2012 SCM RESEARCH JOURNAL
Summaries of Select Research Projects by 2012 Graduates of the MIT Supply Chain Management Program

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http://scm.mit.edu/research
Introduction


The projects included in this journal were selected from the 20 projects submitted by the SCM Class of 2012 at the Massachusetts Institute of Technology. The articles are written as executive summaries of the master's thesis and are intended for a business rather than an academic audience. The purpose of the executive summaries is to give the reader a sense of the business problems being addressed, the methods used to analyze the problems, the relevant results, and the insights gained.

The articles included in this publication cover a wide selection of interests, approaches, and industries. These projects were developed in partnership with companies ranging in size from startups to the largest companies in the world. They cover industries as diverse as office supplies, fresh produce, consumer goods, railroads, and trucking, and also include humanitarian logistics and green supply chain issues.

Each project is a joint effort among a sponsoring company, one or two students, and a faculty advisor. Companies that are members of CTL's Supply Chain Exchange are eligible to submit their ideas for thesis projects in June and July and then present those proposals to the students in late August. In early September, the students select which projects they will work on. From September until early May, the teams conduct the research and write up the results. In late May, all sponsors, faculty, and students participate in Research Fest, where all the thesis projects are presented.

The nine-month SCM 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. Each year, the class size is limited to 30–40 students from around the globe and across all industries. The master's thesis project gives the students a hands-on opportunity to put into practice the learnings that they are acquiring through their coursework.

We hope that you will enjoy the articles. At the end of this journal, you will find a list of the other master's thesis projects. You can view all the executive summaries on the CTL website at: http://ctl.mit.edu/pubs. If you would like to learn more about the SCM program or sponsor a thesis, please contact us directly.

Happy reading!

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Macroeconomic Models of Consumer Demand for Consumer Packaged Goods in Asia

By: Jonathan Mau and Bryan McFadden
Thesis Advisor: Dr. Başak Kalkancı

Summary: This project evaluates the potential of using macroeconomic indicators to forecast consumer packaged goods demand for three emerging markets in Asia. Twenty-seven models were constructed using stepwise multiple linear regression analysis for the three countries and their product segments. Based on our findings, we determined which combination of macroeconomic indicators and time lags produced the models with the highest explanatory power for shipments, market share by volume, and retail sales. Our results indicate that the consumer price index has the most influence on consumption for each country. In addition, a preliminary testing of our models on a limited data set indicated forecasting errors of less than 7.25% error.

KEY INSIGHTS
1. Illustrating the explanatory power that can be derived from macroeconomic indicators, our models produced forecasts with 1.2% to 7.2% error in preliminary testing on a small sample size.
2. For Country A and Country B, the most influential indicator is the consumer price index. For Country C, the average stock index and the consumer price index are the most influential.
3. An increase/decrease in the consumer price index should result in a respective increase/decrease in demand. The same is true for the average stock index in Country C.
4. On average, consumers in Country A react to changes in the macroeconomic indicators a full month quicker than consumers in Country B and Country C.

Introduction
In many business environments, including the consumer packaged goods industry, forecasting demand often seems more of an art than a science. Even corporations possessing significant amounts of historical data and elaborate statistical software packages find it problematic due to variations in demand. While factors such as marketing promotions, seasonal effects, and trends drive the majority of uncertainties in consumption, the existing economic conditions also contribute to the variations, especially in turbulent times. As the effects of the 2008 global recession have taken hold, firms have found themselves beset by large forecasting errors as demand has become tremendously volatile and no longer follows historical trends.

The difficulty of forecasting that exists in developed nations is further amplified in emerging markets, where many of the dynamics have yet to be fully characterized and historical data are limited. Multinational companies whose forecasting horizons are on the yearly scale have difficulty anticipating the rapid market shifts and can be plagued with stock-outs and excess inventories. Our sponsor, CPGco (a pseudonym), is a global manufacturer of consumer packaged goods that found itself in this unenviable position; consequently, the firm is interested in examining the degree to which macroeconomic indicators impact consumer demand for developing markets in Asia and how these variables can be leveraged to act as leading indicators to better inform forecasts.

The purpose of this project was to investigate the effects of macroeconomic indicators on consumer demand for three different product segments across three developing countries in Asia. Our objective was twofold:
Develop working macroeconomic models to forecast consumer demand in each product segment and for each country.

Generate insights on consistencies found across countries and products to provide general rules-of-thumb for CPGCo to complement its existing forecasting process.

**Methodology**

To understand the relationship between the various macroeconomic indicators and consumer demand, we utilized stepwise multiple linear regression analysis and constructed econometric models. Using three different sets of data for each respective product segment and country, we developed a total of 27 models utilizing a combination of Minitab 15 (a statistical analysis program) and Microsoft Excel.

Based on discoveries from our literature review and data availability, six macroeconomic indicators were selected as independent variables. Monthly data was collected for each of the three countries spanning the time period of July 2007 to November 2011:

1. Exchange rate
2. Stock index
3. Interest rate
4. Consumer price index
5. Consumer confidence indicator*

*Only available for Country A

**Data Adjustments**

As referred to earlier, three different types of data were used as the dependent variables. The first set of data contained the firm’s wholesale shipment volume, measured

<table>
<thead>
<tr>
<th>Adjusted $R^2$</th>
<th>Exchange Rate</th>
<th>Stock Index</th>
<th>Consumer Confidence</th>
<th>Consumer Price Index</th>
<th>Interest Rate</th>
<th>Oil Price</th>
</tr>
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| C | Segment 1 Shipment Volume |
| O | Segment 2 Shipment Volume |
| U | Segment 3 Shipment Volume |
| N | Segment 1 Market Share by Volume |
| T | Segment 2 Market Share by Volume |
| R | Segment 3 Market Share by Volume |
| Y | Segment 1 Retail Sales |
| B | Segment 2 Retail Sales |
| A | Segment 3 Retail Sales |

Table 1: Frequency and Explanatory Power of Macroeconomic Indicators in Models

<table>
<thead>
<tr>
<th>Percentage Appearing in Models</th>
<th>15%</th>
<th>33%</th>
<th>33%</th>
<th>81%</th>
<th>19%</th>
<th>44%</th>
</tr>
</thead>
</table>
according to CPGCo’s own standard units—thousands of stat units (MSU)—to distributors. The other two sets of data were compiled by an independent agency and contained both the firm’s retail market share by volume (in MSU) as well as the firm’s retail sales in thousands of U.S. dollars.

Each macroeconomic variable was de-seasonalized in order to evaluate behavior attributed to economic forces and regressed against each dependent variable with time lags ranging from two to four months. Time lags are necessary since CPGCo cannot respond immediately to market changes derived from fluctuations in the various macroeconomic indicators, and few indicators are published more frequently than once per month. Moreover, intuition tells us that macroeconomic factors do not immediately impact consumer demand until several periods later into the future.

**Figure 1: Consumer Price Index Time Lags**

Figure 1 above illustrates the time lags that have the most predictive power for the consumer price index indicator for each country, in each segment. As can be seen from the figure, consumers in Country A appear to react a month quicker than those in Countries B and C, for Segments 1 and 2.

**Regression Modeling**

Stepwise multiple linear regression analysis was used to model the relationship between the dependent variable (Y) and the various macroeconomic independent variables (x1, . . . , xp).

The constructed models take the general form:

\[ Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p + \varepsilon \]

where \(\beta_1, \beta_2, \ldots, \beta_p\) represent the amount of change in \(Y\) based upon the per-unit change of each of the independent variables \(x_1, x_2, \ldots, x_p\), and \(\varepsilon\) is the error term.

**Results and Findings**

Our analysis shows that the consumer price index is the dominant variable across our models, appearing in the final equation 81% of the time. In fact, it is the sole predictor variable in six of the models. Further the consumer price index has the highest overall explanatory power, as can be seen in Table 1.

Additionally, the signs of the coefficients for the price index were consistently positive across the models. The positive signs indicated that if the price index increases, the demand will also increase; conversely, if the price index decreases, so will the demand. We hypothesize that during the global downturn from 2007 to 2011, consumer spending was driven primarily by the anticipation of price increases in the future. This hypothesis is also suggested in the literature regarding demand for nondurable goods.

**Performance of Models**

Figure 2 shows the adjusted R-squared values for the 27 models developed. The values ranged from 0.34 to 0.97—70% of which were above 0.75 and 41% were above 0.90. The high R-squared values of the models indicate the high explanatory power that our independent variables—the macroeconomic indicators—are
capable of.

