2007 MLOG RESEARCH JOURNAL

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www.mit.edu/mlog/research
Introduction

Welcome to the 2007 Master of Engineering in Logistics (MLOG) Research Journal!

The seven papers included in this journal were selected from the 23 theses submitted by the MLOG Class of 2007 at the Massachusetts Institute of Technology. The articles are written as executive summaries and intended for a more business than academic audience. The purpose of the executive summaries is to give the reader a sense of the business problem being addressed, the methods used to analyze the problem, and the relevant results and conclusions. The complete theses are, of course, much more detailed and are available upon request. A complete list of this year’s MLOG theses is at the end of this journal.

The articles included in this publication represent a wide selection of interests, approaches, and industries. The seven articles explore how companies deal with supply chain disruptions, examine how statistical process control can be used to reduce the bullwhip effect, quantify the benefits to retailers and manufacturers for collaborating on promotions, develop heuristics to improve production planning, measure the differential impacts of reducing lead time or delivery frequency, incorporate demand and supply uncertainty into supply chain planning, and create a framework for how different types of private companies can contribute in response to a humanitarian disaster. Indeed, one of the hallmarks of the MIT MLOG program is the ability for students to focus their course work and their research on the topics that most interest them.

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

I hope you enjoy the articles. If you want access to the entire thesis, just let me know and I can make it available to you. Also, if you wish to discuss any other aspect of the MLOG program or wish to find out how your company can interact with MLOG students, please do not hesitate to contact me directly.

Happy reading!

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Inventory Segmentation and Production Planning for Chemical Manufacturing

By Shardul Phadnis
Thesis Advisor: Steve Graves

Summary: This project developed a two-stage production planning heuristic for a specialty chemical manufacturer. Utilizing a power-of-two policy, the heuristic finds a solution that is within 6% of the optimal plan but that is much easier than conventional approaches to implement operationally. This paper thesis was awarded the Outstanding MLOG Thesis prize for 2007.

Shardul Phadnis is a PhD candidate in MIT’s Engineering Systems Division. Prior to MLOG, Shardul was the Director of Continuous Improvement at idX-Baltimore.

KEY INSIGHTS
1. Manufacturers often need to adopt a mix of make-to-order and make-to-stock policies for different products in their portfolio.
2. Make-to-stock policies work best for items with regular demand while make-to-order is better suited to items with sporadic demand.
3. Use of a power-of-two policy when establishing planning periods simplifies operations and is guaranteed to keep costs within 6% of optimality.

Introduction

In today’s competitive marketplace, manufacturers are compelled to offer a wide range of products to satisfy customers, who want them at short lead times and low prices. A manufacturer may adopt either a make-to-order policy and produce items based on actual customer orders, or a make-to-stock policy and produce items to build a finished goods inventory and fulfill demand from there. Both policies have advantages and limitations.

In the make-to-order production environment, a manufacturer benefits from producing items based on actual demand and hence needs to hold no or little finished goods inventory. Thus, inventory carrying costs and risk of inventory obsolescence are low. But, this type of environment has three limitations. First, it ties utilization of manufacturing capacity directly to variability in customer demand, which can create large swings in capacity utilization from one period to another. Second, it may increase setup costs, especially when some products are ordered regularly but still produced in separate lots for each order. This is an important consideration when costs of changing over production from one product to another are high. Third, it has longer lead time, since products are made for each order and not shipped from an existing finished goods inventory.

If the manufacturer has regular demand for its products, it may adopt a make-to-stock system to produce them in larger batches – instead of producing for each order separately – and fulfill demand from the finished goods inventory. This system does not have the three limitations of the make-to-order production system: a manufacturer can plan production to level the load on its production capacity, produce items in optimal “economic production quantities” (EPQ) to minimize total cost of setup changeover and holding inventory, and provide short lead times by fulfilling demand from products already in stock. But, a limitation of the make-to-stock production environment is that the manufacturer has to base the production decisions on a forecast instead of actual demand. The accuracy of forecasts may vary widely, with high accuracy for items with steady demand and low accuracy for items with irregular demand. As the variety of SKU’s offered by a manufacturer increases, the demand of individual SKU’s may become less regular, making their forecasts less accurate.

Given their respective advantages and limitations, a manufacturer may plan for a combination of make-to-stock and make-to-order production, the former for items with regular demand and the latter for items with sporadic demand. A manufacturer thus needs to determine which items should be made-to-stock and which should be made-to-order, and
then determine how items in each category will be produced.

**Inventory and Production Planning**

One way of developing production plans for the make-to-stock items is to calculate the economic production quantity and period for each item, which minimize the total setup and inventory holding cost, and then determine safety stock level using a stochastic-demand model. But, single-item stochastic-demand inventory models, such as “min-max policy” or “base-stock policy,” are inadequate for a multi-item production environment, because they do not account for the capacity constraint. For instance, using a min-max policy to schedule production of multiple items may lead to situations where more than one item needs to be produced simultaneously at a production facility that can produce only one item at a time. Similarly, using a base-stock policy could generate schedules where amount of production needed in some periods is greater than the available capacity. Thus, for making joint inventory and production planning decisions, one needs to solve a single-processor multi-item planning problem known as the Economic Lot Scheduling Problem (ELSP). This problem has been studied for about 50 years and shown to be NP-hard. So, it is hard to find the optimal solution, and one has to rely on a heuristic to find good solutions.

Production of make-to-order items can be planned only when an actual order is received. So, for such items, the manufacturer needs to decide how much capacity should be reserved in each production period and what lead time should be quoted for each item.

Finally, the production plans for make-to-stock and make-to-order items need to be combined to form a cohesive schedule that provides the desired level of customer service at the lowest cost without violating any capacity and technology constraints. I faced these questions while developing production planning policies for a chemical manufacturer.

**Industry Case**

The manufacturer I worked with produces several variations of an interlayer film used in automotive glass. Each SKU is differentiated by six characteristics of the film: adhesive, color, width, length, width of colored band, and roll orientation. All variations are produced on a continuous-production line that can make at most two SKU’s with the same adhesive and color at a time. Changing the line from production of one item to another incurs setup changeover cost, which varies linearly with changeover time, and storage of items in inventory incurs holding costs. Changeover times are very high (up to 10 hours) for switching production from an SKU of one adhesive-color combination to another, compared to an SKU using the same adhesive and color (1 to 15 minutes). Production of multiple items needs to be planned such that the total setup and inventory holding costs are minimized. The goal for my work was to develop a production planning method that can guarantee at least 95% availability of the finished goods at the lowest cost.

**The Two-Part Solution**

The solution consisted of two parts. In the first part, I developed a generic heuristic to solve the Economic Lot Scheduling Problem (ELSP). In the second part, I provided a solution to the specific case of the manufacturer. This involved segmenting inventory into product groups, applying the ELSP heuristic to develop production plans for product groups, testing the effectiveness of plans using simulation, and generating an SKU schedule based on the product group schedule.

**Solution Part-1: ELSP Heuristic**

The heuristic begins with some simplifying assumptions and gradually refines the solution for the actual nature of the problem. The first simplification uses the single-item economic production quantity model to determine eco-
The optimal period can be a non-integer number (e.g. 8.34 days), whereas in practice the period needs to be an integer multiple of some basic period (e.g. day or week). But, using a non-optimal period increases the cost of the solution, and one needs to know how significant this increase is. Developments in the Inventory Theory in the last two decades have shown that the worst-case cost of a solution that uses the best power-of-two (e.g. 1, 2, 4, 8…) as the production period for an item instead of its optimal period is at most 6% greater than the cost of the optimal solution. Such a policy is known as a power-of-two policy.

Figure 1 shows how the best power-of-two period is chosen. In the figure, the optimal period is approximately 11.2 weeks. The cost curve shows that the cost for an 8-week period is lower than that for a 16-week period. Hence, 8 weeks is the best power-of-two period for this item, and the total cost based on an 8-week production period is at most 1.06 times the cost of the optimal solution.

After finding its best power-of-two production period, each item is assigned to different periods in the production cycle such that the load on production capacity in different periods is balanced. Length of the planning cycle is determined in advance and is also a power-of-two multiple of the basic period. Table 1 shows an example of this, as applied to the chemical manufacturer, where products P01 to P53 are assigned to 16 periods.

Figure 2 shows the effect of balancing load on capacity: the thick red line represents capacity available at the plant, the dashed blue line shows the capacity needed in
each period without balancing the load, and the thin black line shows the capacity required after balancing the load.

