2014 SCM RESEARCH JOURNAL

Summaries of selected research projects by 2014 graduates of the MIT Master of Supply Chain Management Program
Introduction


The projects included in this journal were selected from the twenty projects submitted by the SCM Class of 2014 at the Massachusetts Institute of Technology. These 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 these executive summaries is to give the reader a sense of the business problems being addressed, the methods used to analyze the problem, the relevant results, and the insights gained.

These selected articles cover a wide selection of interests, approaches, and industries, and were developed in partnership with companies ranging in size from startups to some of the largest companies in the world. They cover industries as diverse as medical supplies, chemicals, consumer goods, railroads, and trucking. They also include humanitarian logistics in Zambia, green supply chain issues in trucking, and distribution models in megacities.

Each of the projects is a joint effort between a sponsoring company, one or two students, and a faculty advisor. Companies who are members of the MIT Center for Transportation & Logistics's (MIT CTL) Supply Chain Exchange are eligible to submit their ideas for thesis projects in July and August and then present these proposals to the students in early September. In mid-September, the students select which projects on which they will work. From September until early May, the teams conduct the research and write up the results. In late May, all the sponsors, faculty, and students participate in Research Fest where all the thesis projects are presented.

The 10-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. The class size each year is limited to 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 receive in their coursework.

We hope you enjoy the articles. The rest of the master’s thesis projects are listed at the end of this journal. You can also view all of the executive summaries on the MIT CTL website at: http://ctl.mit.edu/pubs. If you would like to learn more about the SCM Master’s Program or how sponsor a thesis, please contact us directly.

Happy reading!

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Estimating Carbon Emissions from Less-than-Truckload (LTL) Shipments | 4

This research proposes a methodology for estimating carbon emissions of individual LTL shipments while considering the complexities of a typical LTL network. Two separate models were developed: a detailed one for the partner carrier’s network (Estes Express Lines), and a low-precision one for when the carrier network characteristics are unknown. A comparative analysis with traditional emissions estimation methodologies showed errors of up to 30% in current estimations due to a lack of understanding of LTL operations.

Real-Time Order Acceptance in Transportation Under Uncertainty | 8

The objective was to create and validate a model to determine if historical demand data can be used by retail firms operating private fleets to make effective real-time order acceptance/rejection decisions. The purpose was to eliminate unprofitable orders in a short-haul transportation setting. A Java tool was developed to instantaneously decide whether or not to accept an order depending on the order location and time of receipt. The tool was then tested against several alternative models.

Increasing Access to Medicines in Southern Africa | 12

This research, in partnership with a global pharmaceutical firm, evaluated how price reductions offered by partner distributors in Zimbabwe translated down the value chain. The cost of insourcing versus outsourcing of distribution and the sales volumes at which the two alternatives are equivalent was analyzed. Trust and information played a pivotal role in the rollout of the price reduction schemes. In addition, the impact that forecasting error, minimum order quantities, and sales volumes have on the decision to outsource was determined.

Supply Chain Risk Visualization and Quantification | 16

This project attempts to bridge the gap between isolated risk mitigation plans and a comprehensive approach for corporations to deploy supply chain risk management (“SCRM”) on an enterprise scale. Through the use of supply chain visualization and value-at-risk modeling, a SCRM strategy was developed for a pilot supply chain of a large multi-national chemical company.

Perfecting Production Plans with POS Data | 20

Designing optimized operations is essential for companies in competitive business landscapes, but unexpected or inconsistent customer demand can significantly reduce the effectiveness of the supply chain. This project creates a framework to use retailer point of sale (POS) data to adjust a consumer-packaged-goods (CPG) manufacturer’s production plan to not only improve the CPG company’s supply chain but also to enhance collaboration between the CPG company and its retail customer.

3D Printing to Streamline Sales Sample Creation | 23

Under competitive pressure to innovate their product portfolio, a leading consumer packaged goods (CPG) manufacturer of cosmetics has begun launching three times as many new products in half the time, given the same resources. In this project, processes and technology innovations such as 3D printing to streamline product introductions were identified and examined.

SKU Segmentation for a Global Retailer | 26

This thesis examines how a global retailer can adjust their supply chain process for different SKUs in order to better meet demand and/or reduce costs. Purchase order data is used to predict which products require an expedited process and which can be managed in a more cost-effective manner. Because the product mix was too diverse and dynamic to use traditional metrics such as product value and demand patterns, a regression model was developed that the company can use to make supply chain decisions.
Introduction

Less-than-truckload (LTL) is a $32-billion sector of the trucking industry that focuses on moving smaller shipments, typically with weights between 100 and 10,000 pounds, that do not require a full 48- or 53-foot trailer to be moved. LTL companies are characterized by serving multiple customers simultaneously with a single truck due to the need to consolidate shipments to build economical loads.

Currently, there are no widely accepted methods to estimate carbon emissions from individual LTL shipments that take into account the complexities of a typical LTL network. Initiatives such as the GHG Protocol and the EPA SmartWay Program provide general guidance on how to estimate carbon emissions from a variety of industries including transportation, but they do not specifically capture the unique characteristics of LTL shipping.

Data and Methodology

Throughout this research, we worked with C. H. Robinson, a Third-Party Logistics Provider (3PL) and a Fortune 500 company, and with Estes Express Lines, a privately-owned freight transportation company that operates primarily in the United States. We developed two different calculation tools: a detailed model, specifically designed for and based on Estes Express’ network and operations, and a low-precision model, adapted from the detailed one so that it could be applied more generally to carriers whose network characteristics are unknown.

Data provided by carrier Estes Express Lines was used in the development of the actual calculation models, while data provided by C. H. Robinson’s TMC (Transportation Management Center) division was used to test the results of our models and to compare the outputs of different estimation methods.

We analyzed information from more than three million shipments that were moved by Estes Express Lines between...
August and October of 2013. We also analyzed fuel data in order to assign a carbon footprint to both the line haul and the pick-up and delivery (P&D) operations of shipments.

1. Calculating Total Emissions

After analyzing historic shipment data from Estes, we developed two separate linear regression models to predict actual shipped line haul miles for LTL using the great circle distance between the shipment’s origin and destination. The predicted line haul distance included added miles due to intermediate stops as well as a factor to account for empty miles. The regression models were used whenever historic shipment data for an LTL lane (origin-destination terminal pair) was not available.

We also analyzed fuel consumption data provided by Estes relative to a full year of operations and determined the miles per gallon (MPG) factors for line haul as well as for P&D operations.

Based on the total fuel burned and using the recommended GHG Protocol emission factor of 10.15 kilograms of CO2 per gallon of fuel, the total line haul emissions of a movement were calculated.

For P&D operations, due to limited data availability, we adopted a simplified approach that assigned a fixed number of P&D miles to each shipment, regardless of its characteristics (weight, volume, or class), but varying by terminal or by region. This approach was chosen to match the common practice in LTL business of trucks running a route performing multiple pick-ups and deliveries simultaneously. To estimate the fixed P&D miles, we analyzed total mileage, total fuel consumption and total shipments moved by each terminal in Estes Express’ network. For the low-precision model, we aggregated these numbers by region instead of by terminal.

2. Allocating Emissions to Single Shipments

After determining total emissions from a movement, our models then proceeded to allocating emissions to a single shipment.

For the line haul operations, Estes provided overall load factors or utilization rates in terms of weight and volume. Estes provided different factors for short haul (no more than 300 miles) and long haul (more than 300 miles) movements. Emissions were then allocated to individual shipments based on the fraction of their weight versus the load factor. Volume, class or density information was not taken into account in our allocation procedures since weight data is traditionally more reliable.

For P&D operations, our approach to estimating emissions was to assign a number of miles and fuel burned to each shipment, regardless of its characteristics, based on its origin and destination. Additionally, since load factor information was not available for P&D operations, shipment weight was not used in the allocation procedures.