While our models were able to account for much of the variability in consumer demand, we had difficulty with product Segment 2 in Country A and Country C. As confirmed by our sponsoring firm, this product segment has been problematic to forecast. It is not clear whether it is possible to use macroeconomic indicators to predict demand for this segment; other variables and methods may be more suitable in explaining the underlying intricacies.

Using adjusted R-squared values to assess the models’ abilities to explain demand variation, we found that retail data—retail market share by volume and retail sales—provide more accurate models, especially for Country C. The adjusted R-squared values for shipment volume data range from 0.45 to 0.58, while the adjusted R-squared values for the retail market share by volume data range from 0.53 to 0.95. Intuitively, the closer the demand data to the consumer, the more representative it is in both magnitude and time lag. The farther upstream the supply chain (e.g., to the wholesaler echelon from consumer-facing retailers), the greater the bullwhip effect; therefore, we recommend that CPGCo place more emphasis on examining retail sales data over wholesale shipment volume data.

Conclusions and Future Research
While uncertainty in consumer demand will continue to challenge firms and forecasters, our project showed that macroeconomic indicators could provide valuable insights into generating more accurate forecasting models. In light of our results, further research is suggested to better understand the effects of macroeconomic factors on consumer demand in emerging markets. We examined numerous macroeconomic indicators but only employed a total of six as explanatory variables in our models. Additional indicators such as Gross Domestic Product and the unemployment rate could add explanatory power to the models, allowing CPGCo to generate more accurate forecasts and better anticipate changes in consumer demand.
Inventory Management Strategy for the Supply Chain of a Medical Device Company

By Poi Chung Tjhin and Rachita Pandey
Thesis Supervisor: Prof. Stephen C. Graves

Summary: This project examines the current supply chain for a family of emergency surgical kits and uses mathematical models and sensitivity analysis to derive the best strategy to reduce the inventory level and the operating cost. Using a Strategic Inventory Placement method, we derived a complementary strategy to further enhance the results.

KEY INSIGHTS
1. The Base Stock Policy as well as review period and lead time reductions can lead to significant savings in inventory level and operating costs.
2. Combining two similar SKUs into one single SKU, while increasing the wastage, can reduce inventory level and operating costs.
3. Increasing inventory of finished products can lead to overall reduction of total inventory.

Introduction
In the medical device industry, which is generally characterized by urgent shipping requirements and long supply lead times, many companies rely on high finished product inventory to meet their customers’ urgent requirements. However, due to the need for sterilization of some of their products that leads to short shelf lives, some companies have to contend with potential product expiration and rework. One example is the company that we worked with for this project, referred to throughout this project as “MedCo.” MedCo is a large company that offers a broad range of neurosurgery-related medical devices, including a family of four surgical kits that is the subject of our study. Each kit consists of a sterilized and a non-sterilized sub-kit. Figure 1 shows the current supply chain for the kits, which we refer to as the Base Case in this project.

The purpose of our study was to examine the company’s current supply chain and its inventory management...
policy, and to propose better inventory management strategies to reduce the inventory level and the operating costs across their supply chain, while maintaining the highest healthcare standards.

Methodology

**Strategy Formulations and Analysis, and Sensitivity Analysis**

We first assumed that the multi-echelon network comprises a serial and parallel connection of six stages of activities, each of whose inventory level is independent of the other. We then developed a few possible strategies, modeled them into different scenarios, and used mathematical formulae to quantify a pre-defined set of Key Performance Indicators (KPIs) for analysis. The KPIs consist of the inventory level and the relevant operating costs. The results were analyzed, and a best strategy was developed from the previous strategies. We also performed a sensitivity analysis to determine the best review period for a few strategies that require a change to the review period. Throughout the analysis, we maintained the same overall performance standard in servicing the customers.

Optimization

We then assumed that the various stages of inventory were dependent and adopted a Strategic Inventory Placement (SIP) method – the Guaranteed Service Level Model – developed by Graves et al. (2000) with some modifications to meet our requirements. The method enabled us to determine the best locations in the supply chain to place the inventories as well as the amount of inventories to place in each location to further minimize the inventory and the operating costs.

Strategies

Various factors affect the inventory level and operating costs. They include: the type of inventory control policy used, the location of the inventory in the supply chain, the point of product differentiation in the supply chain, the product kitting architecture, the review period, and the lead time. Hence, we identified eight strategies, each varying one or more of those factors mentioned above for our analysis. In the following section, we present a brief description of these scenarios, with each of them depicting a strategy.

**Brief Description of Scenarios**

- **Scenario 0: Base Stock Policy** – Apply Base Stock Policy to the whole supply chain with inventory calculations using formulae given by Silver et al. (1998).
- **Scenario 1: Forward Placement of Inventory (a – without partial kits; b – with partial kits)** – Place sterilized sub-kits as well as non-sterilized sub-kits or partial kits* inventory before the full-kit assembly.

Partial kits are formed by combining components common to the same set of finished products.

- **Scenario 2: Reduced Review Period and Lead Time** – Reduce review period to 14 days and shorten lead time to 1.5 days for the full-kit assembly stage.
- **Scenario 3: Combined Kits** – Combine two of the four full kits that have many components in common into one “super” kit. This is, in effect, applying the concept of Postponement as the Point of Product Differentiation is moved to the customers’ end.
- **Scenario 4: Continuous Review System** – Use Continuous Review System across the whole supply chain.
- **Scenario 5: Combined Strategy 2 and Strategy 3 (Best Case)** – (1) Reduce review period to 14 days and shorten lead time to 1.5 days for the full-kit assembly stage; (2) combine two of the four full kits that have many components in common.
- **SIP A – Strategic Inventory Placement Alternative A** – (1) Reduce inventory of components prior to sub-kit assembly; (2) increase inventory of finished products after full-kit assembly.
- **SIP B – Strategic Inventory Placement Alternative B** – (1) Eliminate inventory of components prior to sub-kit assembly; 2) further increase inventory of finished products after full-kit assembly.

Results

**Comparing Scenarios and Sensitivity Analysis**

We compared these scenarios using the Total Relevant Costs (TRC) and inventory level in each case. Figure 2 ranks all the scenarios based on the TRC, which includes the safety stock (SS), cycle stock (CS) and pipeline (PL) holding costs, the stock-out costs, and the ordering costs across all stages of the supply chain.

![Figure 2: Comparison of Strategies Based on Total Relevant Costs (in thousands of $/year)](image)

Our analysis revealed the following results:

- Managing the inventory using the Base Stock Policy (Scenario 0) reduced the TRC by about 30% relative to that of the Base Case.
- Although using partial kits instead of sub-kits offered marginal cost savings, Scenario 1 did not lower...
TRC further from Scenario 0 because of the extra costs incurred from forward placing the inventory.

- While reducing the review period and lead time for the final assembly stage (Scenario 2) reduced costs by 12% compared to that of Scenario 0, combining the two SKUs with common components (Scenario 3) offered only smaller savings. The benefits of risk pooling the demand uncertainties were minimal in the latter case because of the large difference between the average demands and variations in demand of the two kits that were combined.

- The lower holding costs achieved by continuously reviewing the inventory (Scenario 4) were offset by a corresponding increase in the ordering costs. Hence, even this strategy reduced the TRC only marginally relative to that of Scenario 0. However, the added complexities of implementing Scenario 4 made Scenario 3 a better candidate for inclusion in the Best Case (Scenario 5).

- The Best Case, which combined Scenarios 2 and 3, lowered TRC by about 40% over the Base Case and 15% over Scenario 0, and offered relatively easier implementation than the other strategies.

To determine the range of review periods that lead to lowest overall costs in Scenarios 2 and 5, we did a sensitivity analysis of the TRC and the inventory level using different review periods for the full-kit assembly stage. Although the review period of 11 days gave the lowest TRC, we chose to review every fortnight because the results remained close to optimal and provided a more practical time bucket.

Optimization
We observed that optimizing the supply chain further reduced the TRC on average by about 10% over its non-optimized counterpart. While optimized Scenario 0 reduced TRC by about 35%, optimized Scenario 5 reduced TRC by about 45% relative to that of the Base Case. We also noted that although eliminating the component inventory (SIP B) further increased the stock of finished products, it lowered the TRC more than just reducing the component inventory (SIP A).

Figure 3 ranks the strategies based on total inventory level across the supply chain.