Leveling the load on production capacity by assigning products to various periods ensures that the production plans developed for individual items are feasible in the multi-item production environment. Next, the heuristic calculates safety stock for each item based on variability in demand over the production period for that item. Adding the safety stock to the optimal production quantity provides the base stock level for each item. The production period and base stock for an item together define the (R, S) base-stock policy for that item. Individual item base-stock policies along with the assignment of items to periods in the production planning cycle define the production plan for the company. The plan developed for the chemical manufacturer using this procedure is shown in Table 2.

Solution Part-2: Application to the Company and Simulation

In the second part, production planning policies are developed for the company using the heuristic. This begins with forming product groups for the SKU’s manufactured. The cost of switching production between SKU’s with different adhesive-color combinations is many times greater than that for SKU’s using the same adhesive and color. Therefore, adhesive-color combination is used to define a product group. There are 21 such groups, named P01 to P53 and shown in tables 1 and 2. A production plan is then developed for these product groups. The results from this application are shown in tables 1, 2, and Figure 2.

The effectiveness of these plans is then tested under stochastic demand using simulation. The results of the simulation showed that the average availability of the material was 98.3% and ranged between 95% and 100% for individual items, thus satisfying the minimum availability requirement. The capacity required was less than the available capacity in 99.87% of the periods.

The production plan shown in Table 2 is for product groups, and the next step is to generate an SKU schedule from it. To accomplish this, SKU’s are segmented into make-to-stock and make-to-order categories. A regular schedule is developed for the make-to-stock items as shown in Table 2. Product groups are formed for the make-to-order items and instead of scheduling their production, only capacity is reserved for each product group. When actual demand for a make-to-order item is known, it is produced in the period in which capacity is reserved for the product group to which it belongs.

Conclusion

This work presents a heuristic for scheduling a complex production system, where inventory planning and production scheduling problems need to be solved together. The cost of the solution is within 6% of the optimal cost. The method is applied to develop production plans for a chemical manufacturer. Simulation experiment shows that the plans satisfy the capacity constraint and meet the manufacturer’s customer service requirements.
Strategies for an Integrated US Industry Response to a Humanitarian Disaster

By Sheau-Kai Lam & Vanessa Melofchik
Thesis Advisor: Edgar Blanco

Summary: The private sector’s well-orchestrated response to the devastation caused by Hurricane Katrina demonstrated that commercial organizations can play an important role in humanitarian aid. This project, through in-depth case studies, explores how different types of organizations can work together to improve overall response in disaster situations.

Introduction

Our research developed strategies to improve coordination between private businesses, relief agencies, and the government in order to deliver more effective disaster relief within the United States during major national disasters. “Major disasters” are defined as events sufficiently large in scale and impact to overwhelm local response capacity and resources. Our study, confined to the United States, uses the Hurricane Katrina disaster for insights and lessons learned. Based on research in literature, interviews, and case studies, we developed a framework for effective partnerships between private corporations, NGOs, and relief organizations that would strengthen disaster relief efforts. We also developed recommendations for initiatives to enhance disaster relief supply chains.

KEY INSIGHTS:

1. A private company’s ability to contribute to disaster response is dependent on two components: a) consumer reach – its physical ability to deliver product to end users, and b) supply chain autonomy - the amount of control it has over its end-to-end supply chain.
2. Companies should partner with complementary firms to improve their response efforts.
3. Partnerships between private corporations and relief organizations should be developed prior to the event.

Strengths of Industry Supply Chains in Disaster Relief

The scale of private corporations’ contribution to the Hurricane Katrina relief efforts has been unprecedented. Louisiana’s Department of Social Services records, tabulated below, show that as of October 5, 2005, private entities, parish governments, and faith-based and nonprofit organizations were sheltering almost as many people as the American Red Cross but in almost four times as many shelters. The bulk of resources that sustained these relief efforts came from private corporations.

For 2005 hurricane relief, total donations from Business Roundtable members amounted to $362 million, of which

<table>
<thead>
<tr>
<th>Organization</th>
<th>Shelters Provided</th>
<th>Number of Evacuees Housed</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Churches and Faith-based organization</td>
<td>123</td>
<td>5,780</td>
</tr>
<tr>
<td>B. Non-profit, Private entities or Parish Gov’t</td>
<td>62</td>
<td>6,733</td>
</tr>
<tr>
<td>Subtotal (A+B)</td>
<td>185</td>
<td>12,513</td>
</tr>
<tr>
<td>American Red Cross</td>
<td>55</td>
<td>13,617</td>
</tr>
<tr>
<td>Total</td>
<td>240</td>
<td>26,130</td>
</tr>
</tbody>
</table>

Table 1: Number of Shelters and Evacuees housed by various organizations in Louisiana as of October 5, 2005; Source: Weathering the Storm: The Role of Local Nonprofits in the Hurricane Katrina Relief Effort by Tony Pipa, Aspen Institute, 2006
which approximately a third was in kind and the remaining two-thirds in cash. These statistics demonstrate the capacity, capability, and will of U.S. industry to undertake a role in disaster response and relief. Our case studies also revealed intangible contributions from private corporation’s relief efforts. Wal-Mart’s reach into the suburban areas and its large inventory made it exceptionally effective in providing relief to the pockets of small parishes for which federal and state agencies failed to provide. CVS deployed mobile pharmacies at the Astrodome with 20 pharmacists on short notice, when federal medical teams deployed mobile pharmacies at the Astrodome with 20 pharmacists on short notice, when federal medical teams turned to up. They dispensed more than 20,000 prescriptions for 7,000 evacuees – of which 90% were filled in the first 72 hours. Dunkin’ Brands was able to establish a supply chain to Chef John Folse & Company to sustain “hot meal” runs for hurricane victims. They transported about 500,000 pounds of food products through this channel. All of these examples attest that private corporations can complement government relief efforts and form effective public-private partnerships for disaster relief.

**Summary of Findings**

We completed ten case studies on private businesses, relief agencies, and supporting organizations that participated in the Hurricane Katrina relief efforts. Table 2 summarizes the key findings of each case study. The table outlines the strengths and weaknesses of each organization, and improvements that need to be made in disaster relief:

Through these case studies, we identified the following

<table>
<thead>
<tr>
<th>What helped them succeed</th>
<th>Relief Organizations</th>
<th>Industry</th>
<th>Supporting Organizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local Presence or Contacts</td>
<td>Yes – Local Charities / Faith-based Org</td>
<td>Yes – McDonald’s</td>
<td>ALAN</td>
</tr>
<tr>
<td>Extensive Distribution Network</td>
<td>Yes – Foodbank Network</td>
<td>Not in Southern States</td>
<td>A2H</td>
</tr>
<tr>
<td>Pre-Staging / Inventory</td>
<td>Yes</td>
<td>Yes</td>
<td>NA</td>
</tr>
<tr>
<td>Business Continuity</td>
<td>Yes</td>
<td>Yes</td>
<td>NA</td>
</tr>
<tr>
<td>Innovative Solution</td>
<td>Yes - Mobile Trucks</td>
<td>Yes - Mobile Kitchens</td>
<td>Yes - Mini Wal-Mart &amp; Express</td>
</tr>
<tr>
<td>Collaboration within Industry &amp; with Partners</td>
<td>Yes but not enough</td>
<td>Yes - Chef John Folse</td>
<td>Agree</td>
</tr>
<tr>
<td>Local Store Owners Empowered to make Donations</td>
<td>NA</td>
<td>Yes - Chef John Folse</td>
<td>Agree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Problems they encountered</th>
<th>Relief Organizations</th>
<th>Industry</th>
<th>Supporting Organizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of Demand Visibility</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
<tr>
<td>Lack of Supply Chain Visibility</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
<tr>
<td>Poor Communications</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
<tr>
<td>Poor Coordination / Bureaucracy</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
<tr>
<td>Lack of Transportation</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
<tr>
<td>Lack of Storage</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
<tr>
<td>Outdated IT Systems</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
<tr>
<td>Handling Donations</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes – Damaged by hurricane</td>
</tr>
</tbody>
</table>

**Table 2: Case Study Findings Summary**

ARC – American Red Cross, A2H – American Second Harvest, ALAN – American Logistics Aid Network
seven initiatives to enhance the U.S. industry’s ability to participate effectively in major disaster relief operations:

1. Improve humanitarian IT systems and networks.
2. Provide tax break legislation for donated transportation capacity.
3. Increase the amount of pre-staged goods to include inventory stocking in retail outlets in-situ.
4. Create back-up communication methods for disaster relief.
5. Enhance education about disaster relief methods.
6. Establish pre-arranged agreements for donations before a disaster strikes.
7. Conduct emergency scenario training and drills.