Results

We focused our analyses on the outputs of five different methods: TMC’s current estimation formula, TMC’s current formula with an adjusted load factor, GHG Protocol’s short ton-mile approach for freight transportation, our detailed model for Estes Express Lines’ network, and our lower-precision model for an unknown carrier network.

<table>
<thead>
<tr>
<th>Item</th>
<th>Detailed Model</th>
<th>Low-precision Model</th>
<th>TMC’s current formula</th>
<th>TMC’s adjusted formula</th>
<th>GHG Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Emissions</td>
<td>370,285</td>
<td>382,692</td>
<td>140,435</td>
<td>224,697</td>
<td>486,425</td>
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<tr>
<td>Total Line Haul Emissions</td>
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<td>266,355</td>
<td>140,435</td>
<td>224,697</td>
<td>486,425</td>
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<tr>
<td>Total P&amp;D Emissions</td>
<td>101,925</td>
<td>116,338</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>P&amp;D Percentage</td>
<td>28%</td>
<td>30%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Difference (Total Emissions)</td>
<td>BASE</td>
<td>3%</td>
<td>-62%</td>
<td>-39%</td>
<td>31%</td>
</tr>
</tbody>
</table>

Table 1: Comparison of emissions for sample of 2,700 shipments (pounds of CO2)
1. Comparison of Total Emissions

Table 1 presents the results of the five compared methods for a sample of 2,700 shipments moved by Estes Express Lines. This sample included shipments of various weights, length of haul and volume. Results are in pounds of CO₂.

Table 1 shows that TMC’s current estimation formula underestimated the emissions from LTL shipments by 62% on average. Adjusting the formula’s load factor from 40,000 pounds (traditionally associated with full truckload) to 25,000 pounds (more representative of LTL) reduced this difference to 39%.

The GHG Protocol freight transportation approach yielded total emissions 31% higher than our detailed model, a conservative estimate to hedge against not using actual fuel data. However, while total emissions were higher, we observed that this method underestimated the emissions of shipments that moved short distances or that had low weight.

Table 1 also shows that P&D operations accounted for roughly 30% of total emissions on our models. Additionally, there was only a 3% difference in total emissions between the results of the detailed and low-precision models.

2. The Impact of Pick-up and Delivery (P&D)

We observed that P&D operations had a high impact on emissions of lighter shipments, but their influence decreased exponentially as shipment weights increased (see Figure 1 below). As weight increases, our model allocates more emissions to the line haul portion of that shipment, thus P&D emissions become smaller in comparison.

The few shipments on the top-left corner of Figure 1 that displayed 100% of emissions being originated from P&D were those that moved between two ZIP codes that were serviced by the same terminal. In this case, since there was only one terminal involved in the movement, there were no line haul emissions.

In summary, current freight emissions estimation methods do not take the emissions from P&D operations into account, since they were developed primarily with full truckload (FTL) operations in mind. While Table 1 showed that, on average, P&D accounted for 28% of total emissions in our detailed model, Figure 1 shows a much higher impact of P&D operations at the shipment level, especially for light shipments.
3. The Value of Detailed Information

We also compared the results from our detailed and low-precision models when applied to the same sample of 2,700 shipments that were moved by Estes Express Lines. We inserted these shipments into the low-precision model in order to assess the differences in the results if we assumed that there was no information about the carrier’s network.

Figure 2 presents a histogram of the difference between the emissions of the detailed and the low-precision models at the shipment level. The difference was calculated through the following formula:

\[
\text{Difference (\%)} = \frac{\text{Low precision} - \text{Detailed}}{\text{Detailed}} \times 100
\]

Figure 2 reveals that there were large variations at the shipment level estimates, despite the fact that total emissions were similar between the two models (3% difference, as shown by Table 1). 85% of the shipments in the sample displayed a difference lower than 30% in magnitude. However, in some specific cases, the low-precision model yielded results as much as 3.5 times higher than the detailed one.

In summary, a less detailed model may provide enough accuracy for a 3PL, such as C.H. Robinson, or for any company using LTL services, but working with detailed information may provide better understanding of the dynamics of the operations and better shipment-level estimates.

Conclusions

The models we developed in this research provide a contribution in terms of better estimating carbon emissions from individual LTL shipments with minimal input information. Using detailed operational data, we were able to quantify the errors that originate from using traditional estimation methods.

Initiatives such as the GHG Protocol or the EPA SmartWay Program do not specifically capture the complexities of an LTL network when estimating emissions from LTL shipments. These initiatives also focus on corporate-level accounting, as opposed to shipment-level calculations. This has an important implication for 3PLs and for any organization using LTL services: while corporate-level reports allow comparisons of different carriers, some of these companies may be more carbon-efficient overall, but less than some of their competitors on specific regions or to move certain types of freight. This distinction is only visible if emissions are compared at the shipment level, as opposed to comparing the emissions of carriers as a whole.

We also found from our research that traditional emissions estimation methods for LTL shipments are flawed, especially for short distances and light freight, primarily for two reasons: (1) these methods rely on direct over-the-road distances as opposed to actual LTL shipped distances, which must include all the intermediate stops; and (2) they fail to factor in the P&D operations, focusing solely on line haul between the first and the last terminals. We found that P&D operations were responsible for roughly 30% of total emissions according to our models.

We believe our approach captures more of the dynamics of LTL shipping than other current available estimation methods, providing more representative estimates of emissions. The low-precision model provides a good approximation when detailed information about a carrier’s network is not available, especially for total emissions of multiple shipments. Still, a detailed model should be preferred particularly when estimations of individual shipments are of interest.
Real-Time Order Acceptance in Transportation Under Uncertainty

By: Hiral Nisar and Joshua Rosenzweig
Thesis Advisor: Dr. Chris Caplice

Summary: Many industries require the capability to accept, reject, and prioritize incoming orders under uncertain future conditions. Some industries, like make-to-order manufacturing and transportation, use order acceptance criteria often based on capacity constraints and order characteristics to make these real-time decisions. In the transportation domain, orders that are in close spatial and temporal proximity are often aggregated to achieve economies of density and scale. The problem is that companies don’t know if future demand will allow them to effectively combine shipments. The objective of our research was to create and validate a model to determine if historical demand data can be used by retail firms operating private fleets to make effective real-time order acceptance/rejection decisions with the purpose of eliminating unprofitable orders in a short-haul transportation setting. A Java tool was developed to instantaneously decide whether or not to accept an order depending on the order location and time of receipt. The tool was then tested against several alternative models.

KEY INSIGHTS
1. Comprehensive order acceptance criteria are critical for creating an effective decision making model.
2. Demand probability distribution is an important component for use in real-time operational decision making processes.
3. Logistic regression analysis is not appropriate for an order acceptance model, as it does not provide the flexibility required to incorporate capacity constraints.

The Problem

In transportation, cost is minimized by aggregating shipments in close spatial proximity. Accepting orders indiscriminately can put unwanted constraints on the ability to combine shipments. Firms may have to reject incoming orders due to limited capacity. Many industries use order acceptance criteria based on order characteristics, customer priority and capacity constraints. However, minimal research has been done on order acceptance criteria involving probabilities of order deliveries in sub-regions based on historical demand. In this paper, we develop a decision making model based on the probability distribution of orders across service regions, marginal cost of accepting incoming orders, and truck capacity.

Methods

To formulate an order acceptance model based on probabilities, we first determined the criteria that have the largest impact on transportation cost. We found that an order’s destination region most directly affects the transportation cost. Profitability of an order requires that marginal revenue exceed marginal cost for a region; therefore a certain amount of order revenues must be received to offset the cost of delivering to a specific region. Using a transportation cost approximation formula, the breakeven number of orders for a region, where revenues equal costs, was calculated. The model accepts orders for a certain time period, which we call the order acceptance period. After the end of this period, the actual delivery of the orders is executed. However, exact costs from vehicle routing are not explored in this thesis.
The two major criteria for the model are the breakeven number of orders and the probability of receiving that many orders during the time left in the order acceptance period. Available truck capacity is also an important consideration when developing the model. Figure 1 demonstrates the structure of the probabilistic model algorithm.