Comparing the strategies based on inventory level gave overall results similar to those given by comparing strategies based on TRC. In both cases, optimizing Scenario 5 offered the best results. However, this analysis showed that Scenario 0 optimized using SIP B ranks even higher than the Best Case (Scenario 5), closely followed by Scenario 0 optimized using SIP A. Based on these observations, we inferred that there are significant benefits associated with reducing component inventory while increasing the stock of finished products in the supply chain.

Management Insights
Our research shows that there is a tremendous potential for enhancing MedCo’s supply chain for the emergency medical kits. The key insights are:

- First cut is easy to achieve. Managing inventory using the Base Stock Policy gives significant cost savings.
- Postponement drives costs down. With changes to the kitting process, product differentiation can be postponed until consumer use. This induces some marginal wastage, but the overall savings offset this small increase in costs.
- There is no great advantage in reviewing inventory continuously since the order cycles increase inordinately. However, there is ample benefit in reducing lead times and review periods since the inventory level in the network goes down.
- Strategic inventory placement leads to significant cost savings, especially so for inventory level. However, when making decisions on the amount of inventory of components and finished products, MedCo should weigh the decisions against the potential risk of suppliers not delivering on time, especially those overseas suppliers. In this supply chain, costs associated with value-add are low compared to material costs. Therefore, it is recommended to stock more of finished product inventory and maintain as low a component inventory as possible, considering the risks involved.
- Following a spiral or a phased approach to improve the network is recommended since the potential benefits and relative ease of implementation vary widely across different strategies.
Effects of Truckload Freight Assignment Methods on Carrier Capacity and Pricing

By Lukasz Kafarski and David Allen Caruso Jr.
Thesis Advisor: Dr. Chris Caplice

Summary: In this research, we investigate how carrier assignment methods impact available capacity and pricing. In the lane robustness study, we examine how shipment volumes on specific lanes affect price escalation. We also study the role of brokers and asset-based carriers in capacity creation process. In addition, we examine lane aggregation scenarios for different lengths of haul and analyze the optimal carrier location with regard to freight origin and destination. Finally, we suggest techniques to build additional capacity, improve service levels, and provide stable pricing.

KEY INSIGHTS
1. Building lane robustness through carrier assignment is a key factor in achieving stable pricing and high levels of service. Growing a pool of available capacity slows down price escalation and reduces rejection rates.
2. Lane aggregation reduces demand variability and operational complexity. Short haul lanes can be grouped by distance in 10-mile intervals, while custom regions and city zones are most suitable for long haul moves.
3. Carrier location in relation to shipping location and freight destinations has a direct impact on pricing and available capacity for short haul shipments.

Introduction
Transportation is the movement of goods between supply chain parties. According to Standard & Poor (2012), transportation spend in the United States was $694 billion in 2010. Of this, $255 billion was spent on for-hire truckload (TL). Our study focuses solely on the for-hire TL industry where a truck moves one shipment directly from origin to destination.

Throughout our research, we investigated the use of asset-based carriers and brokers as unique sources of capacity on short and medium haul lanes. We examined price escalation issues in the context of load tender rejections and daily shipment volumes on a given lane. A lane robustness study guided our investigation into what factors affect ability of carriers to handle volume fluctuations. A study of brokers and asset-based carriers helped us determine their roles in capacity creation depending on lane activity and daily shipment volume. We also studied the effects of carrier location and its ability to compete with regard to freight location.

The intent of our research is to study the impact of truckload assignment and provide recommendations on different techniques that can be used to build additional capacity, improve service levels, and provide stable pricing.

Methodology and Data
In this study, we worked with a large beverage producer that at the time had six major production facilities across the United States.

To understand its network, we investigated the different players, production facilities, destinations, and service regions. Each was individually studied to see the underlying differences and explore various concepts for our analysis.

Relevant data used in our study included:
• Transactional data (origin, destination, linehaul cost,
distance, and carrier) for 12 months
• Shipment tender data (accepted and rejected tenders) for five months
• Spot market data (spot requests and carrier response) for seven months
• Interviews with asset-based carriers and brokers

We used MS Access, SQL Server 2008, Excel and Google Maps to conduct our analysis. We segmented data for analysis based on:
• Distance brackets
• Carrier classification (carrier vs. broker)
• Tendering sequence
• Daily price ranking

Gathering the information and finding the right tools was a lengthy process. However, having everything organized and ready in advance allowed us to efficiently conduct our data analysis.

**Lane Robustness Analysis**

*Price Escalation*

We defined lane robustness as an ability of the system to absorb demand fluctuations on specific lanes without impacting service levels and price. Our study looked at 41 high-volume lanes across various distances. We determined that the larger the number of shipments on a lane, the higher the average price paid compared to a base or lowest rate paid. As volumes increase on robust lanes, price goes up by 6–10%, while 25–35% on non-robust lanes. Lanes between 100 and 280 miles are the most susceptible to price escalation with an average premium of 12–16.8%.

**Shipment Rejection Analysis**

We used rejection rates across all lanes to measure service level and carrier performance. Lanes between 100 and 400 miles had the highest rejection rates in contrast to almost all shipments being accepted in the range of up to 100 miles. Even though only 3.6% of total shipments have been rejected at least once, spotting lanes with service issues can improve operations and reduce extra costs. As Figure 1 shows, the higher the rejection depth, the higher the average price paid. While the first rejection carries a premium of 6%, the tenth rejection adds 26% to the originally expected price.

Main reasons for shipment rejection are:
• Not enough lead time to secure a truck
• Inconsistent lane volumes
• Shipments on not previously contracted lanes
• Long load times at origin or unload times at destination
• Originally offered rate being too low

**Sources of Capacity**

To lower the rejection rates and moderate price escalation, companies can access capacity directly from asset-based carriers and indirectly by using freight brokers. For shipments up to 100 miles, utilization of brokers stays around 10%, while above 100 miles, it goes up to 40%. The utilization levels are driven by carrier economics with very short haul lanes not being attractive to the non-asset-based carriers. Additionally, our study showed that brokers are used especially on low-volume (less than 20 shipments per year) and high-volume lanes (over 1,000 shipments per year). For these two categories, utilization oscillates around 60%, while volumes in-between stay around 30%.

**The Magic Range between 100 and 300 Miles**

Our study showed that the range between 100 and 300 miles is the most volatile. It is mostly driven by carrier economics changing, because beyond the 100 mile point carriers need to find backhauls to remain profitable. This specific range has the highest price escalation, rejection rates, and broker utilization. Managing this specific range presents the largest opportunity for a company to mitigate risks and ensure a stable level of service.

**Lane Aggregation Methodology**

Lane aggregation offers operational efficiency, reduces variability, and reduces complexity of transportation networks. Companies put together lanes with similar characteristics and award them to the carriers as a single lane with a broader scope. We analyzed scenarios of ag-
gregation for short and long haul lanes and designed a model that explains our methodology (Figure 2).

Figure 2: Circle-Satellite Aggregation Model

**Short Haul Aggregation**
Our study revealed that carriers usually do not use backhauls for shipments up to 100 miles so that they can optimize the number of loaded miles per day, given hours of service constraint. Based on this observation, we designed a model that created Short Haul Circles in 10-mile increments from the origin location (Figure 2). All shipments within a given circle would be awarded the same price regardless of direction. For one location, using this methodology would have reduced the number of lanes from almost 150 to six and improved the demand accuracy provided to the carriers by 21%. During interviews, carriers expressed interest in aggregating lanes using the Circles model and would be willing to do business that way.

**Long Haul Aggregation**
Aggregation can also be applied to lanes with longer lengths of haul. Currently, the sponsor company combines lanes using three-digit zip zones. However, after investigating the geographical demand patterns, we determined that lanes can also be combined at the city or custom zone level. We analyzed two scenarios. For Columbus, OH, aggregating within 20 miles of the city region would have combined volumes on three-digit zip zones and improved the demand accuracy presented to the carriers by 11%. A custom zone with a 20-mile radius around Baltimore, MD, and Washington, DC, would have combined volumes for eight different three-digit zip zones and improved the demand accuracy by 13%.

**Implementation Notes**
Even though lane aggregation presents a high potential for operational improvement, the right method needs to be chosen for a specific situation. Selecting the zones is an arbitrary process that should be based on carrier acceptance of the new process and financial impact in a given region.