In addition to these initiatives, further analysis of our case study findings reveals that a private company’s ability to contribute to disaster response can be attributed to two components. First is consumer reach, which is the company’s physical ability to reach out to consumers. The retail outlet that sells products or provides services to consumers directly is the basic building block of consumer reach. The growing trends in corporate social responsibility amongst companies and the physical density and geographical coverage of retail networks have a positive effect on a corporation’s ability to contribute during a disaster. For example, McDonald’s high store density in New York City is now being incorporated as part of New York City’s emergency vaccination plan against an avian flu pandemic. Second, a company’s supply chain, the sustaining power of its business, is the “lifeblood” of humanitarian aid. The greater the control a company has over its supply chain, the more it is able to commit resources to sustain the flow of aid. Sustaining the flow of aid includes setting aside storage space in distribution centers or warehouses and freeing up transportation capacity for disaster relief. For example, SYSCO was able to muster transport resources from its carriers to make a run to its warehouse facilities in New Orleans and distribute its food inventories to the American Red Cross and Chef John Folse & Company.

Framework for Classification: The ‘Giving’ Strategy

Our case studies led us to develop a “Supply Chain Control – Consumer / Beneficiary Reach” matrix that provides a framework to correlate a business or NGO’s supply chain strengths to the optimum type of contribution they can make in a disaster relief effort (Figure 1). It classifies corporations and NGOs into four quadrants of different roles they play and the different levels of effectiveness they have in disaster relief. The quadrants range from organizations with a limited ability to provide sustainable or immediate aid for disaster relief, to organizations that can be termed “1st Responders” and are highly effective and autonomous in providing large-scale relief.

Figure 2 below maps the private corporations we studied into the framework matrix. Wal-Mart, CVS and McDonald’s fall into the H-H category as they have substantial consumer reach due to their large retail network, and they have high control over their supply chains. SYSCO, on the other hand, is in the H-L quadrant as it has a nationwide network of warehouses and the nation’s largest private transportation fleet. Chef John Folse & Company, a Louisiana-based food manufacturer with few retail outlets, falls in the L-L category. Dunkin’ Brands, in this instance, is considered low on consumer reach as it has relatively few retail outlets in the southern states.

This gave us an additional insight that a company’s business strategy varies in different regions due to varying concentrations of its retail network. As such, the ability to contribute is not uniform but varies according to the geographical context of its retail network. When the same framework is applied to NGOs, relief agencies, charities, and faith-based organizations, we obtain similar insights as illustrated in figure 3. ARC and the Salvation Army are well-resourced NGOs that are effective as first respond-
ers; A2H, a large food bank network, is a good source of aid; and the faith-based organizations and local charities are most apt at distributing aid to hurricane victims but depend on others to sustain their operations.

This matrix framework does not, however, mean that companies that fall under a “more limited” quadrant will be less successful or less effective in contributing towards a disaster relief, although its effectiveness will be limited, if it contributes alone. On the contrary, they can be effective contributors through properly identified partnerships with other corporations or NGOs that have complementary Supply Chain Control – Consumer / Beneficiary Reach attributes. Figure 4 describes the partnership strategies we recommend based on the roles and attributes that were identified for each of the matrix quadrants to maximize disaster relief contribution effectiveness.

For example, A2H, who is low on Supply Chain Control and low on Beneficiary Reach, would benefit from a tripartite partnership with L-H and H-L organizations. Our case study reveals that A2H achieved substantial local reach through local faith-based organizations and charities and was able to sustain its food aid flow through its corporate partners, such as Dunkin’ Brands.

Framework in Action

Our case studies reveal that the right partnerships, such as those observed between Chef John Folse & Company, Dunkin’ Brands, SYSCO, A2H food banks, faith-based organizations, and local charities were effective to provide the right relief to hurricane victims. The strong network of A2H with faith-based organizations and local charities, sustained by corporate donors, is another example of a highly effective partnership, which eventually delivered about 82 million pounds of food aid, the equivalent of 64 million meals, to Hurricane Katrina victims.

Therefore, when searching for the right partners, private corporations need to look deeper and understand how deep and extensive the NGO, relief organization, and charity network is, and assess it based on an integrated end-to-end donations chain. Private corporations should also be cognizant of the local context of their supply chains, because corporations have different market strategies and, as such, have varying degrees of market presence in different regions. Adapting a different “giving” strategy according to the localized supply chain makes perfect sense.

Partnerships should also be developed early, as it assures the partnered NGO or relief organization a certainty of its source of support and, at the same time, provides the donor an assured donations channel that is in line with its corporate responsibility philosophy. Greater operational ease will also be achieved with better response performance during disasters. The “giving” strategy would be more effective, if companies contribute their core competency and collaborate within their industry for better alignment and collaboration. This was observed clearly in CVS’s experience, when they operated under an integrated drug response chain that incorporated federal agencies, all national pharmacy chains, and regional and local pharmacies to meet the needs of the hurricane victims.

Conclusion

In humanitarian disasters, logistics play a dominant role in providing relief. Our research demonstrates that a partnership framework built on supply chain attributes is the most compelling approach to effective corporate contributions toward disaster relief. The seven initiatives we propose will take time to materialize, but private-public partnerships can start today and put private corporations, NGOs, relief agencies, charities and faith-based organizations in good stead to face the challenges of another major disaster when it occurs.
Improving Promotional Effectiveness through Supplier-Retailer Collaboration

By Gautum Kapur and Bin Liu
Thesis Advisor: Larry Lapide

Summary: This paper quantifies the benefits of coordinating promotions between a manufacturer and a retailer. Through the use of a multi-item newsvendor model with a budget constraint, the authors estimated the potential profit improvements for various levels of collaboration. Additionally, they demonstrate how to estimate the potential value of lost sales within a promotional event.

Introduction

In the consumer product goods industry, suppliers and retailers use promotions to maintain consumer and brand loyalty. While promotions attract consumers to the store, positive in-store experience and product availability are necessary to win the consumer. According to a Shoppers Research Study conducted by Gruen, Corsten and Bharadwaj (2002), on average, when retailers face an out-of-stock, suppliers incur lost sales 28% of the time, while retailers lose the sale 41% of the time. For heavily promoted products, out-of-stocks are driven by challenges in determining the appropriate budget and product quantities due to misaligned objectives and limited collaboration between suppliers and retailers.

We researched how a supplier and retailer can better collaborate on the promotions planning process, as well as optimize inventory and service levels to improve sales and profits. We looked at three areas to understand how to improve promotions collaboration. At the strategic level, “Collaborative Planning, Forecasting and Replenishment” was researched to define a process to mutually plan and execute promotions. At an operational level, spreadsheet models were developed to optimize profit or sales for a targeted service level. The model was based on the single period, multi-item newsvendor concept with a budget constraint. Thirdly, the concept of Supply Contracts was also researched to identify some ways to optimize the whole supply chain rather than just the retailer’s. Our research is based on a case study of SupplierCo, a leading consumer product goods manufacturer, and RetailerCo, a leading pharmacy retailer.

In this paper, we first describe the promotions planning and execution processes. Next, we discuss our analysis and results of the profit maximization and revenue maximization models, as well as our analysis of out-of-stocks at the store level. Finally, we summarize our recommendations.

KEY INSIGHTS:

1. Retailers and suppliers can improve overall profitability by optimizing the entire supply chain, as opposed to optimizing just their own end of the supply chain.
2. The selection of products to promote can be made by utilizing a multi-item newsvendor model with a budget constraint.
3. The value of out-of-stocks during a promotion can help store managers evaluate the trade-off between placing an emergency replenishment order during a promotion versus lost sales dollars.
Promotions Planning and Execution Process

In our research, we performed a benchmark of Collaborative Planning, Forecasting and Replenishment (CPFR) standards against the existing promotions planning and execution processes at SupplierCo and RetailerCo. The Voluntary Interindustry Commerce Solutions Association (VICS) defines CPFR as, “a business practice that...