All incoming orders for regions that are already being serviced will be accepted if there is available capacity, as the majority of costs have already been incurred with the acceptance of an initial order. Incoming orders in new regions must be checked for expected profitability. The node labeled “Profitable?” in the decision making tree above will determine the profitability of deploying a truck to a new region. In the event that a region has no prior orders, the model finds the likelihood of receiving breakeven number of orders in the remainder of the order acceptance period. If the probability of receiving the breakeven number of totes is greater than a predetermined threshold and capacity is available, the model will accept the order and subsequent orders in the same region until capacity is fully utilized.

There are several key calculations at the core of the probabilistic model. The breakeven number of orders requires a calculation of cost. Total cost comprises purchase cost, transportation cost, and a fixed operating cost. Purchase cost and operating cost are considered constants in our model, with a fixed purchase cost per tote and a fixed operating cost per truck.

The nature of the model requires that orders are constantly being added to regions, which will ultimately have an effect on the actual route driven at the end of the acceptance period. Because we could not include route optimization in our model due to data constraints, exact transportation cost was impossible to determine. For this reason, we modified an equation from Daganzo (2010) to calculate an approximation of transportation cost upon addition of each order. The equation uses number of customers and customer density of a region to estimate the costs associated with loading and unloading totes, and traveling to and from a region.

After the breakeven number of orders is known for each region, the likelihood of receiving that number of orders must be determined. For the purposes of this model, the frequency of deliveries per customer was assumed constant. This assumption is crucial in allowing the model to determine the number of totes a region can expect to receive in a certain time period. By knowing the total number of customers in a region, a Poisson distribution analysis was done to compute the expected number of totes in a certain time interval. The Poisson output tells us the probability of receiving exactly $k$ orders in a time period given an expected value $\lambda$. In this situation, however, the model determines the probability of receiving at least $k$ orders.

Combining the Poisson distribution analysis with the breakeven analysis, the model is able to determine the likelihood of receiving enough orders to reach the breakeven point for each region. Orders for regions that are not expected to reach the breakeven number of totes in the time left will be rejected.
Alternative Models

Determining the effectiveness of the probabilistic model required a comparison of results of various alternative strategies and a baseline model. The models developed range from overly simple to complex and are described below.

**Optimal Model Overview**

In our problem, decisions must be made instantaneously upon order arrival. In an optimal situation, we would have complete knowledge of all daily orders before making decisions. This model optimizes capacity utilization and maximizes profit and provides a baseline for model comparison. By comparing our model against results from the optimal situation, we can determine the effectiveness of the decision making process in our model.

**Myopic Manager Model Overview**

In this model, orders are accepted sequentially until capacity is filled. As in our probabilistic model, decisions are again made instantaneously upon receipt of orders. This model reflects the actions of a firm with no intelligent operational decision making process and simulates a worst-case scenario.

**Logistic Regression Model Overview**

The binary logistic regression uses explanatory variables and previous decisions to predict the discrete outcomes of future decisions in order to make instantaneous order acceptance decisions. To determine the previous decisions to use for the regression formulation, we used binary outputs from the optimal solution model on a dedicated dataset. In our model, explanatory variables used to create the model are the incoming order’s distance (miles) from the distribution center and order size (number of totes).

**Results**

The results in Figure 2 show that the maximum daily profit earned for the optimal strategy is much higher than that of any other strategy. This is because it has complete information of the demand and only chooses those orders that earn higher revenue and maximize truck utilization.

The maximum daily profit earned by the probabilistic model is lower than that of the optimal model. The profits increase linearly with fleet size until it reaches a peak and then starts decreasing due to the penalty of not utilizing all the available trucks. This is because the model is highly influenced by time and does not deploy new trucks after a certain point in the acceptance period.

The daily profits for the myopic manager model are even lower than the probabilistic model. This is because the model deploys trucks in the regions for earlier incoming orders. As a result, it can accept an order for a region which does not have a high customer density and will cause most of the

![Figure 2: Average daily profit by strategy](image)
truck’s capacity to be underutilized. Therefore, the company will lose money in these unprofitable regions and report lower profits.

The logistic regression analysis offers the poorest performance. One factor causing low profits is that the model does not adequately describe the situation with the available explanatory variables. This attributes to model accuracy of approximately 76% correct decisions. The regression model actually performs worse than the myopic manager model because the nature of the regression parameters allows for orders with small numbers of totes to be automatically rejected even if there is already available capacity to the same region. The inability to incorporate capacity into the regression analysis adds unfavorable inflexibility to the model.

Table 1 compares the average daily profits gained by each model in a scenario where the fleet size is fixed at 13 trucks, which is the ideal fleet size of the probabilistic model. This allows us to compare each strategy against the best case scenario for the probabilistic model developed in this thesis. This comparison is useful from a realistic viewpoint, as companies will not have perfect flexible control over fleet size, and must make decisions that will allow for the best utilization of current available resources.

### Conclusion

Inputting the same simulated demand data sets into each Java tool, we were able to determine that our probabilistic model provided approximately 8% less profit than the optimal solution under a scenario of flexible fleet size; however, it outperformed all other instantaneous decision making models. Average daily profits for the myopic manager model and the logistic regression model were about 11% and 34% lower than the probabilistic model, respectively. We determine that the myopic manager and logistic regression models simply do not offer the insights required to match supply with demand in an effective way.

We are able to conclude that demand probabilities are an important variable for use in real-time operational decision making processes. This research shows that demand probabilities determined by historical demand patterns should be considered by companies with private fleets that make acceptance/rejection decisions under capacity constraints.

### Future Research

To understand how the model would function in a more realistic setting, more research must be done to amend the model to remove naive assumptions.

First, assumptions surrounding customer order frequency, order size, and order revenue should be refined through the use of additional data in related fields. This would allow for the employment of more realistic probability distributions in the creation of demand samples. Second, the model should be adjusted to permit trucks to deliver to more than one region. This would allow the model to be more favorable to orders for low customer density regions that are in close proximity to high density regions. Third, the cost for order rejection must be included in the model. The cost associated with outsourcing tote delivery should be incorporated in the regional break even analysis.

In addition to relaxing assumptions, future research should be done to create accurate models of current practices of retail companies operating private fleets. In our thesis, we simplify the actions of these companies with the myopic manager model, a worst-case scenario in which companies will simply accept every order until capacity is unavailable. This is most likely not true for many companies, as they may adapt strategies and develop decision making heuristics over time. By investigating the real processes used by companies, we can more accurately assess the true benefits of the model.

<table>
<thead>
<tr>
<th>Model Type</th>
<th>Average Daily Profit</th>
<th>Difference from Optimal</th>
<th>Percent Difference from Optimal</th>
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<tr>
<td>Myopic Manager</td>
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<td>Probabilistic</td>
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<td>Logistic Regression</td>
<td>1652</td>
<td>(1242)</td>
<td>(42.9)</td>
</tr>
</tbody>
</table>

Table 1: Comparison of average daily profit with fleet size of 13
Increasing Access to Medicines in Southern Africa

By: Chelsey Graham and Ricardo Ghersa
Thesis Advisor: Dr. Jarrod Goentzel

Summary: Economic instability and poor or lacking physical infrastructure are some of the factors that contribute to price inflation along the supply chain in Zimbabwe. Our research, in partnership with one of the Big Pharma companies, addressed two intertwined yet distinct research areas. On one hand, we evaluated how price reductions (i.e. subsidy) offered by our partner company distributors in Zimbabwe translated down the value chain. On the other, we analyzed the costs of insourcing versus outsourcing of our partner’s company distribution function in Southern Africa, and the sales volumes at which the two alternatives are equivalent. We realized how trust and information sharing played a pivotal role in the rollout of the price reduction scheme, making it relatively more successful for certain distributors, pharmacies, and product lines. In addition, through the application of inventory policies, such as economic order quantities and the power of two policy, and Monte Carlo simulation we were able to determine the impact that forecasting error, minimum order quantities, and sales volumes can have on the decision to outsource.

