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www.mit.edu/mlog
Introduction


The six articles included in this journal were selected from all of the theses submitted by the MLOG Class of 2006 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. They are available upon request.

The articles included in this journal represent a wide selection of interests, approaches, and industries. 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 eighth 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 who come from around the globe and from 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). The topics range from international inbound consolidation opportunities to improved metrics for humanitarian logistics to quantifying the impact of product proliferation in a supply chain.

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, please do not hesitate to contact me directly.

Happy reading!

Dr. Chris Caplice
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Benefits of Consolidation

Economies of scale are possible throughout freight logistics. In general, as shipment sizes increase, per unit freight rates decrease. In the case of shipping freight overseas, per unit rates are greater for less-than-container shipments than for full-container shipments. In the case of shipping packages home to mom, the US Postal Service charges about $4 to ship a 1-pound package priority mail, but only about $8 to ship a 5-pound package priority mail. Freight rates in this case decrease from $4/lb for the 1-pound package to less than $2/lb for the 5-pound shipment.

In addition to achieving better freight rates, consolidation also reduces the number of shipments, which in turn reduces fixed cost. For the graduate student, currently hard at work on his thesis, a walk to the post office costs him precious time. Through consolidation he reduces the number of mailings, and in turn the number of trips to the post office. In the case of an industrial corporation, each shipment requires paperwork, tracking, brokerage, and receiving, regardless of the size of the shipment. Reducing the number of shipments reduces the company’s fixed cost.

Costs of Consolidation

Despite the benefits, consolidation is not without cost. For the graduate student, the timeliness of his letters is critical. His mother is paying for tuition and she gets upset if she doesn’t know what going on. Although the student saves money on economies of scale and fixed costs, he still must balance the tradeoff between cost and timeliness. For an industrial corporation, longer lead-times equal extra inventory and reduced time to market. The tradeoff between time and cost is directly related to the value of the goods being shipped. Measuring this tradeoff is the key to choosing any shipping strategy.
While temporal consolidation consumes time, spatial consolidation consumes distance. Although the student and his sister both live in Boston, the post office nearest to his house is different from the post office nearest to her house. Spatial consolidation thus requires one of them to travel farther than if they shipped individually. If an industrial company wishes to consolidate two ports into one, factories that normally ship to the first port will travel a greater distance to the second port. Differences in distance must be accounted for when measuring the cost of consolidation.

Finally, consolidation requires coordination. If the student and his sister are to meet at the post office, they need to coordinate a time and a location. Coordination takes time and effort. If factories are consolidating freight at the port, do they need to talk to each other? Is there sensitive information that shouldn’t be shared between the two factories? Coordination costs are difficult to measure, but they cannot be ignored.

Rules can help reduce coordination costs. For instance, the student and his sister could set a rule to meet at post office “A” at 3:00 pm every Wednesday. Likewise, an industrial company could set rules for its suppliers to deliver freight to Port “A” on Monday and Thursday, if factory inventory is greater than “X” volume, or if factory inventory is older than “X” days. This paper uses simulation to evaluate such consolidation rules.

Industry Case

The sponsor for this thesis, a large industrial corporation, produces the bulk of its products in China. For this reason, the research project focused on consolidation options for the company’s inbound freight from China to the US. The industrial company has about fifty suppliers in China, although five of the suppliers represent the vast majority of the freight volume. The company’s suppliers are shipping from six China ports, with the majority flowing through Ningbo and Shanghai. The company imports through eight US ports, with the majority of the freight flowing through Chicago and Atlanta. The company has eight DC’s throughout the US. Exhibit 1 provides a graphical representation of the supplier, port and distribution center locations used in this case.

The product being shipped is dense industrial parts and equipment. Due to the nature of the product, the freight “weighs out” before it “cubes out”. For this reason, the paper focuses on weight and does not set constraints for volume. Demand is more or less stable year round, and for simplicity the simulation model assumes no seasonality. The company’s annual China to the US freight volume is approximately 3,000,000 kgs / year.

Spatial Consolidation Options

The industrial company is considering four spatial consolidation cases: Direct Shipment, China Port Consolidation, US Port Consolidation, and Full Consolidation (a combination of China Port and US Port Consolidation). The consolidation cases are described and diagramed below. Temporal consolidation options for each case will be presented in the results section.