**Carrier Proximity Impact**
In regions with significant volume of short haul shipments, carrier location with relation to the freight destination can have a large impact on a shipper’s transportation costs. This is due to the fact that a carrier located far away from the origin and destination of freight must travel more empty miles than a carrier located near one of the two.

To determine the impact, we ran a multiple regression analysis of over 3,500 shipments with the linehaul rate as our dependent variable and total empty miles and loaded miles as our independent variables.

With an adjusted R2 of 94.24%, our study determined that for lanes over 40 miles, Large Co. spent about $1.64 for every empty mile driven by the carrier. We determined that for this particular dataset the empty miles that could be decreased accounted for 11% of the total distance traveled, and eliminating them could reduce costs by about 17%.

**Carrier Co-Location**
Carrier co-location is the best way to reduce the number of empty miles in a round-trip shipping scenario for short haul shipments. Carriers can locate their equipment near the shipper’s facility to increase its asset utilization and potentially gain more freight from the shipper. The shipper can receive better rates while the carrier can improve its network. Building a relationship with a carrier that is located on site or close by creates additional capacity available to the shipper.

**Serviceable Region Map**
When co-location is not an option, we created a methodology for designing an optimal Serviceable Region Map (Figure 3). It demonstrates how carrier assignment can be used to decrease empty miles.

Figure 3 is an example of one of these maps for a pro-
duction facility in Dallas, TX. During the carrier procurement process, carriers would be invited to bid on specific lanes based on whether their origin falls within a specific region. For example, Carriers 1 and 2 would both be invited to the bid for Destination 1, assuming they would offer the best rates due to their close proximity to the shipping destination. Understanding how proximity affects the pricing, the shipper can also try to find other carriers that are positioned more favorably than existing vendors.

Our study has shown that selecting carriers who are close to the freight origin (co-location) or carriers near the freight destination will have the biggest impact on limiting empty miles and decreasing linehaul costs.

Conclusions
Minimizing price escalation and reducing rejection rates and their depth are the key factors to ensuring lane robustness. Leveraging the strengths of carriers and brokers is important in building capacity that is able to respond to changing conditions and demand fluctuations.

Lane aggregation successfully reduces operational complexity for shippers and carriers. However, selecting the right method depends on the specifics of the destination, carrier acceptance, and cost implications. Co-location is by far the best option when attempting to decrease empty miles. Carrier co-location will always result in the minimum number of empty miles. If co-location is not possible, creating a Serviceable Region Map can help guide shippers when selecting carriers during the procurement process.
Optimizing the Distribution Network of Perishable Products to Small Format Stores

By: Aleksandra Titova and Sachin Khandekar
Thesis Advisor: Dr. Edgar Blanco

Summary: FoodCo’s Small Format Stores (SFS) has a complex distribution network characterized by geographically dispersed stores, low sales velocity, a strong bullwhip effect, and distributor premiums not proportionate to the costs. To address the problems in small format distribution, we recommend collaboration and information sharing across the supply chain, and consolidation of all low-volume shipments through a central re-distributor.

KEY INSIGHTS

1. Analysis of the distributors’ cost model for the small format store (SFS) channel shows that full service fees charged to FoodCo are higher than the costs.
2. Low visibility into store sales creates a pronounced bullwhip effect in the supply chain. Collaboration and information sharing are recommended to alleviate this effect.
3. Geographic dispersion of demand of the SFS channel makes direct shipments to the stores economically infeasible. Using a central redistributor would enable FoodCo to consolidate shipments in low-volume channels.

Introduction

FoodCo1 is a leading foods company that has reputed brands and global operations with revenues in excess of USD 5Bn. Although FoodCo’s sales to Small Format Stores (SFS) customers, such as drug and dollar store chains, are a small part of the overall sales, it is a fast-growing segment where FoodCo sees potential. Figure 1 shows FoodCo’s distribution network for the SFS channel. Distribution to the SFS channel is a challenge for many reasons.

1. FoodCo distributes to over 40,000 geographically dispersed stores with national coverage.
2. Frozen products require temperature-controlled transportation and storage infrastructure. This entails higher costs compared to that of dry products.
3. The distribution network is complex (with multiple distribution layers) and involves multiple touchpoints of inventory.
4. Sales velocity at SFS stores is low, increasing the per-unit transportation costs.
5. Monitoring shelf inventory is a challenge, as not all SFS retailers have the necessary IT systems and protocols for sharing POS and inventory data.
6. Some SFS retailers have no backroom storage and no shelf management capability. Such retailers use third-party distributors for managing the shelf.

Project Scope

Our project addressed the following questions:
1. What are the alternatives to FoodCo’s existing SFS distribution network of frozen products?
2. How can these alternatives be incorporated to make the distribution more efficient?

Methodology

We adopted a two-pronged approach for our research methodology – a quantitative and a qualitative analysis of the SFS distribution network. Then, we explored possible improvements and cost reductions in the supply chain, and selected the two most feasible alternatives –
one, fostering collaboration with channel partners, and the other, consolidating volumes to create scales.

The qualitative analysis included interviewing key executives at FoodCo in such functions as sales, marketing, trade and pricing analytics, and distribution. In addition, we interviewed experts and industry practitioners and performed an academic literature review. We also visited retail stores and warehouses to observe their practices in marketing, storage, sorting, and distribution.

The quantitative analysis comprised studying the store sales and order patterns to identify the bullwhip effect, and the supply chain costs at all layers in the distribution network, including transportation, storage, and handling costs.

Data Analysis and Results – Regional Clusters of Demand

One of the challenges faced by the SFS channel is the low ordering volumes. In order to explore opportunities to align the supply network with the demand, we tried to identify geographic demand clusters to see if FoodCo could ship directly to key markets or clusters of stores.

As shown in Figure 1, a Pareto analysis of the SFS store sales showed that 45% of stores contribute to 80% of the total demand. Although there is some concentration of demand, the total number of stores in the top 45% is still large (5,000+ store locations). Therefore, we could not identify any concentrated pockets of demand. Given the national footprint of the SFS channel, we analyzed store sales by state, and found that no state has a significantly large share of high-volume stores that would make a state-level Direct-Store-Delivery economically feasible.

Data Analysis and Results – Bullwhip Effect

Volatible store sales, lack of visibility, and echelons in the supply chain create a bullwhip effect that results in high levels of safety stock across the supply chain. We analyzed the store sales by calculating their coefficients of variation (CV) and contrasted them with the CV of orders that the distributors placed with FoodCo.

To estimate whether visibility of store sales can help FoodCo reduce the volatility of orders, we created a simulation model of the store replenishment orders and compared them with the actual replenishment orders. Figure 3 compares the stores sales and actual orders placed to FoodCo with the simulated orders.

<table>
<thead>
<tr>
<th></th>
<th>Volatility of Store Sales</th>
<th>Volatility of Orders to FoodCo</th>
<th>Volatility of Simulated Orders</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFS retailer, SKU-2</td>
<td>0.27</td>
<td>0.49</td>
<td>0.28</td>
</tr>
<tr>
<td>SFS retailer 2, SKU-2</td>
<td>0.13</td>
<td>0.29</td>
<td>0.11</td>
</tr>
<tr>
<td>SFS retailer 2, SKU-1</td>
<td>0.19</td>
<td>0.35</td>
<td>0.18</td>
</tr>
<tr>
<td>SFS retailer 2, SKU-3</td>
<td>0.21</td>
<td>0.36</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Table 1: Comparison of actual volatility with simulated volatility

Based on Table 1, we can see that the simulated orders are less volatile than the actual orders across every SKU. Although the simulation model assumed perfect forecast capabilities, it still provided us with the best-case scenario of volatility. Our analysis of retail store sales and distributor/redistributor orders of the three SKUs clearly identified a bullwhip effect.

To quantify the benefits of perfect information sharing, we attempted to answer the following questions:

- How much inventory would FoodCo save?
- How much inventory would the distributor save?
- How much would FoodCo and the distributor save through reduced shrinkage?

We calculated the costs for each of the distribution network scenarios and compared those to the costs in the existing distribution network. We considered the cost of storing inventory and transportation as the main drivers of the total costs. To calculate the inventory costs, we used the simulated replenishments model assuming that we needed to keep two weeks of supply in each store and that each store started out by having two weeks of inventory at the beginning of the year.