KEY INSIGHTS
1. The logistics fee contributed to lowering prices across distributors and narrowing the gap between prices charged by the different distributors.
2. Pharmacies passed the savings to the final consumers and the prices charged for certain product lines became very close to their generic alternatives.
3. Minimum order quantities (MOQ) can have a large impact on inventory holding costs, and in the case of our partner company, affect the decision to outsource. Due to large MOQ’s, the MOQ was ordered for 50% of the SKUs over the EOQ in our model. This resulted in a 25% increase in inventory holding costs.

The Problem
Our research focuses on two research areas involving the distribution of medicines of the private sector, in partnership with a pharmaceutical company operating in Southern Africa. 1) Will price reductions at the distributor level in Zimbabwe translate to the consumer, and if so, how does this impact over sales volume? 2) What is the cost of insourcing the distribution function vs. outsourcing at varying service levels, and what sales volumes are required to motivate the switch from outsourcing to insourcing?

Methodology
1. Logistics Fee Implementation
The key data source used for evaluating how the logistics fee was implemented by the different actors across the supply chain came from semi-structured interviews we conducted with distributors and pharmacists during a visit to Zimbabwe in December 2013.

The Questionnaire
In order to effectively conduct our interviews, we compiled a questionnaire to be used as a guide and aimed at gathering specific data on sale volumes and prices, as well as gaining visibility on the key operations and challenges faced by both distributors and pharmacists, so as to be better placed...
to correctly interpret the data collected.

**The Sample Selection**

Next, we selected a stratified sample of pharmacies by classifying them according to two criteria: population density and level of income. By so doing, we captured the purchasing trends of the main categories of the population living in and around the capital city of Zimbabwe. As for distributors, we were able to meet with all five that distribute our partner company’s medicines.

**Value Chain Analysis & Sales Volume Review**

The data collected were then used for three purposes:

1. To quantify the mark-ups applied by the different players along the value chain for medicines sold in Zimbabwe, from the original manufacturing sites all the way through until to the final consumer.
2. To determine how sales volumes at the wholesaler and the distributor level where affected by the implementation of the logistics fee.
3. To determine the profitability of the pharmacies visited and discuss how they would be impacted by a new change in prices.

**2. Warehouse and Distribution Model**

**EOQ vs. MOQ**

To aid our partner company in the decision of whether or not to continue to outsource the warehousing and distribution functions, we developed a model that calculates the inventory holding costs (based on cycle stock, safety stock, and in-transit stock), warehousing costs, and transportation costs from the manufacturer to Lusaka, Zambia – the potential warehouse location. Using historical sales data for products that made up 80% of total Southern African sales, we applied the economic order quantity policy to determine the optimal order quantity. We then compared this to the MOQ required by the manufacturer to determine the impact that MOQ’s have on inventory holding costs.

**Sensitivity Analysis**

We used the forecast for these same products to determine the forecast error in order to calculate required safety stock. We varied the service levels (90, 95, and 99.5%), k factor, to determine the impact on total costs and the actual service level being provided by the current third party logistics provider (3PL).

**Optimal Mode of Transportation**

In order to determine the cheapest mode of transportation by supplier site (ocean vs. air), we calculated the average fixed and variable rates by mode for each supplier site based on historical data. We then calculated the optimal interval between orders ($T^*$), and applied the power of two policy by supplier ($T_{practical}$). This allowed us to determine the weighted average of the number of orders by supplier site, while remaining within 6% of the optimal cost. This was then used to calculate fixed transport costs (per shipment).

Overall, the logistics fee succeeded in better aligning the price structures of distributors. An analysis on two of the distributors showed that the distributor who originally charged lower prices did not need to pass on the full price decrease received from the wholesaler to the pharmacies in order to continue to provide lower prices than the competitor. See table below for price changes before and after the logistics fee implementation.

$$T^* = \frac{Q^*}{D}$$

$$T_{practical} = \frac{\ln \left( \frac{T^*}{\sqrt{2}} \right)}{2 \ln(2)}$$

Logic within the model chose the cheapest mode of transportation by supplier site. We were then able to compare the total costs using this method to the total costs of using “all air” or “all ocean” modes of transportation.

**Warehousing Costs**

The one-time setup cost of opening a warehouse was estimated using Warehouse-in-a-Box™, a Supply Chain Management System (SCMS) solution. The size of the warehouse required was calculated by converting average inventory on-hand to pallets using dimensional data provided by our partner company. Labor costs were provided as a percentage to sales by an external party currently subcontracted by our partner company.

**Simulation**

We used @Risk Monte Carlo simulation to determine how the total warehousing and distribution costs changed as a function of sales volume, ranging from 4 to 13 million, increasing in increments of 1 million for each simulation.

**Results**

**Logistics Fee**

1. Overall, the logistics fee succeeded in better aligning the price structures of distributors. An analysis on two of the distributors showed that the distributor who origi-
nally charged lower prices did not need to pass on the full price decrease received from the wholesaler to the pharmacies in order to continue to provide lower prices than the competitor. See Table 1 above for price changes before and after the logistics fee implementation.

2. A clear increase in volume sales was detected for two out of the five distributors. Figure 1 below displays how volumes reacted for one distributor post implementation.

3. The gap in prices of the branded versus the generic alternatives became decreased for two out of the company’s four top-selling product lines.

4. Pharmacies passed the full price reduction to the final consumer. In particular, the retail price reduction applied by the pharmacies was a reflection of the pricing applied by the distributor.

Comparative Warehouse Cost Analysis

Our model and simulations allowed us to determine that the current costs of outsourcing is 67% cheaper than the option to insource at the current sales volume (at a 99.5% service level). At four times the current volume, the cost of outsourcing will be more expensive than insourcing 95% of the time. Inventory holding costs make up 60% of the total costs, which is in part attributed to high levels of safety stock due to large forecast error. Large MOQ’s required by the manufacturer are another cause for high inventory holding costs. The MOQ was 77% higher on average than the EOQ, causing a 25% increase in the total inventory holding costs (for all simulations). This explains why such high sales volumes are needed before insourcing becomes the more financially attractive option.

Varying Service Levels

We compared the cost of outsourcing vs. insourcing at varied service levels, and determined that at a 90% service level (excluding one-time cost of opening a warehouse), the total cost of outsourcing is 30% less than insourcing at current sales volumes. This remaining gap could be attributed to the following differences between our partner company and the 3PL: forecasting capabilities, safety stock policies, and capital and non-capital costs. This small gap leads us to conclude that the service level being provided by the 3PL is no greater than 90%. Figure 2 compares the cost of insourcing by mode to 80% of the total cost of outsourcing. The cost of the 3PL is 5.3% of total sales; 80% of this was taken...
in order to compare against the model outputs, which are based on the top products that make up 80% of total sales.

**Conclusion**

We noticed how the different distributors implemented the logistics fee with varying levels of effectiveness, depending on their original price structures, and that the fee contributed to lower prices across all distributors. A review of the sales volume (at the distributor level) confirmed the insight that the fee was particularly successful in increasing volume with certain distributors and product lines. Similarly, at a pharmacy level, the application of the price reduction to the final consumer varied substantially depending on the specific pharmacy and products. In effect, the retail price reduction applied by the pharmacies was a reflection of the pricing applied by the distributor.