<table>
<thead>
<tr>
<th>Phase</th>
<th>To Be Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategy and Planning</td>
<td>• Define detailed process for information sharing during promotions</td>
</tr>
<tr>
<td></td>
<td>• Define clear roles and responsibilities for promotions, which includes a key</td>
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<tr>
<td></td>
<td>stakeholder from SupplierCo and RetailerCo accountable for promotional planning</td>
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<td></td>
<td>and execution</td>
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<tr>
<td></td>
<td>• Create product profiles across product categories</td>
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<td></td>
<td>• Align promotion resources (e.g. budget) between SupplierCo and RetailerCo</td>
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<tr>
<td></td>
<td>• Collaboratively define promotions event calendar</td>
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<td></td>
<td>• Define short term and long term strategic initiatives to improve promotional</td>
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<td></td>
<td>performance</td>
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<tr>
<td>Demand and Supply</td>
<td>• Share event sales forecast estimates</td>
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<tr>
<td>Management</td>
<td>• Gather promotions data</td>
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<td></td>
<td>• Collaborate on aggregate and SKU/Store level forecast</td>
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<td></td>
<td>• Execute the optimization model to define budget and inventory allocations to</td>
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<td></td>
<td>products</td>
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<tr>
<td></td>
<td>• Collaboratively determine aggregate dollar amount for each promotion</td>
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<td></td>
<td>• Communicate updates of promotions details</td>
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<tr>
<td>Execution</td>
<td>• Place promotions order</td>
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<td></td>
<td>• Deliver promotions quantities to DC</td>
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<tr>
<td></td>
<td>• Monitor store inventory and sales performance during the event</td>
</tr>
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<td></td>
<td>• Maintain Scorecard for Out-of-Stock at store, DC level</td>
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<tr>
<td>Analysis</td>
<td>• Provide emergency shipments to stores which run out of inventory early in the</td>
</tr>
<tr>
<td></td>
<td>promotion</td>
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<td></td>
<td>• Collaboratively Perform post event analysis of promotions through weekly meetings</td>
</tr>
<tr>
<td></td>
<td>• Define recommendations to improve promotions process</td>
</tr>
</tbody>
</table>

Table 1: To-Be Promotions Planning and Execution Process

combines the intelligence of multiple trading partners in the planning and fulfillment of customer demand.” The primary objective of CPFR is to increase product availability, while reducing inventory, transportation, and other logistics costs.

Based on our CPFR literature review, we found that SupplierCo and RetailerCo’s existing processes were aligned to the Retail Event Synchronization standard published by the VICS committee, which focuses on the communication aspects of collaboration. A “to-be” promotions planning and execution process was recommended, which includes collaborative execution and decision making, in addition to the communication aspects. This process aligned with the Retail Event Collaboration standard, also published by the VICS committee. Table 1 describes our recommended activities for the promotions planning and execution process.

Analysis and Results

We first analyzed the promotional SKU’s demand pattern. This was used as an input into the optimization model, which maximized profit or revenue under a budget constraint based on the multi-item newsboy approach. The key outputs of the model were the optimal budget and order quantities. Finally, we conducted store level analysis to estimate lost sales during a promotion to enable store managers to decide whether an emergency replenishment should be made to address an out-of-stock.

Single Period Multi-item Newsboy Model with a Budget Constraint

The single period multi-item newsboy concept with a budget constraint can be explained in the context of the decision a newspaper boy needs to make everyday. Let us assume that the newspaper boy has a budget of $150 and needs to decide how many Wall Street Journal and New York Times newspapers to order for the next day to gain maximum profits. This is a single period decision, since the newspaper becomes out-of-date within one day and has a very low salvage value at that point. The newspaper boy needs to essentially balance the cost of overage, or ordering too much, versus the cost of underage, or ordering too little. The cost of overage is the loss made on each unit by selling it at its salvage value. On the other hand, the cost of underage includes the loss of margin and customer goodwill due to out-of-stocks. Similar to the newspaper boy’s decision, SupplierCo and RetailerCo need to decide each SKU’s order quantity for a single promotional period based on a budget constraint. We developed profit maximization and revenue maximization models based on this concept. The profit maximization model was run to maximize profits for the retailer and the entire chain. The results were compared with an actual promotion, the baseline in our analysis. When only the retailer profit was maximized, compared with the baseline, the optimization model resulted in 5.9% profit improvements for the retailer and 2.8% profit improvements for the entire supply chain. However, when the entire supply chain profit was maximized compared with the baseline, the optimization model resulted in 37% profit improvements for combined supplier and retailer profit. This confirmed the findings from our literature review on Supply Contracts that retailers and suppliers can improve the profits of each party by optimizing the entire supply chain and sharing risk, as opposed to optimizing just their own end of the supply chain.

In the profit maximization model, sensitivity analysis between budget and service level (Figure 1), as well as budget and profit (Figure 2), can be used to determine the optimal budget for promotions based on a target service level. An initial increase in the budget leads to a significant increase in profit and service levels, because at this point the risk of lost sales is higher than the risk of excess inventory. Hence, ordering more leads to a higher profit. Beyond a certain point, a further increase in the budget leads to a service level of almost 100% and lower profits, because the risk of excess inventory is higher than the risk of lost sales. The revenue maximization model is used by RetailerCo, when they want to meet financial measures such as increasing their market share at
the end of a quarter or year. The results from this model show that beyond a certain budget level, the revenue will remain constant even with a budget increase. This is because a service level of 100% is achieved and additional budget would not result in any increase in sales.

At the operational level, we analyzed the demand pattern, developed profit and revenue optimization models, and created a method to estimate lost sales at the store during a promotional week. The demand pattern analysis helps determine which SKUs should be used for promotions based on the ability to forecast accurately. The profit maximization model clearly shows that maximum profits are achieved when optimizing the profit of the entire supply chain, as opposed to just the retailer’s profit. However, further research would need to be conducted to determine the right type of Supply Contract between SupplierCo and RetailerCo to share profits.

The profit maximization and revenue maximization models also show the trade-off between budget and service level, and budget and optimal profit. This is an effective decision making tool for SupplierCo and RetailerCo to determine the optimal budget and order quantities based on the goal of the promotion. Lastly, a method to estimate out-of-stocks during a promotion helps store managers evaluate the trade-off between placing an emergency replenishment order during a promotion versus lost sales dollars. The research discussed in this paper can also be applied to new product introductions, seasonality of products, and daily replenishment.

Out-of-Stocks Analysis
During a weekly promotion, if the store runs out of inventory in the middle of the week, there is a trade-off between losing the sale versus incurring costs to replenish the store with more inventories. The store manager can make this decision by estimating the potential lost sales dollars for the remaining week and comparing this with the cost of an emergency replenishment. The first step is to understand the store’s true daily demand pattern by analyzing sales at stores that do not run out of inventory. Next, the lost sales can be estimated by tracking Point of Sale data at the store level and comparing this data with the store’s daily demand pattern. Figure 3 shows an estimation of lost sales for a store, which runs out of inventory on a Friday. The emergency replenishment costs include the ordering costs and transportation costs.

Conclusions
In this research, we have addressed how to improve promotional effectiveness between a retailer and supplier at the strategic level and operational level. At the strate-
Supply Chain Disruptions: Managing Risks vs. Managing Crises

By Zen-Lee M. Chang and Garrett J. Lee
Thesis Advisor: Yossi Sheffi

Summary: This project explores how a large multi-national company handled two separate supply chain disruptions. The authors develop a framework for risk management, estimate the costs of proactive risk versus crisis management, and make recommendations on how firms can better manage these risks.

KEY INSIGHTS:
1. Crisis management should never replace risk management.
2. Supply chain risk management should be incorporated within the procurement organization.
3. Constantly monitoring critical vendors for key warning signals can provide advance notice of potential disruptions.

Introduction

SpecChem (a pseudonym), a specialty chemical company, fought its way through two back-to-back supply chain disruptions: one due to a sole-supplier bankruptcy and the other caused by Hurricane Rita. Unprepared and overwhelmed, the company resorted to managing these crises through sheer brute force and learned the hard way that managing risks is better than managing crises. To manage risk, SpecChem has sought ways to improve the firm’s supply chain readiness, resilience, and flexibility. This was the impetus for our research, where our findings, using SpecChem’s disruptions as case studies, present a repeatable four-step process to manage supply chain risks. In examining SpecChem’s disruptions, we found that managing risk is 45% cheaper than managing crisis for the company. We developed a method for SpecChem to use for managing the risk of supply chain disruptions, one which we expect may be applied to other companies.

Our Four-Step Framework

Our four-step framework to manage supply chain risks at SpecChem comprises the following:
1. Determine SpecChem’s ability to manage supply chain risks,
2. Calculate SpecChem’s opportunity cost of managing crises,
3. Identify and evaluate SpecChem’s current supply chain vulnerabilities, and
4. Assess SpecChem’s potential supply chain risks to prepare accordingly.