We modeled a zero lead time (warehouse on wheels concept) and a review period of one week. Weighted average cost of capital was assumed to be at 8%. Shrinkage and expiration rate was assumed to be 5% of the shipments currently in the distribution network.
The calculated inventory levels were compared with the actual (or the best-known estimate of) inventory levels across the supply chain. Savings were based on reduced inventory levels and on reduced shrinkage. Although the detailed calculations of the cost savings have been withheld on request, the results showed that FoodCo has the potential to reduce the channel inventory and operating costs.

Data Analysis and Results – Distributor’s Cost Model
Distributors charged additional premiums for services beyond the basic transportation. Such service included replenishing the shelf, ensuring proper product placement on the shelf, and managing unsaleables. To determine if these premiums could be reduced, we developed a Distributor Cost Model. Through this model, we obtained a per-unit cost of transporting FoodCo’s products to the SFS stores. The distributor’s transportation costs were compared with the estimated shelf management costs and the markups charged by distributors to FoodCo. The shelf management premium was estimated using the following assumptions:

1. The distributor serves about 12 stores per day when they do not need to service the shelf. However, shelf management requires additional time, and hence the distributors can serve only eight stores per day.
2. A distributor that services the shelf would charge an additional markup over the one that does not service the shelf.

Figure 2 compares the price with the cost of full service.

[Figure 2: Distributor’s cost and premium structure]

There were two main drivers in the distributor cost model:
1. Number of stores we assumed a driver is able to serve in one day.
2. FoodCo’s share of distributor’s shipments and costs.

Insights from the model:
• The shelf management premium that FoodCo pays to the distributor is higher than the actual cost of shelf management.
• The distributors are making a loss on the basic services and are leveraging the full-service premiums to boost their margins.

Recommendations
Based on our store replenishment model, distributor cost model, and insights from literature, we recommend that FoodCo:

1. Collaborate and share information: We recommend that FoodCo start collaborating with its channel partners and share information, such as rolling demand plans, merchandise plans, new product introduction plans, and desired planograms. In the long term, FoodCo can involve the retailers in key decisions such as product design, pricing, promotions, and merchandising.

2. Achieve volume scales through a central redistributor: Since it is a common practice for manufacturers to consolidate shipments through distributors to achieve lower transportation costs, we recommend the use of a central redistributor. In addition, this central redistributor could also hold the inventory, relieving FoodCo of its inventory holding costs. There are a few things to consider in this model, however:
   • The consolidation adds a layer to the distribution network. This has the potential of aggravating the bullwhip effect if information is not shared efficiently.
   • To ensure that the redistributor breaks even, FoodCo needs to reconsider the margins of all channel partners.
   • FoodCo could start out implementing consolidation for the channels that have low volumes.

3. Use distributors for their basic services:
   • Collaborating with the retailers and leveraging POS sales information for an integrated demand planning would enable FoodCo to prescribe storewide replenishments for each SKU every week. This might enable FoodCo to use the distributor only for the basic services of dropping the case to the backroom of the store.
   • Considering the average sales volumes, creating a smaller case pack would enable FoodCo to replenish the stores more effectively.
   • The retailer would also stand to gain from doing shelf management itself, as the savings would be shared between FoodCo and the retailer.
   • Collaboration and information sharing would benefit the distributors by reducing their inventory, transportation costs, and operating costs, in general.
Assessing the Value of Sustainability Initiatives in Business-to-Business Relationships

By: Jeffrey Ransom
Thesis Advisors: Dr. Başak Kalkancı and Dr. Eva Ponce

Summary: Environmental sustainability has witnessed remarkable growth in popularity over the past decades. Companies are investing significant amounts of money into green initiatives to reduce their environmental impact. This project identifies the sustainability priorities of customers within the business-to-business (B2B) segment of RetailCo, a popular consumer packaged goods (CPG) company. By understanding the preferences of their customers, RetailCo may better prioritize their investments to attract and maintain their customer base.

KEY INSIGHTS

1. Recycling programs are significantly more popular than other sustainability initiatives. Sustainable packaging and responsible sourcing initiatives have also been gaining momentum. Surprisingly, customers favored carbon emissions reduction and renewable power as least important to their business.
2. Despite the positive support shown for green initiatives, companies continue to value price, quality, and service above environmental sustainability.
3. The sustainable business customer is located in the Northeast region of the United States, is larger in size, spends more with RetailCo, and is typically a government or educational organization.
4. There is a significant difference between employee sustainability priorities and executive/manager sustainability priorities.

Introduction

There are several different initiatives that reduce a company’s direct and indirect impact on the environment. This project identifies common green processes or initiatives that are practiced by a diverse group of companies. Data was collected from Requests for Information (RFIs) and Requests for Proposals (RFPs) within the B2B procurement process. Additionally, a survey was constructed and disseminated to RetailCo’s business customers to determine their priorities. Finally, interviews were conducted with two sustainability executives at large companies to provide a supervisory perspective.

RetailCo, the partner organization, is a popular CPG company with over $20 billion in revenues. The company has provided customer data and survey resources to assist in this study. The goal of this project is to determine the value for RetailCo to invest in sustainability initiatives.

Methodology

RFIs and RFPs were examined for the frequency of sustainability initiative inquiries. Customers submit these documents as part of the procurement process to determine if RetailCo meets their environmental standards. They may ask questions such as: “Does your company utilize renewable power sources for energy?” or “Does your company have waste and water reduction goals?” The frequency of these inquiries was tallied to determine how often companies asked about specific initiatives.

RetailCo assisted in the construction and dissemination of a conjoint analysis survey, the primary method of data collection for this project. Customers were first asked about their company profile, including size (by employees), annual spend with RetailCo, job title, and knowledge of their sustainability strategy. The survey then inquired about currently practiced green initiatives as well as company interest in predetermined sustainability practices. Using a simple 1-to-5 ranking structure, respondents were asked to rank their company’s interest in the following initiatives:

- Carbon Emission Reduction
- Responsible Purchasing
- Electronics Recycling
- Paper Product Recycling
- Sustainable Packaging
- Sustainable Products
These initiatives were chosen based on the current sustainability priorities of RetailCo and were presented in no specific order.

Finally, respondents were asked to choose between two vendors in a willingness-to-pay (WTP) discrete choice test. Questions were phrased in this manner:

“You need to purchase some ink and toner for your place of business. Which vendor would you choose? Vendor 1 is selling ink and toner and they allow you to return empty cartridges. Because the recycling service has an up-front cost of $14, the price of ink and toner is $153.99. Vendor 2 is selling identical ink and toner for $139.99, but they do not allow you to return empty cartridges.”

Each question contained a different product, price, and company sustainable initiative. The purpose of this discrete choice test was to determine if customers were sensitive to a 5% or 10% premium associated with sustainability costs. As such, two different surveys were distributed. The first asked if customers would choose the sustainable vendor when a 5% premium was applied to a product price. The second survey used a 10% premium.

**RFI/RFP Results**
Analysis of customer inquiries revealed a snapshot of sustainability strategies. The majority of company inquiries focused on waste management or recycling programs (73%). Other popular initiatives included carbon emissions (64%), ISO 14001 certification (64%), and energy consumption (55%). Companies did not provide a weighting structure, so company preferences could not be accurately determined.

**Sustainable Business Customer Profile**
The survey results revealed the following sustainable business customer profile:

- Educational or governmental organizations
- Located in the Northeast region of the United States
- Larger in size (typically greater than 500 employees)
- Higher annual spend with RetailCo (typically greater than $100K annually)

Respondents were most often administrative assistants, office managers, or procurement personnel. The survey was not intended to be completed by higher-level executives because those individuals are not typically involved in this type of procurement.

**Supplier Selection Criteria**
Respondents were asked to rank certain criteria when selecting their suppliers. Figure 1 shows that Quality, Price, and Service remain top priorities for companies. These standardized coefficients from linear regression use Sustainability as a reference point. Only Long-term Relationship and Risk were indicated as less important than Sustainability.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
<th>Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>0.271</td>
<td>0.99</td>
</tr>
<tr>
<td>Price</td>
<td>0.231</td>
<td>0.99</td>
</tr>
<tr>
<td>Service</td>
<td>0.204</td>
<td>0.99</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.179</td>
<td>0.99</td>
</tr>
<tr>
<td>Convenience</td>
<td>0.153</td>
<td>0.99</td>
</tr>
<tr>
<td>Sustainability</td>
<td>0.000</td>
<td>N/A</td>
</tr>
<tr>
<td>Long-term Relationship</td>
<td>-0.006</td>
<td>0.21</td>
</tr>
<tr>
<td>Risk</td>
<td>-0.074</td>
<td>0.99</td>
</tr>
</tbody>
</table>

*Figure 1: Supplier selection standardized coefficients from linear regression.*

**Linear Regression Modeling**
A model was developed to predict the ranking for each initiative (on a 1-to-5 scale). The independent variables included location, industry, company size, employee size, and initiative. Company industry was determined by the respondent’s email address Top Level Domain (TLD). Analysis of the linear regression standardized coefficients confirmed the sustainable business profile characteristics and initiative priorities. Due to the qualitative independent variables and limited numerical outputs (1-to-5), a strong goodness to fit (R2) was not observed.