As far as the results of the insourcing decision are concerned, we verified that large MOQ’s and forecast accuracy greatly impact inventory holding costs. In general, larger sales volumes are needed in order for the insourcing of logistics functions to make sense financially (four times the current volume in the case of our partner company). Forecasting accuracy will also improve with higher, more stable volume levels and the EOQ has less of a chance of being overridden by large MOQ’s, ensuring that a balance between transactions costs and excess inventory costs is maintained. However, outsourcing may also mean sacrificing service levels for lower costs. The model established that at a 90% service level the cost of insourcing is 550,000 GBP greater than the current cost of outsourcing (sans the one-time cost of opening a warehouse). This gap may be attributed to poor forecast accuracy and high MOQ’s, but also raises the question of whether a service level less than 90% is being provided by the 3PL.
Supply Chain Risk Visualization and Quantification

Thesis title: Application of Supply Chain Risk Management through Visualization and Value-at-Risk Quantification
By Rainy Lu and David Xia
Thesis Advisor: Dr. Bruce Arntzen

Summary: This project attempts to bridge the gap between isolated risk mitigation plans and a comprehensive approach for corporations to deploy supply chain risk management ("SCRM") on an enterprise scale. Through the use of supply chain visualization and value-at-risk modeling, we have developed a SCRM strategy for a pilot supply chain of a large multinational chemical company ("GlobalChem").

Rainy Lu received her bachelor degree in management from Fudan University. Prior to the MIT SCM Program she worked as a Project Manager at Procter & Gamble. Upon graduation, she will join Schlumberger as a Supplier Manager.

David Xia received his bachelor degrees in mathematics and economics from the University of Chicago. Prior to the MIT SCM Program, he worked as an Actuary for SCOR. Upon graduation, he will join Deloitte as a Senior Consultant.

Sourcemap.com, a web supply chain mapping platform that will interface with current enterprise resource planning ("ERP") systems. Thus, in the future the solution can be applied broadly across all of GlobalChem's product lines.

KEY INSIGHTS
1. Supply chain risk can be quickly analyzed through visualization.
2. The value-at-risk for each node in a supply chain network can be quantified using a risk exposure index and location-based disruption probability data.
3. GlobalChem can reduce its supply chain risk by either increasing inventory or adding new suppliers for components with a high VaR index.
4. This methodology can be expanded from our pilot product line to an enterprise scale for more comprehensive risk analysis.

Introduction

Many companies fail to mitigate supply chain disruptions effectively because they lack an integrated, practical approach for SCRM that can be implemented on an enterprise scale. According to a 2013 World Economic Forum report, share prices are estimated to drop by 7% on average for companies that suffer a major supply chain disruption. To mitigate this risk, companies need a well-established strategy for supply chain resilience that incorporates a cross-functional risk management process, an integrated monitoring system, and close cooperation with upstream and downstream supply chain partners. Our SCRM solution is developed on Sourcemap.com.

For most geographical locations, there is historical frequency and severity data collected by public organizations such as the U.S. Geological Survey and private organizations such as Applied Insurance Research (AIR, Inc.). When mapped, we may view the hazards in risk heat maps, which can quickly convey the likelihood of such disruptions in any particular region of the world. Figure 1 shows a risk heat map of earthquakes in the U.S.
Taken a step further, this information can be combined with a risk exposure index to calculate a VaR for every node in a supply chain network. Risk exposure is a measure of the maximum loss potential should a disruption event occur. For our purposes, this would mean the amount of revenue lost should a node be removed from the supply chain network. For each node in our network, we defined this risk exposure amount to be equal to the daily revenue dependent on this supplier, multiplied by the difference in recovery time and the days of inventory positioned between the supplier and the customer,

\[ REI = \text{Daily Revenue} \times (\text{Recovery Time} - \text{Inventory Days}) \]

The purpose of VaR is to be an unbiased measure of risk. It is not particularly useful on a stand-alone basis, but is more useful as a comparison tool across time or physical dimensions. In our project, VaR is used to calculate the expected value of loss due to natural catastrophes. Specifically it is the product of risk exposure index and the probability of disruption,

\[ \text{VaR} = \text{Risk Exposure Index} \times \text{Pr(Disruption)} \]

Exceedance probability (“EP”) curves from AIR, Inc. allow us to identify the probability of novel events that may greatly exceed normal losses, which the insurance industry would then categorize as a “catastrophic event.” In the example shown in Figure 2 on the next page, we can see that there is a 1.3% probability of a catastrophe creating more than $1,000 of damage per $1 million of assets, which we defined as our disruption threshold.

After calculating the VaR of each node in the network, we integrated the information into our supply chain map in Sourcemap, which color-coded our network based on the relative VaR of each node. Such visualization helped Global-Chem to identify the nodes that had the highest concentration of risk.

**Findings**

We mapped an end-to-end supply chain of selected product lines, quantified the amount of risk at each node in the network, and demonstrated the new supply chain set up with risk mitigation (Figure 3). As a result of our study, we mitigated the VaR from single-source vendors with moderate disruption probabilities and primary vendors with high disruption probabilities. The strategies were developed for the specific operations and industry but they could also be applied more broadly with adjustments.

**Single-Source Vendors**

While more multi-national organizations seek lean strategies such as reducing the supply base, their supply chains become more vulnerable to any type of disruptions that occur around the world. Multiple sourcing is effective in mitigating disruptions from single sources. It is also critical to keep the sources geographically scattered, so that the supply chain is more flexible in response to unpredictability. Given the high cost associated with multiple sourcing, an internal target is necessary to keep a balance between risk mitigation and cost control.

Additional time and costs need to be taken into consideration because vendor qualification is often determined by cross-functional teams. Many single sources are in essence sole sources because no other vendor in the market is capable of meeting the internal standards of product quality,
process reliability, and regulatory compliance. The strategy is still to diversify the supply by either investing in the enhancement of other vendors’ capabilities or to negotiate for the vendor’s geographic expansion.

**Upstream Strategic Partners**

Our model has identified enormous risks with a primary supplier situated somewhere with high disruption risk probability. The mitigation strategy is to lessen the company’s dependence on the risky primary supplier. One way is to adjust the split of supply among vendors, as is experimented in the model. In reality, companies can also sign option contracts with other vendors to reserve excessive capacity that deals with any type of disruptive events occurring to the primary supplier.

The other way to mitigate risks associated with a risky primary supplier is to increase inventory of certain raw materials in central warehouses. This is effective for the materials that are needed in many product lines, but in small quantities.

**A More Integrated Platform**

Over the course of the project, we have identified a few areas for improvement in the enterprise to facilitate a more automated data collecting and processing platform in future. One key recommendation is to more explicitly document procurement strategies. Following the current practice, the metrics that evaluate vendor performance or development plans that capture sourcing strategies could hardly be translated into any single value of estimate to determine disruption risks. We suggest some key operational aspects be documented by procurement including supplier’s factory location, recovery time, capacity, sourcing splits and inventory.

**Conclusion and Further Research**

When corporations are able to quickly visualize their supply chains, assessments of risk exposure and mitigation solutions will surface more quickly. Yet, there will be questions about which solution would be most cost effective and provide the most risk mitigation. The scope of our project includes risk identification and quantification, but a natural extension of our research would have been to include scenario planning and stress testing.

When we showed GlobalChem the key risk in its supply chain, the next step was to find an appropriate response to reduce that risk. However, there were questions whether the best response was to find additional suppliers and, if so, how many were adequate. To address this question, our visualization and VaR quantification methodology can be applied to hypothetical situations. The scenario tests can be used in conjunction with a cost-benefit analysis to determine the best course of action. Finally, we can stress test our supply chain to understand resiliency. By simulating disasters, we can identify weak spots in our supply chain that our calculation missed.

After reviewing our project with our sponsor and hearing their feedback, we noted potential additions to our SCRM strategy that could further enhance value for organization.
First, live real-time alerts from monitoring organizations could provide risk managers with warnings of upcoming disasters. Second, an intercompany visualization platform could connect the company with external suppliers and distributors, which would create a vertically integrated and resilient supply chain.