Step One

Proceeding through the above four steps, we first determined SpecChem’s ability to manage supply chain risks, using Pickett’s note on the six stages of risk maturity (Picket, 2006), which goes from Pickett’s first stage, the
Step Two

Next, we calculated SpecChem’s opportunity cost of firefighting its crises by studying the company’s past disruptions, specifically a sole-supplier bankruptcy and a supplier failure caused by Hurricane Rita. We then determined the factors impacting specific operations at SpecChem, such as the purchase of raw materials, the holding of raw materials, additional management hours, and additional worker hours.

Using a Risk Impact Scorecard we developed, we surveyed SpecChem’s managers involved in handling both crises and asked them to rate, on a scale of one to ten of severity, the seventeen factors we believe were most impacted by these disruptions. We then averaged the scores received from all participants and designated a factor with an average score greater than five as a critical cost driver. Employing, for example, four critical cost drivers such as raw materials purchased, raw materials inventory held, management hours spent, and worker hours accrued above the firm’s normal operating level, we discovered that SpecChem had spent $700,000 managing these crises, which cost 45% more than managing the same risks, had SpecChem had a risk-management strategy.

Step Three

Once we had established that managing risks made more economical sense than managing crises, we proceeded to identify and evaluate SpecChem’s existing supply chain vulnerabilities by focusing on examining the company’s supplier-sourcing convention. Using SpecChem’s raw material inventory data obtained from its Enterprise Resource Planning (ERP) system, we analyzed the company’s supplier structure before and after each disruption. Prior to the sole supplier’s bankruptcy, SpecChem employed one supplier that provided the firm with 99% of the key ingredient needed in its line of cement additives. Subsequently, SpecChem increased the number of vendors to three, with no supplier in a dominant position, after narrowly averting a complete supply chain disaster. As for the supplier failure caused by Hurricane Rita, we learned that several months later SpecChem had added one more vendor, increasing its number of suppliers to four, to better mitigate its supply risks for the raw material used in the company’s line of high-performance concrete chemicals.

Even though a multi-sourcing strategy has been adopted by SpecChem, it is not clear that a future crisis would be averted merely because of this approach, unless the following three conditions are also true. One, the alternate suppliers have enough combined excess capacity available to fill the raw material void that a failed supplier has left behind. Two, the alternate suppliers can produce the additional raw material required in a timely fashion. Three, this additional raw material can be purchased without an excessive premium added to the current price. Based on our discussions with SpecChem, these conditions are not necessarily met. Nonetheless, it appears that while SpecChem is still vulnerable, the company is in a better position now than it was before the disruptions.

Step Four

Finally, we assessed SpecChem’s potential supply chain risks, by scanning for disruption-based warning signals, or risk indicators, in documentations and reports written about the company’s suppliers. For instance, before the sole supplier became insolvent, SpecChem’s Purchasing Manager noted in his trip report that the vendor had requested a dramatic increase in its raw material price, admitted to unresolved matters with its worker’s union, and indicated that it would be cheaper to purchase raw material from its competitors than to produce the material itself. These alarming signals should have alerted SpecChem’s upper management and triggered an immediate response. Instead, no action was taken, leading to a series of firefighting activities two weeks later.

In addition, the company could have monitored its suppliers’ performance regularly to assess SpecChem’s potential supply chain risks and plan preventive measures accordingly. By constantly scanning and inspecting documents such as a supplier’s financial reports, public records, Moody’s Industry Review, trip reports from on-site visits, meeting summaries, and news about the supplier, SpecChem could learn about, as well as gauge, the supplier’s overall health. In SpecChem’s case, we found several risk indicators in a local newspaper of the bank-
rupt supplier’s hometown related to management change, workforce reduction, impasse with union representatives, closing of plants, and prolonged financial losses that were worth investigating. Using these warning signs as precautionary measures, managers could present clear, substantiating evidence of a potential supply chain disruption in a logical and compelling manner that captures executive management’s attention and assists the executives in constructing a sensible resolution.

Conclusion

Supply chain risk management, up to a certain level, can be cost effective, but it is by no means free. Having deep relationships with multiple suppliers, for example, is costly and more time-consuming than having an intimate relationship with only one supplier. Likewise, the cost of adding and/or switching vendors to mitigate supplier risks is expensive and depletes resources. Therefore, having the right balance of risk management in place involves a cost-benefit trade-off. Nevertheless, crisis management should never replace risk management. If applied properly, risk management cannot only save a company a lot of money but also make the difference in a company’s ability to survive. Whether or not a company is low on the risk-maturity level or has already integrated risk management into its corporate culture, our four-step process outlined above is an effective tool for helping businesses structure a more dynamic, resilient supply chain.

Cited Sources:

Statistical Process Control Approach to Reduce the Bullwhip Effect

By Harikumar Iyer and Saurabh Prasad
Thesis Advisor: Chris Caplice

Summary: This project investigates a better way of reducing the bullwhip effect within a manufacturing environment. The authors apply Statistical Process Control (SPC) methodology to the inventory management of a large medical equipment manufacturer. They find that for Class A and B items, the SPC approach can significantly reduce the bullwhip effect as well as smooth production.

KEY INSIGHTS:
1. Using Statistical Process Control (SPC) principles to manage inventory can reduce the level of the bullwhip effect.
2. The SPC approach can also lead to better production smoothing.
3. The SPC approach works best for high volume Class A items – slower moving SKUs might be better managed with a make-to-order system.

Introduction

The Bullwhip Effect causes inefficient use of resources and higher supply chain costs. These costs are due to higher inventory being stocked and transported to meet target customer service levels. Strategies to reduce the bullwhip effect and thus inventory levels include information sharing, channel alignment and improvement of operational efficiencies. These approaches are used by different firms with varying degrees of success. The continued focus on improving efficiency and reducing costs has led researchers to explore new concepts and different techniques to improve supply chain planning. This thesis applies the Statistical Process Control (SPC) principles, primarily used to monitor process variations in manufacturing, to develop an inventory management technique and assesses its impact in reducing the bullwhip effect.

This thesis addresses research and modeling to address the question as to whether the principles of SPC can be applied to manage inventory held at a distribution center, while level loading the upstream production facility in order to reduce the bullwhip effect and lower the overall supply chain costs. In a case study, this SPC approach is compared against the current inventory policies at a medical device company.

The Bullwhip Effect

Demand variability increases as we move up the supply chain. This phenomenon is called the Bullwhip Effect. Lee, Padmanabhan and Whang (1997) identify four rational factors that create the bullwhip effect:

1. Demand signal processing: When demand increases, firms order more in anticipation of further increases, thereby communicating an artificially higher level of demand.
2. The rationing game: To obviate potential shortages, firms order more than their forecast in anticipation of receiving a larger share of the items in short supply.
3. Order batching: Fixed costs at one location lead to batching of orders.

4. Manufacturer price variations: Volume based discounts encourage bulk orders.

Information sharing amongst supply chain partners, channel alignment, and improving operational efficiencies are the three broad strategies to reduce the bullwhip effect. Different approaches like fuzzy sets theory, non-linear goal programming, and integrated production-inventory models have been explored to improve the operational efficiencies.

In this thesis, the bullwhip effect is quantified in terms of the coefficient of variation of orders placed by the echelon upstream relative to the coefficient of variation of demand. The following sections describe the SPC-based inventory management system and its impact in reducing the bullwhip effect.

Statistical Process Control (SPC) based Inventory Management System

SPC offers a graphical means of monitoring a process in real-time using control charts. Process variables are typically assumed to have an underlying normal distribution. By establishing an upper and lower bound on a process, such as manufacturing, one can determine if the process is within or outside normal operating conditions.

This research examines if the inventory management technique based on SPC principles can be used within the replenishment cycle. The thought is that using a control chart to establish a statistically valid range, defined by upper and lower control limits instead of standard point replenishment, will dampen the overreactions that can cause the bullwhip effect. The periodic review or (R, S) inventory policy, where R is the length of the review period and S is the ‘up to’ order point, is modified by incorporating SPC techniques to create a system that monitors and responds to changes in demand characteristics and inventory levels.

Control charts have a center line which represents the mean of the process variable, and upper and lower control limits that represent +/- 3 standard deviations (σ). Control charts can be created for demand and inventory by treating them as process variables. In order to make the control chart adaptive, a set of outlier rules can be framed. For example, an out of control event can be signaled, if a single observation exists above +3 σ limits, if two consecutive observations exist above the +2 σ limits, or if six consecutive observations exist above the +1 σ limits. These rules are flexible and can be modified as per the discretion of the process supervisor.