Direct Shipment

Under direct shipment, there is no spatial consolidation. Factories ship by truck to the China port closest to them. From the China port goods are shipped by ocean to the US port closest to the final distribution center. The goods are then picked up at the US port and trucked to the distribution center. Factory consolidation is analogous to the student and his sister shipping from independent post offices.

China Port Consolidation

Under China port consolidation, factories ship by truck to their assigned consolidation port (in this case, Shanghai). From Shanghai, the goods are shipped by ocean to the US port closest to final distribution center. The goods are then picked up at the US port and trucked to the distribution center. China port consolidation is analogous to the graduate student and his sister meeting at the post office. Please note that due to the realities of long distance trucking in China, the model assumes that factories in northern China do not consolidate in Shanghai.

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The industrial company is considering four spatial consolidation cases: Direct Shipment, China Port Consolidation, US Port Consolidation, and Full Consolidation (a combination of China Port and US Port Consolidation). The consolidation cases are described and diagramed below. Temporal consolidation options for each case will be presented in the results section.

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US Port Consolidation

Under US port consolidation, factories ship by truck to the closest China port. From the China port goods are shipped by ocean to the assigned US consolidation port, in this case Los Angeles. From LA, goods are shipped by long-haul truck to the distribution center. US port consolidation is analogous to the student and his sister shipping packages independently to their mother, who then combines the packages and distributes the contents to aunts, uncles, and grandparents who live in the area.

Full Consolidation

Under full consolidation, factories ship by truck to their assigned China consolidation port. From the China port, goods are shipped by ocean to the assigned US consolidation port. From the US consolidation port, goods are shipped by long-haul truck to the distribution center. Full consolidation is a combination of China port and US port consolidation. Full consolidation is analogous to the graduate student and his sister meeting at the post office to ship one package to their mother, who then distributes the contents of the package to aunts, uncles, and grandparents who live in the area.

Temporal Consolidation Options

Temporal consolidation options are divided into two parts:

1. Maximum Wait Time: How long are we willing to wait?
2. Cutoff Value: What are we waiting for?

Let’s take an example: A company decides to have factories ship (a) if factory inventory is older than 7 days, or (b) if factory inventory is greater than 10,000kgs. In this case, the factory maximum wait time is 7 days, while the factory cutoff value is 10,000kgs.

For this paper, we assume that the cutoff value is always equal to 16,000kgs. Maximum wait time is thus the only active temporal consolidation option. Constraints for full truck shipments and for 20 foot (TEU) full container ocean shipments are assumed to always equal 17,000kgs. Partial order shipments are also permitted.

A summary of the settings for each consolidation case is found in Exhibit 5 below. Active temporal consolidation options are listed in bold italic in Exhibit 5.

Results

Let’s first examine how different temporal consolidation settings affect transit cost and transit time. Each point in Exhibit 6 and Exhibit 7 represents a combination of two temporal consolidation settings: China port max wait time and US port max wait time. Transit cost refers to all of the costs (fixed and variable) that a company incurs from the end of production until the goods arrive at the distribution center. Transit time refers to the time from the end of production until the goods arrive at the DC.

The steep downward slope in Exhibit 6 shows the benefits of consolidation through economies of scale and reduction of fixed costs. From Exhibit 6, we can infer that longer max wait times result in larger shipment sizes, reduced per unit transportation costs, and reduced fixed costs. The upward slope in Exhibit 7 shows the cost of temporal consolidation. As max wait times increase, transit times increase across the board. These two exhibits shows that savings from consolidation comes at the cost of time.

To examine the transit cost vs. transit time tradeoff more precisely we combine the results from Exhibits 6 and 7.
for all four consolidation cases into one graph (Exhibit 8). The points in Exhibit 8 represent the transit cost vs. transit time tradeoff for all active temporal consolidation options described in Exhibit 5.

From Exhibits 8 and 9 we find that direct shipment and China port consolidation offer slower transit times at lower costs, while US port and full consolidation offer faster transit times at higher costs. But most strikingly, the combination of temporal consolidation options across consolidation cases seems to form a continuum of transit time vs. transit cost options.

In the case at hand, US port consolidation and full consolidation both function like different modes of transportation.

In these cases, long-haul truck service from LA expedites goods that would still be on the water or rail to provide dramatic improvements in transit time. Nevertheless, long-haul truck service comes at a premium to rail and ocean service.