Furthermore, there are areas of improvement for this approach to SCRM. First, the model for risk exposure can be further improved by incorporating vendor capacity. Second, operating risks at vendor level can be built into the model. Finally, the threshold for disruption at some nodes can be differentiated when more data is available about construction quality or other risk factors.

Business organizations that have focused on cutting costs by aggregating orders to fewer suppliers have also concentrated the risks in their supply chains. In order to balance risk and efficiency, we recommend that organizations examine our approach for risk identification, evaluation, and mitigation. We hope that our research will help organizations like GlobalChem to find a balance in building an economically resilient supply chain and to create a sustainable system for all stakeholders.
Perfecting Production Plans with POS Data

Thesis title: Perfecting Visibility with Retailer Data
By: Daniele Primavera and Hang Shi
Thesis Advisor: Dr. Jarrod Goentzel

Summary: Designing optimized operations is essential for companies in competitive business landscapes, but unexpected or inconsistent customer demand can significantly reduce the effectiveness of the supply chain. This project creates a framework to use retailer point of sale (POS) data to adjust a consumer-packaged-goods (CPG) manufacturer’s production plan to not only improve the CPG company’s supply chain but also to enhance collaboration between the CPG company and its retail customer.

Daniele Primavera holds 6 years of experience working for the United Nations World Food Programme. He worked in humanitarian supply chain execution and strategy both at field and HQ level. Prior to the SCM program, Daniele received a Master Degree in International Relations and Diplomatic Studies at Bologna University, Italy.

Hang Shi received his bachelor’s degree in Electrical Engineering from Georgia Institute of Technology. Prior to attending the SCM program at MIT, he worked as a technical sales engineer. Post-graduation, Hang will join PricewaterhouseCoopers as a sr. management consultant focusing on Operation Strategy.

Introduction

Companies have always been interested in the theoretical benefits POS data to their supply chains but due to the amount of time, effort, and cross-team collaboration, its actual implementation is not nearly as commonplace. This project uses retailer POS data to adjust production planning to reduce production and inventory costs but maintaining high service levels.

Products in Question

The four different SKUs analyzed in this project were produced in the same manufacturing process and sold to the same retail customer. The time frame expands 26 weeks. SKU 2 (Figure 1) & SKU 4 customer’s inventory position remained at a consistent ratio to POS volume.

This results in the customer orders volume tracking to that of the POS but with a time shift delay and an amplification of its magnitude. The time shift delay is due to the retailer collecting the data, aggregating it, and then placing the order. The amplification is primarily due to an overreaction to the actual sales. This amplification is the Bullwhip Effect. SKUs 1 & 3 in comparison do not exhibit a consistent inventory policy, which conversely resulted in an order pattern that does not correlate to POS data. SKU1’s inventory to POS ratio varied from week to week unexpectedly without a sensible pattern. The retailer’s inventory to POS ratio of SKU3 declined by 50% from week 12 to week 26. The inventory policy of SKU1 and SKU3 necessitates open communications between the retailer and the manufacturer because quantitative analysis is no sufficient to effectively plan production.

Analysis

The focus of the analysis was to develop a model to investigate the benefit of incorporating POS data into production planning. Inventory holding cost and equipment changeover/setup cost were the optimization goals of the model while production capacity and item fill rate were its...
constraints. Due to the production planning freeze period of 3 weeks, the model used POS from week 1 through 4 to make the first production adjustment for week 8 through 11. The results were then used to adjust the subsequent weeks of production through week 26. Three models were developed: (1) Using only historical customer orders data; this most closely represented the existing forecast and production plan, (2) Using POS to forecast orders and adjust production to fulfill customer orders, (3) using POS data to adjust production to fulfill future POS, thereby eliminating customer orders altogether.

Results

The three models produced consistent results regarding the effectiveness of integrating POS data into production planning. The base model (1) provided the baseline and it was also the most costly model. Although model (2) improves over model (1), it only does so slightly on average of 5% primarily because model (2) still aims to fulfill to customer orders, which does not reduce the bullwhip effect. Model (3) resulted in the most costs savings because in addition to using POS to produce a better forecast, it also aims to fulfill future POS, thereby removing the extra layer of inefficiency of customer orders and the associated bullwhip. Figure 2 shows the inventory comparison between model (1) and model (3) for SKU 2.

Conclusions

The practical application of POS data can create substantial improvements in the supply chain. Figure 3 shown on the next page provides a framework on how to leverage POS data. If the bullwhip is minimal, then using POS data to im-
prove customer orders forecast produces the most benefit to the cost. On the other hand the higher the bullwhip, generally the higher the inventory volume and stress on production and thus the more significant the potential to reduce inventory and production related costs if POS data is used effectively. So in this case, it is best to persuade the retailer to place orders that more closely resemble the POS. In the case that the average customer orders do not align to the volume of POS, regardless of the bullwhip effect, the manufacturer must engage the retailer to discuss the misalignment. The misalignment can be caused by a change in the retailer’s inventory policy that could create critical longer term consequences to the manufacturer if discovered too late. POS provides an early warning to decreases or increases in customer order volume with respect to actual sales. As the research in this project illustrates, POS data can be used “passively” to be analyzed and improve forecasts but to maximize the potential of POS, action must be taken to engage with retail customers.

Not only can POS data impact immediate and tangible financial aspects of the manufacturer’s supply chain, but the real value of POS is to encourage and enhance communications between the retailer and the manufacturer. The overall supply chain is made more efficient creating a win-win situation. This also strengthens the long term relationship between customer and supplier thereby giving the supplier an added advantage over the competition.

![Figure 3: POS Framework](image-url)
3D Printing to Streamline Sales Sample Creation

Thesis title: 3D Printing Your Supply Chain
By Hala Jalwan and Greg Israel
Thesis Advisor: Dr. Alexis Bateman

Summary: Under competitive pressure to innovate their product portfolio, a leading consumer packaged goods (CPG) manufacturer of cosmetics has begun launching three times as many new products in half the time, given the same resources. We identify processes and technology innovations such as 3D printing to streamline product introductions.

Introduction

InnerBeauty Inc. (actual name disguised) is a leading CPG manufacturer of cosmetics. In response to recent market pressures, the pace of product introduction has accelerated to every six months, with triple the number of new product concepts. A full year before the launch date, InnerBeauty would present sales samples to their largest retail customers, estimating demand volumes and shelf configurations. Historically, these samples were just a 2D design of the product concept, whereas today full shelf-life quality samples are now the standard in convincing the retailer’s buyers that their products are the “next big thing.”

Our challenge is to identify the critical path in the product development process and provide recommendations to streamline it. In some instances, it takes InnerBeauty up to three years to get a product concept to store shelf. Despite InnerBeauty’s industry leadership, there tends to be poor execution of the sales samples process as compared to their mass production capability.

Methodology

Due to the low volume and short lifecycle of these products, the product sales samples process has traditionally been an afterthought for the CPG industry. Consequently, data is not systematically tracked and is thus mainly qualitative in nature. Data collection consisted of a site visit to InnerBeauty’s headquarters, weekly interviews with company stakeholders, a real-time tracking of individual products, a series of tracker documents and an exploration of 3D printing vendors.

The Critical Path and Bottlenecks

The thesis focused on activities that are on the critical path, such that any improvement will reduce the overall completion of the project.

The design phase of new product development is a critical and time-consuming aspect in the product lifecycle. Capturing more accurate consumer data while reducing the time spent in consumer testing is a tremendous opportunity for CPG firms. Executives may hesitate to finance these

KEY INSIGHTS

1. CPG firms’ supply chains have traditionally been focused on maximizing efficiency and minimizing cost, failing to adopt an appropriate strategy for products whose primary requirement is responsiveness.
2. Integrating 3D printing technology in the early design phase can decrease 10% to 20% from a CPG product’s development time.
3. 3D printing is still a developing technology, with limited technical capability from a “mass prototyping” standpoint.