![Figure 1: Relationship between demand and inventory control charts](image-url)
Since demand is the primary reason for a firm to hold inventory, the 'Demand Control' charts drive the 'Inventory Control' charts. One needs to monitor the mean and standard deviation of demand, since changes in mean demand affect cycle inventory and changes in the standard deviation of demand affect safety stock inventory. Therefore, both $\sigma$ chart (which monitors variation in process standard deviation) and $X$ chart (which monitors variation in process mean) are used for the demand control charts. Once the demand control charts are constructed, the inventory control chart can be derived. The chart is used for the inventory control chart.

To illustrate the concept, consider the demand in three states over time (Figure 1).

In state 1 of the demand control chart, demand has a particular mean and standard deviation. In state 2, the standard deviation increases due to higher variability, but the mean demand remains at same level as in state 1. Finally, in state 3, the mean demand shifts to a new level, and the standard deviation decreases. The inventory control chart shows the operating limits of the inventory process for each state of demand. From state 1 to state 2, the safety stock represented by the minimum inventory level increases due to the increase in the standard deviation of the demand process. The maximum inventory level also shifts by the increase in the safety stock. The difference between the maximum inventory level and the minimum inventory level represents the fixed order quantity of the system in this state. This fixed order quantity is purely a function of the mean demand and remains unchanged from state 1 to state 2. From state 2 to state 3, the mean demand increases and the standard deviation of demand decreases. The inventory chart responds by reducing the safety stock and increasing the fixed order quantity.

The framework for the SPC-based inventory management system is described by the flow chart in Figure 2.

Changes are made to inventory and replenishment parameters only when statistically significant demand changes occur. In this manner, the effects of demand signal processing based on speculation is minimized, and the system responsiveness is based on a set of well-defined rules. The inventory control chart is used as a feedback correction mechanism to augment orders placed by the SPC-based inventory management system, if the inventory falls below the lower control limit on the chart. In the following section, the technique is applied to a medical devices company.
Case Study: Medical Devices Company

Medical Devices Company, a leading developer and manufacturer of breakthrough products for interventional medicine, sells cardiovascular catheters to hospitals worldwide. Annual sales for the 397 SKUs of the product family are 1.5 million units. Cardiovascular catheters are in the mature phase of the product life cycle. The supply chain for cardiovascular catheters is described in Figure 3, the yellow box indicating the scope of the case study.

The lead time for the plant-distribution center echelons is 14 days. Periodic review (R,S) inventory policy with a review period of 3 days is followed for replenishment at the distribution center. There is a wide variation in annual demand of individual SKUs ranging from less than 1,000 to 200,000 units. There are a large number of SKUs that contribute to a very small percentage of the total demand for the product family and on the other hand, a few SKUs contribute to a large percentage of total demand, as shown in Figure 4.

The ABC analysis is a framework used in multi-product inventory systems, where the trade-off between the cost of controlling the system and the potential benefits that accrue from that control are assessed by firms. Based on demand volume, variability characteristics, and level of bullwhip among the SKUs, these SKUs were classified into ‘A’, ‘B’, and ‘C’ class items (Table 1).

The present level of bullwhip on an overall basis using a simple average is 1.17. However, given the wide variation in the demand of the individual SKUs, it is considered more appropriate to use the weighted average, using volume sold as the basis for measuring overall bullwhip effect. The level of bullwhip using the weighted average is 1.44. The following section summarizes the impact on bullwhip and inventory, when the SPC-based inventory system is applied to the cardiovascular catheter product family.

Results

The SPC-based inventory management system leads to the significant reduction in the level of bullwhip. On an overall basis for the cardiovascular product family, the level of bullwhip decreases by 32% from 1.17 to 0.85. By using weighted averages on the basis of demand, the level of bullwhip reduces by 61% from 1.44 to 0.56. The SPC-based inventory management system results in production smoothing as the level of bullwhip is less than 1. Along with the reduction in bullwhip, the SPC system also results in overall inventory reduction of 12.4%.
There is significant reduction of 60-75% in bullwhip on average for Class ‘A’ and ‘B’ items. This is accompanied with average inventory reduction of 11-13%, while maintaining customer service levels. However for ‘C’ class items, only two-thirds of the products show a reduction in the level of bullwhip with the SPC-based system. The one-third of the Class ‘C’ items which show an increase in bullwhip generally have very low demand (0 to 20 units per week). In addition, such items have fill rates issues due to drastic reduction in inventory of around 65% on average.

Conclusions

The SPC-based inventory management system attenuates the bullwhip effect, while reducing inventory investments and maintaining customer service levels for fast-moving Class ‘A’ and ‘B’ products that have reasonably stable demand, and where level-loading of production can provide significant cost savings. For Class ‘C’ products with sporadic demand characteristics, the authors recommend a make-to-order policy rather than a SPC-based inventory system. Such orders make the demand characteristics unpredictable and difficult to forecast. Applying the SPC methodology to manage inventory for these products would result in a nervous stocking policy with possible fill rate issues. It is recommended that fulfillment of ‘special’ orders must be managed separately in a manual process.

The methodology developed in this thesis can be configured to manage inventory for products with a variety of demand characteristics. The authors recognize that the methodology developed in this thesis has been restricted to items in the mature phase of their lifecycles with a set of predefined outlier rules. Additional research is required to explore the sensitivity of this methodology to changes in the outlier rules and its effectiveness in the launch and declines phases of the product lifecycle. Since the methodology has been applied only to medical devices, its effectiveness in reducing the bullwhip and inventory levels for products in other industries also needs to be researched.

Cited Sources:

Quantifying the Value of Reduced Lead Time and Increased Delivery Frequency

By Sean Walkenhorst
Thesis Advisor: Steve Graves

Summary: This paper examines the costs and benefits faced by a manufacturer for increasing delivery frequency versus reducing delivery lead time. Several different operational scenarios are tested to quantify the effect for a variety of different customer types.

KEY INSIGHTS:
1. The value to the customer of increased delivery frequency or reduced lead time is difficult to measure and at times is not worth the cost of doing so.
2. Increasing delivery frequency tends to provide the most significant customer inventory savings for products with high demand variability.
3. For retailers that are highly dependent on promotions for stimulating demand, there is little benefit to improving either delivery frequency or lead time.

Introduction

A large consumer package goods company that we will call SupplierCo has improved its profitability by optimizing its part of the supply chain to minimize its costs. As the company considers other options to further improve its supply chain, it has identified options that might improve the overall supply chain but would add internal costs. These costs might actually be less than the benefit to its customers; however, to see whether or not the options do improve the total supply chain, SupplierCo needs to be able to estimate the potential benefits to its customers. A change which would benefit its customers more than it would add to SupplierCo’s costs could then be pursued by negotiating with customers to adjust pricing or share costs so that all companies within the supply chain could realize some of the joint benefit.

For example, if SupplierCo built more distribution centers (DCs) around the country, then the lead time to ship products to retailers would be shorter. That shorter lead time could benefit its customers through lower inventory levels, lower handling or storage costs, or fewer out of stocks; but it would also translate into higher costs for SupplierCo. Similarly, if SupplierCo shipped more frequently to retailers, retailers could achieve lower inventory levels, lower handling or storage costs, or fewer out of stocks; but SupplierCo would incur increased freight costs. Thus, the purpose of this thesis is to evaluate the potential savings for the retailers from possible network changes that SupplierCo could implement. In particular, it addresses the question: What is the value to the customer of increased delivery frequency or reduced lead time?

Project scope

This question was studied for SupplierCo by looking at three national retailers in the United States: a mass merchandiser (MassCo), a grocery store chain (GroceryCo), and a drug store chain (DrugCo). The three retailers provide an opportunity to examine various retail channels that attract different types of customers and which are fairly representative of SupplierCo’s overall customer base. These retailers have different levels of shipment frequency and demand volumes allowing us to see the potential benefit to each type. For instance, MassCo has a high frequency of shipments from SupplierCo to its DCs, while DrugCo has only one-third to one-sixth of MassCo’s

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Lead time</th>
</tr>
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<tbody>
<tr>
<td>Big&amp;Fast</td>
<td>High</td>
</tr>
<tr>
<td>Big&amp;Slow</td>
<td>High</td>
</tr>
<tr>
<td>Small&amp;Slow</td>
<td>Low</td>
</tr>
</tbody>
</table>

Figure 1 – Products Studied

Sean Walkenhorst is currently working for Intel in Oregon as a Supply Planning Organization Benchmarking Business Analyst. Prior to MLOG, Sean worked as a Process Engineer, Operations Manager, and Silicon Systems Engineer for Intel Corporation.
frequency going to its own DCs.