As we see in Exhibit 9, without temporal consolidation shipping choices are limited. Temporal consolidation is the means to adjust the transit time vs. cost tradeoff. Simulation modeling provides a clear picture of the wide range of cost vs. time options available through consolidation. The questions for the company remain: What are its priorities? How does it value the tradeoff between cost and time? Can it find a balance that fits its strategy?
Creating Transportation Policy in a Network that Utilizes both Contract Carriers and an Internally Managed Fleet

By Michael Jay Mulqueen, Jr.
Thesis Advisor: Dr. Chris Caplice

Michael Jay Mulqueen, Jr. is currently Director of Supply Chain Systems at C&S Wholesale Grocers. Before entering the MIT MLOG program, Michael worked as an operations/logistics manager for First Asia Corporation in New York, NY. In addition to his MLOG degree, he earned a Bachelor of Arts in Economics from Davidson College.

Introduction

At no time in recent history has the need for an efficiently designed and executed transportation policy been more important for U.S. domestic Truckload (TL) shippers. Figure 1 illustrates the combination of economic, regulatory and demographic factors that have converged to create a severe shortage of TL capacity in the U.S. freight market.

In the past, shippers were somewhat shielded from the financial repercussions of their inefficiencies by the power they wielded over carriers. The excess freight capacity in the open market assured that rates stayed low. Shippers could easily replace carriers who performed poorly or dared request rate increases.

In recent years, the dynamics of the relationship have changed as the balance of power has shifted to carriers. As capacity has tightened and freight costs have risen, the financial penalty for a poorly designed and run transportation policy has increased. Shippers that relied on threatening carriers with loss of their business as a means to keep transportation costs low no longer have that option. Conversely, those shippers that have developed transportation policy in a manner that leverages their internal economies of scope as well as those of their carriers now have a strategic cost and service advantage over their competition.

Defining ‘Transportation Policy’

Shipping organizations create and maintain transportation policy as a means to systematize the process of assigning logistics resources to freight. An organization’s transportation policy is developed strategically and used as the blueprint for operational decision making. Based on the attributes of any given freight movement, the transportation policy will specify the appropriate transportation mode, the use or bypass of intermediate points (such as cross docks or pool distributors), as well as the specific transportation service provider(s) to be used for that shipment.

In most instances, transportation policy modal decisions are straightforward. The majority of freight movements fall neatly into a single mode of transport based on the size, value, and origin/destination of the shipment. For example, a full container of low value product originating in Asia and destined for the United States will nearly always travel via an ocean carrier. Similarly, a 5 lb package requiring shipment from Boston to Chicago will invariably use a parcel delivery service. Within each mode there may be additional decisions, such as, “Should the pack-
age go Federal Express, DHL or UPS?” and “What is the appropriate service level for the shipment?” However, these policy decisions are normally limited to be within a mode.

The exception to this rule is when an organization utilizes an internally managed fleet, be it private or dedicated, in conjunction with for-hire TL carriers. In some organizations, the transportation policy will remove ambiguity in the assignment process by requiring fleet resources to be used for outbound distribution to customers and for-hire carriers be used as the primary means to transport the inbound shipments to their facilities. This is the approach commonly used in the wholesale distribution, grocery, and retail verticals.

In the consumer package goods (CPG) vertical, no such distinction exists. Shipments originate at manufacturing plants, or their distribution facilities, and are transported to the company’s customers. Since private fleets and carriers are both servicing the same echelon within the overall distribution network, they are completely interchangeable in terms of what freight each is capable of servicing. There is no attribute associated with a TL quantity freight movement that indicates whether the load should be serviced by the fleet or a carrier. This can only be determined by analyzing how well the lane and its associated volumes interact with the shipper’s internal network as well as the networks of the available for-hire carriers.

### How Fleets and For-Hire TL Carriers Differ

Private fleets and for-hire carriers use the same types of equipment and each must adhere to the same governmental regulations. They can operate in the same geographies and service the same customers. So how do they differ? The fundamental difference between an internally managed fleet and for-hire carriers is how the shipper incurs costs. A large portion of a fleet resource’s costs are fixed and are realized regardless of how or where the vehicle is operated. The fleet also incurs distance based costs for all miles driven without regard to whether the equipment is loaded or empty. Fleet resources can be viewed as perishable assets which explain why shippers are eager to keep them as highly utilized as possible.