Hala Jalwan has 1 year of project management experience in the construction industry. Upon graduation, she joined Facebook as a Technology Partner in Supply Chain Operations.

Greg Israel has 7 years of experience in supply chain consulting, both as external contractor and internal manager. Upon graduation, he joined SpaceX as a Procurement/Supplier Development Manager.
projects if they suspect any chance of failure as the cost of cancelling it at this point is exponentially less than if it is abandoned later. Having the ability to provide a shelf-ready product for consumer feedback would improve a firm’s confidence in a new product’s design, thus mitigating the risk of failure, accelerating design freeze and hastening the pace of product launches.

Additionally, the metal alloy cast mold used in blow and injection molding requires extensive processing. The cast mold tooling process has long lead times, high costs, where multiple iterations may be needed to ensure its quality.

**The Proposed Pre-Unit Tooling Solution**

We termed our proposed solution the “pre-unit tooling process,” an intermediate phase introduced between the primary package design and initial consumer’s feedback stage (as shown in figure). The pre-unit tool would provide 10 to 100 shelf-quality 3D units that can be used during the consumer feedback input sessions in lieu of the current 2D concept drawings or 3D mock-up prototypes.

The pre-unit tool enables more flexibility by allowing InnerBeauty to discover and re-engineer design issues earlier in the process. Though the five to nine month reduction in timelines is incremental over a three year timeline, the savings allows a CPG firm to launch a new to the world product a full sales season earlier than planned.

**The Benefits of Rapid Tooling as a Process**

The pre-unit tooling solution has three key benefits:

1. Fewer design iterations: Providing a fully functional, high quality, hands-on model of the product would yield more accurate feedback from consumers, resulting in fewer design iterations. Each product currently undergoes three to five design iterations, each lasting four to six weeks. As they reside on the critical path, each design iteration removed would shorten the project completion date by this amount.

2. Improved confidence in product success: More accurate consumer feedback would also strengthen senior executives’ confidence in the product’s potential success. Based on our analysis, it is the delay in the senior executive “design freeze” that suspends the rest of the sales samples process. Accelerating this step will help launch new products to the market sooner.

3. Testing activities moved to in-parallel with the critical
Conclusion

Over the course of ongoing discussions with InnerBeauty and an analysis on the state of additive manufacturing, our proposed solution had evolved. We came to realize that the sales samples’ supply chain is so intertwined with that of its mass production that making any changes to one would significantly impact the other. As a result, what began as an open ended approach exclusively focused on 3D printing sales samples, gradually pivoted toward streamlining the entire product development process. Thus, the “pre-unit tooling” solution was born: a technology-driven process step integrated between preliminary product design and unit tooling development. Using the pre-unit tooling would allow for some of the testing to be done earlier or in-parallel in the process, shaving 14% to 26% from the product’s development timeline. More importantly, putting a shelf-ready finished product into the hands of consumers for testing would improve the feedback’s credibility, providing more confidence to the executives who approve its launch. Furthermore, having the capability to provide the design team with a shelf-quality product within two weeks of concept inception would give them ample freedom to experiment with more innovative concepts. In the words of a project manager at InnerBeauty, “if the designers were in the room right now they’d be applauding.”

Future Considerations

Though the sophistication of 3D printing technology is quickly advancing, we also provided a realistic assessment on the limitations of the technology’s capabilities. For example, instead of only being able to produce limited unit quantities on the scale of tens, 3D printed molds of the future may allow thousands.

To implement our proposed solution, we recommend that InnerBeauty run a pilot on a non-strategic product to ensure integration with existing people and processes, experimenting with the capabilities of rapid tooling.

From the standpoint of product innovation, companies that seek innovation faster may locate some suppliers in close proximity to their R&D innovation centers. InnerBeauty’s adoption of mass-production procedures for the purpose of creating sales samples illustrates the pitfalls of a typical CPG firm using an efficient supply chain rather than an appropriately responsive one. Though we did not explore on-shoring their supply base, developing an adaptive supply chain via on-shoring or dual sourcing is an area for InnerBeauty to explore going forward.
SKU Segmentation for a Global Retailer

By Brad Gilligan and Huiping Jin
Thesis Advisor: Dr. Edgar Blanco

Summary: In this thesis, we determine how a global retailer can adjust their supply chain process for different SKUs in order to better meet demand and/or reduce costs. We do this by using purchase order data to predict which products require an expedited process and which can be managed in a more cost-effective manner. Because the product mix was too diverse and dynamic to use traditional metrics such as product value and demand patterns, we develop a regression model that the company can use to make supply chain decisions.

Introduction

The cost of transportation, excess inventory, and lost sales can vary greatly between products. This is why it does not make sense for companies to use a one-size-fits-all supply chain for every product. Instead, companies should create multiple supply chain configurations that are tailored to the types of products they sell. This is commonly achieved using SKU segmentation designed to optimize the tradeoff between supply chain speed and cost. Our sponsor company asked us to perform a segmentation for them, but their unique business model created some challenges.

Methods

The sponsor company has suppliers and retail stores in multiple countries, but in order to make the scope of this project more manageable we focused only on items that are purchased in China for sale in the United States. This data alone included over thirty thousand Purchase Orders (POs), forty thousand unique SKUs, and one thousand different suppliers.

Our approach involved thorough qualitative analysis and process mapping in order to understand the current supply chain from procurement to store delivery. We toured deconsolidation centers and distribution centers, and interviewed employees across the organization. After gaining this understanding, we moved on to analyzing historical shipment data.

We used a combination of histograms, box-plots, and scatter-plots to illustrate the supply chain timing of products based on various attributes. These visuals helped us detect patterns and trends in supply chain timing that could be related to PO data. We then built models to validate these relationships.

Linear regression and ordered-probit regression models were able to assess the strength of relationships between PO data and supply chain timing. However, these models could not predict the required speed with much accuracy.

KEY INSIGHTS

1. A traditional SKU segmentation based on high level attributes such as volume, margin, and demand may not work for a company that is constantly changing their product mix and suppliers.
2. Analysis of historical data can help identify which product attributes might indicate the required supply chain speed for a given product.
3. When segmenting using high level attributes is not reliable, a mathematical model can be used to predict required lead times at the PO or SKU level.
We eventually developed a neural network model that achieved the desired predictive capability.

Analysis

Our research of the current supply chain process helped us understand the following key milestones:

- **PO Create Date** – Buyer agrees to buy items from the supplier.
- **Cancel Date** – Supplier is required to deliver the PO at origin, or the order can be cancelled.
- **Origin Receipt Date** – Cargo is actually received at origin.
- **Destination Receipt Date** – Cargo is received at destination distribution center.
- **Sale Date** – Product is expected to be at retail store.

The problem is that some products are received well in advance of the sale date while others are received without much time to get from China to a store in the US. Because the company cannot see which products may fit one of these descriptions, some products arrive at destination very early and take up space in distribution centers while others do not meet the planned sale date.

Figure 1 is a histogram that shows the number of days between the date a product arrived at the company’s distribution and the date it was needed in order to meet their sales plans, we referred to this amount of time as the destination DC dwell time.

The large values on the right show the opportunity to utilize a slower more cost-effective supply chain process, and the negative values on the left show where products could have been expedited in order to meet sales plans. The objective of our model is to adjust these lead times so that more products will fall within the acceptable DC dwell time range of zero to seven days.

Model

After identifying data that appeared to be correlated with the dwell time, we first built a standard linear regression model. This model had very limited success in predicting dwell time. We then attempted to use an ordered-probit regression model, which we thought would be more effective because it does not predict an exact value but instead predicts the probability that a value will fall within a given range. This seemed appropriate for our application since we wanted to identify products that could be early, on-time, or late. Again, we did not have much success in predicting dwell times. However, these models did confirm the correlation of certain variables which we were able to use in our next and final model.

