasible, can provide cost and process advantage. Because LTAs are very flexible contracts, they are ineffective if not priced right. The research suggests that a good LTA price falls within the range of a spot price minus the supplier’s LTA process savings and a normalized spot rate plus the contractor’s LTA process savings.