For-hire carriers only generate costs to the shipper when they are contracted to move a specific load. The shipper is not responsible for payment associated with getting the carrier’s equipment to the origin point, nor is the shipper responsible for any empty miles the carrier incurs to go from the destination of the load to the carrier’s next load origin point. The rates quoted by for-hire carriers are normally high enough to pay for the anticipated empty mileage plus a reasonable profit.

By understanding how private fleets and for-hire carriers pass costs to the shipper, an approach based on leveraging the distinct characteristics of each mode can be developed. The perishable nature and large sunk cost of a private fleet makes it best suited for high volume lanes that terminate at or near the origination point of lanes with equally high load volumes. By stringing together lanes into closed loop tours, the fleet is able to stay utilized, minimizing empty miles, and idle time. The costing mechanisms employed by for-hire carriers are better suited to support lanes that are distant from other load origination points, and therefore are not synergistic with the internal shipper’s network or lane volumes that are not consistent and/or large enough to warrant allocating a full-time fleet resource. These attributes make for-hire carriers better suited to act as both a hedge against volume surges as well as a means to move freight on lanes that will not support high fleet utilization.

### Defining a Transportation Policy Framework for a Mixed Network

Transportation policy in a mixed network, where both fleet and for-hire carriers are utilized, requires a more nuanced approach than normal. The policy must be developed in a manner that exploits the cost structures of fleet and carrier resources and provides benefit to both the shipper and carrier by leveraging each entities economies of scope. The policy must also provide a level of flexibility that enables it to adjust to the variability inherent in all distribution networks.

![Figure 2. Framework for creating a transportation policy.](image-url)
In Figure 2, we see a framework that designed to efficiently allocate fleet and for-hire TL carriers across a shipper’s distribution network. The remainder of this section describes each task.

**Lane Segmentation**

Lane segmentation is used to identify the freight lanes that are the most desirable for the fleet. Shippers make this determination by looking at four factors: Lane volume, Lane variability, Relative cost between for-hire and fleet costs, and miscellaneous qualitative reasons, such as service levels.

A systematic approach to filter out the undesirable lanes using these factors will reduce the number of lanes that the tour creation and assignment process will need to consider. Most shippers will see a relatively small number of lanes account for a substantial portion of the total freight volume. These are the lanes that are best suited for keeping the fleet utilized.

**Tour Identification**

The process of identifying tours can be time consuming and complex. The number of potential tours in even a moderately sized network can be staggering or even infinite. However, the use of rules that require tours have certain characteristics will limit the total number that need to be created. Common rules include:

- Requiring that a tour start and end at the tour’s origination point
- Require that a tour cannot visit the same region twice
- Require that a tour does not have two consecutive empty legs.

**Confidence Level Assignment**

A flaw most systems share when creating transportation policy is their inability to account for lane volume variability. Nearly all systems calculate a statistical average, and then use that value as the basis for optimization. However, the average gives no indication as to the variability of the lane. When optimized, the resulting solution is developed without any consideration of lulls and surges in volume that are typical in virtually all distribution networks.

The purpose of confidence levels is to limit the lane volumes the tour assignment process is able to consider. Volumes outside the confidence level are left for for-hire carriers. In the lane detailed in Figure 3, for example, the average volume is 14. If 14 fleet resources are assigned to this lane, by definition, 50% of the time 1 or more vehicles will be idle. If however, an 80% confidence level is specified, the tour assignment process will have access to assign up to only 10 loads, thereby reducing the probability of underutilized fleet resources.

**Tour Assignment**

The tour assignment process is a fairly standard mixed integer linear program that maximizes savings through the assignment of load lane volumes to tours. This was developed as a maximization problem since in extensions we considered the use of the private fleet in for profit backhaul operations for other companies. The inputs into the optimization are the segmented lanes that were viewed as potentially desirable for the fleet, the pre-defined tours, as well as the lane volumes which are specified through the use of confidence levels. The outputs of the process are the tours that are created along with the associated tour volume. Lane load volume not assigned to a tour is also an important output, since these loads are assumed by the solution to be hauled by for-hire carriers.

**Simulation**

The use of simulation enables variability within the network to be modeled, thereby providing an indication as to the resiliency of the transportation plan. Lane volumes are simulated for an extended period with weekly volumes generated based on each lane’s specific distribution curve. The optimal deterministic solution created in the
tour assignment process is tested to see how well it reacts to variability.