**Ranking Sustainability Initiatives**
Responses were filtered according to customer profile factors, including size, spend, location, and industry type. Non-sustainable companies, or those that indicated they were unaware of company sustainability initiatives, were not included in the final analysis to increase survey accuracy. According to the survey, the most popular sustainability initiatives remain paper product and electronics recycling programs. Results are indicated in Figure 2:
Figure 2: Average Ranking of Interest in Sustainability Initiatives Based on Company Size and Annual Spend with RetailCo.

Willingness-to-Pay Analysis
Analysis of the WTP discrete choice surveys revealed no significant difference between a 5% or 10% premium associated with each initiative. The majority of respondents (56%) chose the sustainable vendor. Most respondents selected the sustainable vendor when asked about electronics recycling or paper product recycling programs as indicated in Figure 3 below. Further analysis revealed customers were especially sensitive to the price of the product or service being offered.

<table>
<thead>
<tr>
<th>Initiative</th>
<th>Sustainable Responses (5%)</th>
<th>Sustainable Responses (10%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics Recycling</td>
<td>66%</td>
<td>58%</td>
</tr>
<tr>
<td>Responsible Purchasing</td>
<td>65%</td>
<td>73%</td>
</tr>
<tr>
<td>Paper Recycling</td>
<td>62%</td>
<td>67%</td>
</tr>
<tr>
<td>Greenhouse Gas Reduction</td>
<td>49%</td>
<td>42%</td>
</tr>
<tr>
<td>Renewable Energy</td>
<td>47%</td>
<td>43%</td>
</tr>
<tr>
<td>Sustainable Packaging</td>
<td>45%</td>
<td>57%</td>
</tr>
</tbody>
</table>

Figure 3: Comparison of WTP surveys.

Interview Analysis
Interviews were conducted with sustainability executives from two large companies. The manager from DrugCo, a major pharmaceutical organization, indicated that their priorities largely consisted of carbon emission reduction, sustainable packaging, and renewable power investment. These observations differ from the above results, where recycling programs remain the most popular.

It is very possible that employees and executives from the same organization have opposing views on the importance of specific green initiatives. Consulting reports have indicated increased decision-maker interest in energy conservation, sustainable packaging, and sustainable products. Future research should further examine the opinions of high-level managers and executives.

Conclusion
This study examined multiple aspects of sustainability within the B2B segment. Although there remains substantial interest in environmental sustainability, companies are primarily focused on the price, quality, and service of their suppliers.

RFP/RFI analysis indicated that companies inquire most about recycling programs, carbon emissions, and ISO 14001 environmental management certification. Survey results showed some interest in the certification programs: 14% of larger companies were involved in ISO 14001, while 40% participated in Leadership in Energy and Environmental Design (LEED) certification.

Survey analysis identified the typical business profile of a company likely to support sustainability initiatives. Respondents ranked their interest for specific initiatives and participated in a WTP discrete choice test. Respondents clearly valued recycling programs above other initiatives.

It is very likely that sustainability initiatives will continue to gain popularity as the economy strengthens and popular opinion supports greener practices. This project was one of the first studies to quantify the value of sustainability within the B2B segment. Further research and analysis of this topic will allow RetailCo and other companies to prioritize their sustainability strategies.
The Effect of Data Sharing on a Perishable Goods Supply Chain

By Darren Wilson and Gerald Yeung
Thesis Advisor: Roberto Perez-Franco

Summary: This project explores the benefits of retail data sharing in a high-velocity fresh produce supply chain. Produce shrinkage due to spoilage is a major source of waste in the fresh produce retail industry. Our primary objective was to identify the impact data sharing could have on the issue. We found that data sharing has a limited effect on reducing shrinkage, and that retail stores with higher sales volume generally experience lower shrinkage rates.

Key Insights
1. Data sharing has a limited effect on reducing perishable product shrinkage, as vendors are unable to influence the distribution center-to-store ordering process.
2. In general, retail stores with higher sales volumes experience lower shrinkage rates, unless this volume exceeds a certain level.
3. Although automated ordering systems appear to decrease shrinkage rates, stores do not generally have specialized ordering processes for perishable goods.

Introduction
Because of its high perishability, fresh produce requires an extremely efficient supply chain. Shrinkage due to spoiled product is a source of significant waste that affects the profitability of suppliers and retailers alike. A collaborative approach is required to reduce this waste, and data sharing provides the foundation for such inter-firm coordination. By removing traditional functional barriers, firms should be able to reduce inventory throughout the supply chain, resulting in less shrinkage. The potential benefits, however, are difficult to quantify. As a result, many companies have had limited success in convincing their partners to collaborate in this fashion. A strong case is necessary to persuade companies to adopt this strategy for long-term sustainable cost reductions.

Effect of Data Sharing on Product Shrinkage
Using the point-of-sale data of three major retailers, given the aliases of Alpha (data sharer) and Beta and Gamma (non-sharers), we were able to assess the effect of data sharing on shrinkage. Specifically, we wanted to compare shrinkage rates between data sharers and non-sharers. We were able to make this comparison as our project sponsor company currently manages Alpha’s inventory as part of a vendor-managed inventory (VMI) agreement. In addition to the above analysis, we wanted to confirm that there is indeed a correlation between shrinkage and store volume, as multiple SuperSalad employees had suggested that higher stock keeping unit (SKU) or store volumes typically result in lower shrinkage rates.

Where Does Shrinkage Occur?
In the supply chain of our project sponsor, who we will give the alias SuperSalad, we found that the vast majority of product shrinkage takes place in the retail stores, rather than at the distribution centers (DCs) of SuperSalad or retailers. The efficiency of DCs plays a significant role in this, as the faster the stock turns in those locations, the longer the product’s shelf-life will be after store delivery. Based on sample store data, we conclude that the distribution networks of our sample retailers are similar in efficiency, as indicated by the average shelf life remaining upon store receipt. The variance in shrinkage rate between stores, therefore, is the result of different store performances rather than DC efficiency.
Using a confidence interval test, we found that when data sharing is introduced, one can expect a 0.7% to 4.3% reduction in shrinkage 98% of the time. These results suggest that while data sharing has some effect on shrinkage, it is not substantial. Looking deeper into the data sharing process of Alpha, we discovered that our sponsor company was only able to manage Alpha's inventory at a DC level, and not down to the individual store level. Our research indicates that the shrinkage issues are caused primarily by inefficiencies in the store ordering process. SuperSalad's VMI process is efficient; however, its effectiveness is limited by its lack of scope, as shown in Figure 1.

Our findings suggest that the DC-to-store segment of the supply chain requires the most attention, as demand at an individual store level is far more volatile than at the aggregated DC level. In order for suppliers and retailers to significantly reduce shrinkage, a more coordinated effort is necessary all the way through the chain. Functional barriers between supplier and retailer responsibilities should be minimized; both parties should collaborate to manage inventory all the way from production to final store locations.

**Correlation between Volume and Shrinkage**

Many of our interview subjects suggested that a negative correlation between store volume and shrinkage exists – SuperSalad employees believed that high volume introduces a “cleansing effect” that reduces the negative impact of a suboptimal ordering policy. From our initial data analysis, it did not appear that a significant statistical relationship existed between store volume and shrinkage. In fact, we found that the highest volume stores in two of the three retail chains actually had higher shrinkage rates than their respective chain averages. Figure 2 shows the upward curve of Alpha's shrinkage rate, as store volume increases beyond an “optimal” point.

It was also significant that the largest Alpha stores processed significantly higher volumes than the largest Beta stores in their respective samples. This could indicate that once a store exceeds a certain level of volume, the management of inventory becomes progressively more difficult. We attempted to test this theory by comparing the best 30 stores in terms of shrinkage in each sample, as this would remove any volume bias in the analysis. The results are shown in Figure 3.