Using the variables that showed a strong correlation with the dwell time, we developed a neural network model. The model consists of one hidden layer, 10 neurons and one output layer. The model starts by initializing a weight vector to calculate the initial predicted value. The predicted value is then compared to the actual value to calculate the error term. The weight vector is then adjusted by using the back-propagation method until the error is minimized.

After training and validating the model, we tested the model performance using one year of actual data and found that our model has very robust forecasting performance and overall fitness that is consistently above 90%. Figure 2
demonstrates the model’s fitness and forecasting accuracy for predicting 100 PO’s dwell time.

Based on the predicted dwell time, we can then segment the purchase orders into three categories:

- Late Shipments (dwell time <= -21 days)
- On-time Shipment (dwell time >-21 days and <= 0 days)
- Early Shipment (dwell time > 0 days)

For each of the three categories, a different supply chain speed can be applied in order to optimize the on-time delivery performance.

**Conclusions**

Even with constantly changing suppliers and products, we were able to identify PO attributes that could be used to predict how much time our sponsor company has to get a product from origin to destination. In test simulations, these predictions were able to improve on-time performance from 36% to 60%. Additionally, no products arrived late and the products that did not arrive on time were less than ten days early.

The predictive capability of our model will allow the sponsor company to reduce transportation and holding costs because they will know when they have time to ship products slower or hold them at origin. They will also be aware of products that need to be expedited, allowing them to meet their sales plans more consistently and potentially increase total sales.

Another advantage of the neural network model is that it can be updated automatically as new data is loaded into it. This means that the sponsor company can continue to use this model without repeating this entire process.
Figure 3: Actual on-time performance and on-time performance that can be achieved using model to adjust lead time
Additional 2014 SCM Theses

New Product Forecasting in Volatile Markets
by Alexander Baldwin and Jaesung Shin
Rapid innovation leads to products with demand patterns that could differ greatly from prior generations. In such instances, forecasting techniques that rely more on judgment and naïve expectations are commonly used. The shape and volatility of the demand trend in volatile-market products were tested using sample data from a partner firm. Significant differences were found in skew and variance over the life cycle, presenting an opportunity for supply chain stakeholders to incorporate life cycle effects into forecasting models.

Strategy for Direct to Store Delivery
by Amit Panditrao and Kishore Adiraju
Many grocery retailers embrace Direct to Store Delivery (DTS) as an effective replenishment strategy. This project examined the effect of DTS on the supply chain and suggested ways to curtail transportation cost, manage inventory better and improve collaboration between manufacturers and retailers. Using simulation models developed for Niagara Bottling LLC, it was noted that the manufacturer’s transportation cost increased by 42% under DTS and the total safety stock in the supply chain reduced by 26%.

A Root Cause Analysis of Stock-outs in the Pharmaceutical Industry
by Xuewen (Benny) Sun and Bangqi Yin
A large pharmaceutical company suspected that manufacturing quality defects were causing stock-outs, reducing the production yield and preventing the company from meeting customer demand. This research examined the stock-outs using a customized Root Cause Analysis model and revealed that, instead of manufacturing quality defects, regulatory issues were a major cause for stock-outs. Regulatory challenges associated with developments such as new product launches and formulation modifications need to be addressed to reduce stock-out levels.

Visualizing and Quantifying Global Supply Chain Risk
by Ranjana Mary Ninan and Christopher Sean Wang
The objective of our thesis is to demonstrate a technique to 1) visualize the supply chain and, 2) quantify areas of risk pertaining to natural disasters. By obtaining internal data on suppliers, parts, links, and revenues from our sponsor company, we aim to highlight the areas in the supply chain that have the greatest vulnerabilities. Ultimately, our goal is to help executives effectively manage their supplier base and ensure business continuity.

Tie Inspection Model at a Class 1 Railroad
by Alireza Sarmadi Rad and Juan Carlos Gomez Vidrios
This research analyzed a large railroad’s tie inspection model to determine the impact of factors in driving their prioritization of tie replacement projects, and compare the results of their semi-manual inspection process with their newly integrated automated inspection system. Sensitivity analyses were run to analyze the impact of the 14 factors used to prioritize the replacement projects. It was determined that 6 of those factors are enough and key to accurately drive the model.

The Exploration of Attributes Aligning Supply Chain Strategy & Resilience Execution
by Alexander Cope and Liqing Yuan
This research characterizes the resilience of an organization by quantifying differences between executive strategy and tactical execution. Hierarchical, functional and geographical segments are analyzed across the manufacturing and supply chain organizations of a multinational agriculture chemicals company. Results demonstrate a 7% difference in responses between strategic and tactical roles, uncovering opportunities to increase alignment by evolving management practices and decision making processes. The findings suggest that there is no common “blueprint” of a resilient employee.

Impact of 3D Printing on Global Supply Chains by 2020
by Varun Bhasin & Muhammad Raheel Bodla
A model was developed for comparing the current total supply chain processes and costs with the future total supply chain processes and costs after the adoption of 3D Printing. The analyses suggest that 3D Printing will reduce the total supply chains cost by 50-90% as production will move from make-to-stock in offshore/low-cost locations to make-on-demand closer to the final customer with major reductions coming from transportation and inventory costs.
Carrier Strategies in the Spot Trucking Market
by Paul Jeffrey R. Leopando and Kyle A.C. Rocca
A simulation model was created and alternative strategies were tested for carriers to choose freight in the spot market. Strategies that enhanced revenues earned and utilization achieved were identified. These strategies produce improvements in average revenue per mile of up to 16% over the performance of current actual carriers. Our findings can be used to improve the operating procedures of the key stakeholders in the spot trucking market: shippers, carriers, and freight brokers.

Segmentation Strategies in Urban Retail: An Application to Nanostores in Bogotá
by Xiaodan Pan
This study analyzes two product segmentation strategies in the nanostore retail market with a pilot company in Bogota, Colombia. The work illustrates how one of the strategies (precision segmentation based on diffusion mapping) can be applied in assortment planning and identify more valuable products for the pilot company. Since product diffusion is key in the nanostore market, using the precision strategy helps the pilot company best improve the diffusion of those valuable products.

A Joint Inventory and Sourcing Strategy to Balance Efficiency versus Risk
by Wan-Yu Huang and Jierui Liu
This research seeks the right strategy to mitigate the risk of supplier disruption while maintaining supply chain efficiency for medical device company. By comparing the impact on the ROA ratios, the authors prove that in this industry holding additional inventory is generally a better strategy than establishing a second source to reduce the possible risk of supplier disruption. The research also shows which key factors influence the strategy for each SKU.

Business Continuity Planning for a U.S. Supply Chain
by Arthur Chee and Tzu-Hsueh Lee
A quantitative business impact analysis of four scenarios of downstream distribution network disruption highlighted the importance of a short time to recovery (TTR). However the financial impact of carrying large amounts of high-valued inventory as a hedge against disruption is also significant. Qualitative information from industry participants in the study highlighted the importance of tailoring continuity plans to the unique supply chain needs of an organization.

Statistical and Causal Analysis of Inbound Supply Chain Inefficiencies
by Tyler Haley and Hossein Nasseri
This project helped CVS/pharmacy design operational improvements across its inbound supply chain to minimize the number of non-value-added activities. Statistical sampling, statistical process control models and root cause analysis were used to develop a complete procedure for continuous evaluation and improvement. Once implemented this innovative approach to perfect order performance measurement will lead to efficiency gains and cost savings across the entire inbound supply chain.

How to Identify Leading Indicators for Scenario Monitoring
by Xia Xu
This research develops a systematic quantitative approach to identifying potential leading indicators for scenario monitoring. This approach calculates the correlation between various datasets from public databases, identifying, screening then consolidating the key driving forces of particular business scenarios. This process, in concert with a thorough qualitative assessment by business leader practitioners, enables an effective practice of scenario planning. This approach allows a business to adapt its strategic long term plans in a constantly shifting global environment.