Three products were chosen to focus the research: Big&Fast that ships frequently to customer DCs and has short lead times from customer order to delivery; Big&Slow that ships frequently to customer DCs but has long lead times; and Small&Slow that ships infrequently to customer DCs and has long lead times. A summary table of the attributes for these products is shown in Figure 1.

Finally, for each retailer we selected three of its DCs: one in the East, one in the Midwest, and one in the West. This will allow us to examine whether there are differences due to geography, primarily when it comes to lead time. Since SupplierCo’s distribution points are located mostly in the Midwest, shipments to the West Coast take several more days. The retailers, products, and DC locations were selected as a representative sample to reveal as much insight as possible in the time available for the project.

Methodology

Possible sources of benefit to SupplierCo’s customers could come from lower inventory levels, lower handling or storage costs, or fewer out of stocks. In talking with several supply chain managers at these companies, all agreed that the main benefit would be lower inventory levels, so the analysis focused on quantifying the amount of possible inventory reduction through various scenarios.

An analytical deterministic model was built in Excel that calculated a theoretically optimal inventory level for each product in each customer’s DC. The inputs to this model were the averages and standard deviations of demand and travel time, target service levels, frequency of shipments, current inventories, and product prices. The outputs of the model were cycle stock and safety stock for several scenarios. These inventory levels could then be compared among the various scenarios to determine which scenarios provided the greatest benefit.

The scenarios varied frequency, average lead time, or lead time variability to determine what offered the largest potential benefit for the different types of products. Some of those scenarios studied were:

1. Combining multiple product families together on the same truck to achieve a daily shipment frequency. If more products could ship together, all would ship more frequently, and the DCs would need less cycle stock of each.

2. Increasing the frequency of shipments for Big&Slow and Small&Slow by shipping these products together. Focusing frequency improvements on those products that have the most room for improvement might deliver the most value for the lowest cost.

3. Reducing lead time variability by 50%, which would reduce the need for safety stock.

4. Reducing the lead time by one day for all shipments. This could most likely be accomplished if SupplierCo were to improve its response time to orders. This could reduce the amount of safety stock needed in the DCs.

5. Limiting the lead time to no more than four days for all products and locations. This would require SupplierCo to have more inventory in more locations but could examine the potential inventory reduction at customer DCs due to all products having a short lead time.

Results and Potential Savings

Each of the five scenarios was compared to the theoretically calculated inventory level, and the percent improvement for each is shown below in Figure 2.

It can be observed that the largest potential improvement for all customers would be to increase frequency

![Figure 2 – Potential Inventory Reduction of Five Scenarios, Grouped by Customer](image-url)
Theoretical benefit of making the following changes
Lead time = order to delivery time

![Diagram showing potential savings](image)

Figure 3 – Potential Carrying Cost Savings of Five Scenarios for all Customers

Table of potential savings:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Savings (in millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing frequency to achieve daily shipments</td>
<td>$10M</td>
</tr>
<tr>
<td>Increasing frequency by shipping Big&amp;Slow &amp; Small&amp;Slow together</td>
<td>$20M</td>
</tr>
<tr>
<td>Reducing lead time variability by 50%</td>
<td>$30M</td>
</tr>
<tr>
<td>Reducing lead time by 1 day</td>
<td>$40M</td>
</tr>
<tr>
<td>Reducing lead time to 4 day max for all products &amp; locations</td>
<td>$50M</td>
</tr>
</tbody>
</table>

Best in Class potential savings are $120MM.

MassCo & SupplierCo often negotiate joint value creation that results in a 5x benefit. This may be a one time benefit (additional merchandising event) or continuous (additional SKUs) - not reflected below.

DrugCo currently won’t benefit from lead time improvements but other similar customers might.

to daily shipments. Even just combining Big&Slow and Small&Slow creates more value than improving the average lead time. However, it is interesting to note that reducing lead time variability has a large potential benefit for MassCo. This is true for the Big&Fast and Big&Slow products, which already have a relatively high frequency and stable demand. Since frequency is high, cycle stock is not a significant component of inventory. Since demand is stable, demand variability is not a significant component of safety stock. That leaves lead time variability as the largest driver of safety stock and of overall inventory.

In converting these percent improvements into dollars, several assumptions were made after consulting with several SupplierCo employees. First, it was assumed that 50% of SupplierCo’s sales went to companies like MassCo, 25% to companies like GroceryCo, and 25% to companies like DrugCo. Second, it was assumed that 20% of all sales came from products like Big&Fast, 50% from products like Big&Slow, and 30% from products like Small&Slow. This allowed us to look at total sales for SupplierCo and estimate total possible inventory savings for all customers. Multiplying these savings by a 15% inventory carrying cost gives us expected annual savings, which is shown below as Figure 3. This could then be compared with the potential costs of network changes SupplierCo could make to determine which would be most beneficial for the entire supply chain.

**Effect of Heavy Promotions**

The three customers focused on in this study had very different strategies for using promotions to generate sales, and this affects the ability of SupplierCo’s network to create value for its customers. MassCo only had about 5% of its sales come from promotions and had fairly stable demand. GroceryCo had about 40% of its sales come from promotions and saw much more variable demand.

DrugCo had about 75% of its sales come from promotions and had the highest demand variability. As a result of DrugCo’s high use of promotions, its promotional planning process drove inventory levels, and orders were submitted to SupplierCo up to two months in advance. Therefore, any changes SupplierCo could make to its network to improve its ability to respond quickly would not benefit DrugCo at all.

The heavy use of promotions also made the calculations in the model questionable since demand variability was so high. To better account for the promotional effect, demand variation could be determined from forecast errors. Since forecast data was not available, an assumption was made that demand variability would be similar to MassCo but somewhat higher because of the difficulty in accurately forecasting promotions. Since GroceryCo had 40% of its sales from promotions, it was assumed its demand variability would be 50% higher than MassCo. Similarly, since DrugCo had 75% of its sales from promotions, it was assumed that its demand variability would be 100% higher than MassCo. These assumptions allowed the model to better predict inventory levels and gave greater confidence to the calculated potential savings from the various scenarios.
Conclusions

To summarize the key findings of this study, the following 2 by 2 matrix is shown below as Figure 4. It highlights what factor is likely to be the key lever in reducing inventory. Some results are fairly intuitive, but one is not.

When shipment frequency is low, it makes sense that improving frequency is likely to have a big opportunity to reduce customer inventory. Also, after thinking through the key drivers of cycle stock and safety stock, it makes sense that when frequency is high and demand is stable that lead time variability would be the key driver. The part that is most surprising is that when frequency is high and demand variability is high that frequency still has a greater potential for inventory improvement. Higher demand variability drives a higher safety stock level, so if frequency is already relatively high, how could increasing frequency further reduce cycle stock more than lead time improvements could reduce safety stock? The answer lies in the relative amounts of improvement possible in the overall frequency versus the overall lead time. Shipping more products together can increase frequency by 20-600%, while lead time can likely only be improved by 10-50%.

Conversely, for retailers who had the ability to replenish their stores during promotions, reducing average lead time would be more valuable than increasing frequency. DrugCo does not replenish its stores to respond to high promotional demand, but GroceryCo does. Both companies could benefit from improved frequency, but only one would benefit from reduced lead time. Meanwhile, MassCo would benefit more from improved frequency than from reducing average lead time.

These insights can help guide SupplierCo in allocating limited resources most effectively to improve its supply chain. In most cases, increasing frequency will provide a greater benefit than reducing lead time. This may not be true for all businesses, but this same methodology could be used for other businesses in other locations to determine what the key driver for supply chain improvement is.
Incorporating Supply Chain Risk into a Production Planning Process

By Joshua Matthew Merrill
Thesis Advisor: Ed Schuster

Summary: This project explores how a company that is facing uncertainty in both demand and production yield can develop an effective approach to production planning. The author develops a two-stage approach using a mixed integer linear program to develop an initial solution and then applies a Monte Carlo simulation to test its robustness. Applying this methodology to the premium agriculture industry illustrates how both profitability and customer service can be improved.

A Two-stage Approach to Production Planning

A two-stage planning approach, involving optimization and simulation, is developed to help production managers make the most profitable production plans, while considering all the inherent supply chain uncertainties. The core of the approach is recognizing the existing supply chain uncertainties and quantifying them by estimates of their probability distributions. This could be as simple as identifying the average demand and expected standard deviation of demand, compared to using the point estimates from the sales forecasts. Likewise, instead of assuming supply is a single predictable number, it may be more realistic to estimate an average and standard deviation of supply using historical data.