This analysis shows that while the overall average shrinkage rates of Alpha and Beta are not significantly different, the best stores from Alpha (data sharer) perform better than the best stores from Beta (non-sharer), in terms of shrinkage. Confidence interval testing suggested that for these best stores, one can expect a 3.1% to 4.5% reduction in shrinkage 98% of the time when data sharing is introduced. It is also evident that the best stores of Alpha are not the highest volume stores, indicating that there may be a sweet spot in terms of store volume, beyond which shrinkage increases. This is supported by the fact that the best stores of Alpha are relatively similar, in terms of sales volume, to those of Beta.

Thus, it appears that store level shrinkage can be attributed to a number of factors. Store volume is one such factor, with greater store volume resulting in reduced shrinkage up to a point, after which the volume begins to have a negative effect. Another possible factor is hu-
man error, as once store volume exceeds a certain level, ordering may become too complex to manage effectively.

**Conclusion**

1. In our analysis of the fresh produce industry, data sharing does not result in a significant reduction in shrinkage. The current functional barriers between supplier and retailer responsibilities limit the effectiveness of the solution.

2. Volume has some effect on shrinkage in stores; in general, greater store volume results in lower shrinkage rates. However, when store volume exceeds a certain level, shrinkage actually begins to increase.

3. While data sharing has proven to be effective for other industries, such as Consumer Packaged Goods (CPG), a solution in the highly perishable fresh produce industry requires further adaptation. Such a solution should take overage costs, such as shrinkage, into account.
Inventory Segmentation Strategies for Aftermarket Service Parts in Heavy Industry

By: Randolph Bradley
Thesis Advisor: Dr. Jarrod Goentzel

Summary: A common inventory segmentation strategy for consumable service parts used in heavy industry was compared to a more sophisticated strategy by evaluating performance using a discrete-event simulation of warehouse operations and a companion Monte Carlo simulation of supply chain metrics. Unlike the simple strategy, the sophisticated strategy achieved performance goals, lowered inventory investment 20%, and enabled buys for parts in low annual consumption categories to be automated.

KEY INSIGHTS
1. Stock levels are frequently set to achieve an off-the-shelf fill rate with inventory optimization software, while supply chain performance is measured by speed of service. Simulation can resolve this often costly disconnect.
2. The right inventory segmentation strategy can lower inventory investment in consumable parts as much as 20% while increasing performance on speed of service metrics.
3. To be successful, technical solutions and their implementation must be aligned. An internal review board that meets monthly and an acquisition policy that provides quarterly funding were each shown to degrade performance by unwittingly changing the review policy for stock levels.

Introduction
Heavy industries operate equipment having a long life to generate revenue or perform a mission. These industries must invest in the specialized service parts needed to maintain their equipment, because, unlike in other industries such as automotive, there is often no aftermarket supplier. If parts are not on the shelf when needed, equipment sits idle while replacements are manufactured.

Randolph Bradley came to the SCM program with 25 years of industry experience optimizing global supply chains for heavy equipment. Upon graduation, he returned to The Boeing Company as a Technical Fellow in the Supply Chain Management organization in St. Louis, MO.

Simple Strategy Segmenting Inventory on Cost
A simple strategy segments parts into A and B categories based on unit price, as shown in Figure 1. Each segment is optimized separately to a fill rate goal using a commercial inventory optimization model.1 A business rule ensures that all parts are at least stocked to the Economic Order Quantity (EOQ) amount, ensuring a minimum 50% fill rate by part. This simple strategy is common in heavy industry.

Consumable parts, often grouped by segment, are commonly optimized to fill rate targets. Supply chain performance is frequently gauged against a speed of service measure such as Order Fulfillment Lead Time (OFLT), the time from order placement to customer receipt. This research evaluates inventory segmentation strategies for consumable parts, as measured by OFLT and inventory investment, by analyzing an industry representative dataset.

Figure 1: Simple strategy for inventory segmentation, segmenting consumable parts on cost (top), and showing ordered unit cost vs. cumulative part count (bottom).

compared to cumulative part count on the vertical axis, and graphed in Figure 1. Since an inventory optimization model uses a technique known as a “greedy heuristic” to select the lowest cost mix of spares required to achieve a given fill rate goal, this means that for Segment A, 1¢ parts are competing with $1,740 parts on “bang for the buck” to increase the fill rate. Because this strategy achieves fill rate goals without stocking many expensive parts, the business rule was added in an attempt to better balance the mix of parts.

**Sophisticated Strategy Segmenting Inventory on Consumption**

A sophisticated strategy segments parts into ABCDE categories based on consumption (annual demand multiplied by unit price), as shown in Figure 2.

<table>
<thead>
<tr>
<th>Segment</th>
<th>% Annual Consumption</th>
<th>% Part Count</th>
<th>Fill Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80% % Consumption &amp; Unit Cost &gt; $25</td>
<td>79% 7%</td>
<td>90%</td>
</tr>
<tr>
<td>B</td>
<td>16% % Consumption &amp; Unit Cost &gt; $25</td>
<td>14% 14%</td>
<td>92%</td>
</tr>
<tr>
<td>C</td>
<td>5% % Consumption &amp; Unit Cost &gt; $25</td>
<td>4% 42%</td>
<td>99%</td>
</tr>
<tr>
<td>D</td>
<td>$1 &lt; Unit Cost ≤ $25</td>
<td>3% 30%</td>
<td>99%</td>
</tr>
<tr>
<td>E</td>
<td>Unit Cost ≤ $1</td>
<td>0% 7%</td>
<td>99%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cumulative Percent Annual Consumption</th>
<th>Cumulative Percent Part Count</th>
</tr>
</thead>
<tbody>
<tr>
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**Hypothesis**

This research tests the hypothesis that the sophisticated strategy, which segments consumable parts on consumption, will outperform the simple strategy, which segments on cost, when measured on both Order Fulfillment Lead Time and inventory investment.

**Methodology**

A previously published discrete-event simulation of warehouse operations was linked to a new Monte Carlo demand categorization and metrics simulation, resulting in the ability to predict tomorrow’s supply chain performance from today’s logistics data. The linked simulations analyze supply chain data from a representative industry dataset and historical orders from operating organizations maintaining equipment.

Required supply chain data includes the inputs (current on hand, due-in, and backorder inventory position, demand, condemnation rate, lead time, and price) and outputs (target stock level, reorder point, and reorder quantity) of commercial inventory optimization software. Also required are historical requisition data (part number, order quantity, and date), shipping performance data (days’ shipping delay by requisition, priority by requisition), performance (as reported within a company), and operational data, including equipment delivery schedule and future operating hours by period.

Unlike most supply chain simulations, which require an extended warm-up period and estimate only steady state conditions, these linked models take into account the existing state of the supply chain, due-in orders with scheduled delivery dates, and optimized stock levels and reorder points in order to estimate OFLT over time, as of the exact date of the data pull. By eliminating the warm-up period, these simulations extend the state of the art to provide short-term in addition to long-term predictions of performance to service metrics.

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Further, this methodology demonstrates how complex legacy simulation models can find new life by analyzing their results with companion simulations that measure contemporary metrics.

**Results: Sophisticated Strategy Outperforms Simple Strategy**

First, the null hypothesis – that there is no difference between inventory segmentation strategies when measured on OFLT – is rejected with a 95% level of confidence. At the start of the simulation, orders are placed to bring inventories for parts at or below reorder point up to the target stock level. Performance improves as these parts arrive in the warehouse after manufacturing lead time. Indeed, simulation results for high-priority consumable parts indicate that by August 2013, the mean OFLT for the sophisticated strategy will achieve the desired goal, as indicated by the vertical dashed green line in Figure 3, unlike the simple strategy, which fails to meet goals.

Second, the sophisticated strategy also achieves a 20% reduction in investment compared to the simple strategy. This was unexpected, because the latter skews stock levels in favor of low unit price parts. A business rule requiring a minimum 50% fill rate by part was added to improve the parts mix, reducing the benefits of cost optimization in the simple strategy. Given the reduction in investment, another iteration of the sophisticated strategy, increasing Segment A parts to 92% fill rate and Segment B parts to 95%, should be evaluated to further improve performance and increase the margin for error.