The first stage of the planning approach is to find an optimal production plan for one set of assumptions. These assumptions would traditionally be the average values of demand and supply. By definition, however, the average values have only a 50 percent chance of occurrence. Production managers would be equally well off to fly to Vegas and bet on red. Another common approach is for production managers to adjust their assumptions to be “conservative” or look at a “worst-case” scenario.

Alternatively, a more systematic approach to developing supply and demand assumptions is to start by choosing a point on the estimated probability distributions of these random numbers that corresponds to a given level of certainty (Figure 1). For example, historical data or best guesses can be used to estimate that “95 percent of the

KEY INSIGHTS:

1. The combined uncertainties in both demand and supply make production planning exceptionally difficult, particularly when customer service is an important performance metric.

2. A two-stage approach using optimization and simulation can improve the precision and robustness of production planning.

3. The two-stage approach can also provide a firm with a better understanding of the trade-off between profitability and customer service.

Introduction

Firms must often make production planning decisions without exact knowledge of demand for their products. Most firms also face some degree of uncertainty in their product supply. This could be due to risk of machine malfunction, variability in ocean shipping schedules, or some other unpredictable supplier or processing related issue. The combined uncertainties in both demand and supply make production planning exceptionally difficult, particularly when customer service is an important performance metric.

Figure 1: Example of choosing a certainty level on the estimated distribution of yield

Yield

95%

Production Certainty Level (PCL) = 20 units

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Josh Merrill has joined Chiquita Brands in Cincinnati, Ohio as a Transportation Planner. Prior to MLOG, Josh worked for ABG, Inc. as a Senior Business Analyst and as a Sustainable Agriculture and Food Chain Analyst for Syngenta AG.

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time supply will never fall below 20 units a day.”

Using certainty levels to define each of the random inputs is essentially scenario planning and allows an optimal production plan to be found with a mathematical model, such as a linear program or a mixed integer linear program.

In the second stage of the planning approach, the optimal solution from stage one is a fixed input into a simulation model. The simulation incorporates the truly random nature of demand and supply, as quantified earlier. The observed distribution of outcomes from the stage two simulation indicates the robustness of the stage one solution. Specifically, if the desired levels of customer service or profitability are not reached, the stage one model can then be re-optimized with different certainty levels to give a better solution. This process is repeated until the minimum service level or profit requirements are reached (Figure 2).

The two-stage planning approach is designed to improve the precision of production planning by recognizing the inherent uncertainties in the system and compensating for them in the most economically efficient manner. To test the approach against current risk management practices, the two-stage approach was applied to a premium fresh produce supply chain.

**Background on Premium Fresh Produce**

Trends in consumer preferences and production innovations are changing the agriculture and food marketplace. There are an increasing number of differentiated food products that appeal to specific consumer values, such as environmental-friendliness or locally grown. Furthermore the success of specialty retailers, such as Trader Joe’s® and Whole Foods Market®, demonstrates that high-quality, high-margin agriculture can be sustainable and successful in mainstream grocery retail.

The growth of successful niche agriculture markets brings both opportunities and risks to agriculture and food supply chains. The opportunity to differentiate agriculture produce and earn price premiums provides a welcome alternative to producers who lack the scale to compete effectively in commodity markets. On the other hand, high product value and limited market demand creates greater incentives to avoid under or over-supply situations. These premium fresh produce supply chains must balance customer service requirements against costly agriculture production investment. Targeting a specific quantity of demand makes production planning particularly challenging, given the inherent biological and environmental uncertainties in agriculture.

**The Case of a Premium Tomato**

The suggested two-stage planning approach is applied to a U.S.-based, premium-branded tomato production and marketing venture, forthwith referred to as “MaterCo.” The tomatoes marketed by MaterCo are grown under strict controls and protocols, segmented through the supply chain, and only sold at select retail locations. The value offering from MaterCo to the grocery retailer is consistent high quality, including superior taste, full traceability, environmental stewardship, good agricultural practices employed on the farm, and retail-merchandising support. The premium-branded tomatoes from MaterCo are referred to as “SuperT”.

The suggested two-stage approach is used to improve the matching of supply to demand by MaterCo’s production managers, by focusing on the following supply decisions:

- How many acres to plant
• Where to plant
• What times to plant

In this case, the two-stage planning approach uses a mixed integer linear programming and Monte Carlo simulation to develop a production plan. Output from the optimization model is sequentially put into the simulation to provide management with information on expected profit and customer service levels at the grocery retail distribution centers. The models are formulated to incorporate uncertainty in demand, yield, and harvest failure (inability to harvest in a given week due to environmental or logistical constraints). The outcome of the approach is an annual production plan for tomato production that meets minimum customer service requirements, while optimizing profit.

By recognizing customer service as a planning goal, the suggested two-stage planning approach takes a unique, holistic supply chain view for agriculture production planning. Increasingly, agricultural production managers must understand and consider the needs of their downstream customers. In addition, instead of trying to define a particular production manager’s optimal solution based on their perceived risk preferences, the suggested two-stage planning algorithm allows production managers to determine their own acceptable risk levels.

Testing the Approach

To test the validity of the proposed approach, it is important to understand how current supply decisions, i.e. production plans, are made within MaterCo. Similar to other agriculture-based businesses, planning decisions are made primarily with industry accepted heuristics and knowledge based on past experience. Though risks are recognized and managed under the current decision-making systems, they are seldom quantified enough to be used in making even more effective decisions.

MaterCo currently uses point forecasts for sales and demand as base inputs into their production planning model. The SuperT sales forecasts are extracted from the business plan. The weekly yield forecasts are derived from the average yield of growing trials. To account for yield variability from week to week and the uncertainty of a large scale crop failure because of unpredictable weather, a common heuristic used by production managers is to plant redundant acreage.

In stage one of the approach, optimizations are run for various certainty levels of demand and yield, using the average yield and demand to represent current practices. The runs performed in the analysis are shown in Figure 3.

The solutions from the stage one optimization are run through a simulation, where they can be evaluated on two primary dimensions: profit to MaterCo and Type I Customer Service Level (percentage of weeks where demand is met in full at the grocery retail distribution center). To represent the doubling heuristic (A2), the planted acreage suggested in Run A is doubled before simulation.

Results

The more sophisticated two-stage, risk-incorporating approach demonstrates significant saving to MaterCo, when compared to the doubling heuristic. An acceptable level of customer service, defined as 90 percent, is achieved with 20 percent less planted acres, and almost three times as much profit than the industry heuristic of doubling the acreage (Figure 4).

Figure 4 shows how the mean profit decreases
as mean customer service levels increase. The highest profits are observed for the lowest customer service levels. The graph also illustrates the gap in service levels and profitability between the production plan based on expected (average) demand and yield and the risk-inclusive optimizations. Though the profitability is most attractive when no risk measures are taken, the customer service levels are not realistically acceptable.

Intuitively, the risk of poor service to the customer decreases as the planted acreage base increases. Nevertheless, as the customer service level increases, the profitability decreases, because a higher level of production is required to service the tails of the demand distribution and to compensate for the tails of the yield distribution. This reinforces the importance of finding the right balance between customer service and profitability.

Given a minimum customer service level of 90 percent, the optimal production plan suggested from the two-stage approach is from Optimization Run H. This production plan achieves at least 90 percent customer service with the least amount of acres. Compared to the doubling heuristic, the mean profit from Optimization Run H is approximately $40,000 more (almost three times as much). Therefore, higher profitability can be achieved in this instance using the suggested production planning approach and models versus the simple doubling heuristic.

Summary

The research presented demonstrates that MaterCo, or similar firms, can save unnecessary production expenses by using the suggested two-stage planning approach, while still providing acceptable service to their retail customers. With better understanding of the trade-off between profitability and customer service, MaterCo can also make more informed promises to customers.

The suggested two-stage planning approach is simple enough that production managers can easily scale their models to include more uncertainties, or more decisions, without complex statistics. It is an approach that is capable of wide spread application in agriculture supply chains, as well as other situations that involve uncertain supply and demand.
Complete List of MLOG 2007 Theses


Leveraging Downstream Data in the Footwear/Apparel Industry, by Jeff Axline, Brian Lebl. Advised by Larry Lapide.


Demand and Supply Synchronization for Promotional Events, by Gautam Kapur, Bin Liu. Advised by Larry Lapide.


Who Stocks the Shelf? An Analysis of Retail Replenishment Strategies, by Philip (Jiaqi) Kuai Chris Caplice.


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