**Stocking Policy**

Stocking policy, review policy, and acquisition policy go hand in hand. A continuous review stocking policy is appropriate for a flexible contract that funds purchases when stock levels fall to reorder points. A review board that meets monthly to approve orders results in a de-facto periodic review policy. Similarly, quarterly or annual funding cycles result in a periodic resupply contract. In these cases, the stocking policy must be changed from continuous review (with frequent buys to stock level) to periodic review (with monthly, quarterly, or annual buys to stock level). The appropriate review period must be added to the procurement lead time. The stock levels recommended by an inventory optimization model increase as the review period increases.

The key to understanding the impact of the review period and acquisition policy is realizing their effect on OFLT metrics, also shown in Figure 3. A monthly spares requirements review board imposes a 30-day delay on placing orders, resulting in a five percentage point penalty on OFLT, sufficient to cause an organization to continuously miss goals. The 90-day delay incurred from a quarterly acquisition policy drops performance another few percent. The 360-day delay incurred from an annual acquisition policy degrades performance over time.

**Conclusions**

Heavy industry can achieve supply chain service metrics, lower inventory investment, and lower asset management costs by drawing inferences from this analysis. Based on results from the industry representative dataset:

1. Organizations that stock service parts can lower inventory investment in consumable parts by as much as 20% and increase performance on speed-of-service metrics using a more sophisticated segmentation approach.

2. Organizations must be cognizant that review policy and acquisition policy impact results. Automating the reorder of parts in the CDE Segments eliminates the pipeline stock required by the review period, and allows asset managers to focus their analysis on critical A and B Segments. Authorizing flexible funding eliminates the need to add additional months of pipeline stock to compensate for funding cycles.

3. Supply chain simulation not only can reveal whether service goals are achievable, but also when and with what confidence.

In summary, inventory segmentation is a straightforward technique for improving the mix of service parts, which benefits heavy industry when aligned with review policy and acquisition policy. The maintainers servicing an organization’s heavy equipment receive the parts they need. The availability of equipment to generate revenue or perform a mission increases. It’s a winning strategy.
Complete List of 2012 SCM Theses

Impact of Risk Sharing on Competitive Bidding in Truckload Transportation – by Molly Abramson and Ajit Sawant
This project explores how a shipper’s fuel surcharge (FSC) program affects its per-load transportation cost in the United States truckload transportation industry. We built a cost model using ordinary least squares regression analysis to quantify the effect of an FSC program on transportation cost. We controlled for well-known transportation cost drivers, including distance, geography, and time of year.

Estimation of Run Times in a Freight Rail Transportation Network – by Kunal Bonsra and Joseph Harbolovic
This research aims to improve the accuracy of individual freight train run-time predictions. A regression model is proposed utilizing a broad selection of explanatory variables. The performance of the proposed regression model is compared against a baseline simple historical averaging technique. The proposed regression model offers substantial improvements in accuracy over the baseline technique: 36.79%, 28.74%, and 20.95% for low-, medium-, and high-priority trains, respectively. The model justifies further exploration by the partner railroad to enable more accurate train schedules with subsequent improvements in railroad capacity, customer service, and asset utilization.

Modeling the Impact of Complexity on Transportation – by Jose Fernandez and Henry Okafor
In this research, we examined the behavior of transportation costs during supply chain complexity events, in particular, new product launches in the distribution network of an FMCG manufacturer. We analyzed the cost to serve a customer in the network, recommended a method for picking the lowest transport cost factory, and analyzed how these costs change with carrier mix and seasonality. This should enable transportation planners to make better transport allocation decisions. Finally, we recommended strategic, tactical, and operational steps for managing transportation costs during complexity events.

Simulating a Storage Production System with Three Oilseed Crops – by Luiz Figer
The supply chain for oilseeds is permeated with uncertainty. This work is based on a company that is expanding its business into Mato Grosso, Brazil, a region where, on top of the regular uncertainties, rapid growth and a number of developments may significantly alter the landscape for business. The company is considering expanding operations with a grain elevator and a crushing facility that convert grain into oil and meal in this region. This work developed a framework for the company to make decisions on capacity planning and budgeting, through a series of scenario building and sensitivity analysis. More important, the tool developed allows for the company management to build new scenarios and change parameters every time they think it is necessary.

Increasing Return on Assets through Insourcing Logistics – by Devjit Ghose and Kevin Murphy
This project explores the financial impact of insourcing logistics for a major oilfield services company. Insourcing the transportation of their drilling and measurement tools to offshore oil rigs at sea – a function currently provided by their customers – will increase asset velocity of their most important tools, and allow them to service more customers with fewer tools. We attempted to quantify the asset velocity benefits of insourcing on return on asset (ROA).

Building a Framework for Determining the Optimal Supplier Shipping Performance – by Max Hurd and Izak van Rensburg
Most companies aim for perfect on-time delivery from suppliers, since late deliveries cause supply disruptions. But some companies incur direct costs in maintaining supplier delivery performance. Our empirical research looked at a company that invests in suppliers to help them achieve a desired performance level. We developed a framework that captured the costs of late deliveries and target attainment. Using regression analysis, we modeled cost behavior in order to determine a delivery target that minimizes total cost.
Creating a Framework for a Humanitarian Response Capacity Index – by Ariahna Knight

Analysis of inventory stock levels, supplier contracts, and supplier manufacturing capacity can provide insights to humanitarian organizations on their capacity and ability to respond to disastrous events. For organizations, this information can aid in determining adequate inventory levels and negotiation of supplier-contracted transportation times in order to maximize response capacity. The insights could also be used to create a framework for an index of response capacity.

Inventory Strategies for Patented and Off-Patent Products for a Pharmaceutical Supply Chain –

by Prashanth Krishnamurthy and Amit Prasad

This project assessed the inventory strategies for patented and off-patent products in a pharmaceutical supply chain with a focus on service level, forecast accuracy, lead times, and supply reliability. The safety stock equation used in the current distribution model is examined, and a revised model with a new safety stock equation is proposed. Sensitivity analysis then evaluates the impact of variations in input parameters on the safety stock. The study shows that there is a significant difference in inventories between the proposed model and practice, demonstrating an opportunity to reduce working capital.

Tracking and Fleet Optimization of Equipment Chassis for Ocean Transportation –

by Jean-Marie Lefebvre and Dameng Yue

This project explores the strategies, methodologies, key metrics, and tools for the optimal management of chassis in an extensive multi-depot network. Using an ocean shipping company, we analyzed global fleet management as an integrated system embracing tracking capabilities, planning, processes, and data analysis. We evaluated the opportunity for a company to invest in real-time tracking technology, and showed that fleet size can be reduced by increasing asset utilization. We also analyzed how leasing can impact operations and costs.

Supply Chain Network Considerations for e-Retail of Luxury Goods in Canada –

by Dilek Tansoy and Yi Linn Teo

This research explores supply chain network considerations for the e-commerce business of Ralph Lauren in Canada. The company’s strategic objective of elevating the brand is at the core of our research while recommending possible supply chain network considerations. This leads to recommendations on how to build a successful website for a luxury goods e-retail channel, including suggestions on projecting the luxury image online and on customer-facing features on the website in line with the company objectives. Also, the supply chain network should be reshaped to accommodate these changes.

Perspectives for Logistics Clusters Development in Russia – by Andriy Tantsuyev

This paper is a normative work aimed at identifying locations in Russia with high, medium, and unclear potential for logistics cluster development. As a framework, this work used four different models of logistics clusters: Major Seaport, Auxiliary Seaport, Major Inland, and Auxiliary Inland logistics clusters. Conclusions are based on the analysis of port connectivity, population incomes within eight hours of driving from a specific location, auto roads’ accessibility, economic effectiveness of local government, and quality of auto roads.

Strengthening Informal Supply Chains: The Case of Recycling in Bandung, Indonesia – by Michael Tuori

Using the case of recycling in Bandung, Indonesia, this research aims to identify effective ways to use public policy to evaluate and enhance informal supply chains. I examined the current dynamics of the recycling middlemen industry and proposed a framework for evaluating informal supply chains from a public policy perspective. Based on these analyses, I then suggested policy recommendations for improving the informal recycling system in Bandung.

e-Commerce Fulfillment Strategy for Luxury Brands in South Korea – by Mark Vanderbilt and Danny Yunes

Analysis of e-luxury from a systems-thinking perspective can give companies valuable insights into how to organize their supply chain and align their operations to capture demand. In the South Korean market, the luxury retailer that can simultaneously elevate its brand, segment its products and services, and unify the online and in-store luxury experience will win the hearts and minds of customers.