This process provides an interesting insight into the danger of using solely deterministic optimization to develop transportation policy. Figure 4 shows the simulated transportation costs for the same network for a variety of confidence levels. Recall that the higher the confidence level, the less planned lane volume is available for use in the private fleet tours. It is clear that the deterministic optimization approach will continue to identify increased savings as the confidence level is reduced (i.e., lane volume is increased). However, when normal lane variability is introduced during simulation, the results diverge considerably. As expected, this occurs consistently with the divergence between optimized and simulated results becoming more pronounced as greater variability is introduced. In the case shown in Figure 4, using the standard practice of average lane volume in generating tours, would result in almost 7% increase in planned costs.

It is interesting to note that the simulation cost curve is convex and has a minimum. Adding too much volume to the tour generation leads to idle dedicated assets while adding too little results in missed opportunities. This implies that there is an optimal confidence level for a specific transportation network. In this case, it is close to 80% - that is, the volume to be considered within the dedicated fleet tour generation should be at the 80th percentile for each lane.

Summary

The creation of transportation policy in a mixed fleet/carrier distribution network is difficult due to the similarities of the modes. A load can be picked up and delivered by either mode, with the fundamental difference being how the shipper will be charged. The framework described above is designed to exploit the strengths of each mode. This will enable a shipper to create transportation policy that is both efficient and resilient.

The use of only deterministic network design methodologies can lead to over estimation of cost savings opportunities. This analysis showed that the use of statistical methods and simulation combined with the traditional optimization practices can lead to better – more achievable - results.

Figure 4. Comparison of simulated and optimized tours for difference confidence levels.
Key Performance Indicators in Humanitarian Logistics

By Anne Leslie Davidson
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Introduction

When disasters strike, relief organizations respond by delivering aid to those in need. Their supply chains must be both fast and agile, responding to sudden-onset disasters which may occur in cities such as New Orleans, or on the other side of the globe in places like rural Pakistan. Since 2004, two large-scale natural disasters have captured the attention of the international media: the 2004 tsunami and the 2005 earthquake in South Asia. Disasters of this magnitude cause donors, beneficiaries, and the media to closely monitor how quickly and efficiently relief organizations are able to respond.

A disaster response operation involves trade-offs of speed, cost, and accuracy with regard to the type of goods that are delivered and their quantities. Balancing these trade-offs requires a means of measuring supply chain performance; however, the inability to centrally capture time and cost data related to the procurement and distribution of goods has prevented a systematic process of performance measurement from being implemented. Today in the logistics department of the International Federation of Red Cross and Red Crescent Societies (IFRC), software that was co-developed with the Fritz Institute makes it possible to capture the necessary data which will inform the IFRC of their supply chain’s performance.

This executive summary begins by examining the underlying principles of logistic performance measurement systems from the military and commercial sectors and applying them to disaster relief operations. These principles were used to develop four indicators which measure logistic performance in terms of the trade-offs of speed, cost and accuracy: appeal coverage, donation-to-delivery time, financial efficiency, and assessment accuracy. Taken together, these indicators create a “scorecard” that will help the logistics department gauge performance both during and after a relief operation. To show how this system would be used by a relief organization, scorecards have been re-created for the 2005 South Asia earthquake operation of the IFRC. The executive summary concludes by describing one of the key issues which may arise when a performance measurement system is implemented, which is how to manage the cultural change that is needed in organizations unaccustomed to performance measurement. Although this research was performed with an international non-profit humanitarian organization in mind, the principles of measurement that are described are relevant to other organizations which participate in disaster relief operations, such as government agencies or national non-governmental organizations.

Principles of Performance Measurement from the Commercial and Military Sectors

Supply chain professionals in the commercial sector face many of the same issues of trade-offs in performance as a professional working in a disaster relief operation. In business and in disaster relief supply chains, speed is of the essence. Even more striking in parallel are military supply chains, which often face similarly short deployment periods and challenging working environments. Because of these similarities, it is important to understand the underlying principles of commercial and military performance measurement systems when developing a system for disaster relief operations. The following three principles emerged from business research journals and from research studies of the U.S. Army as the most applicable to the humanitarian sector.

Align metrics to the organization’s core strategy (Lam-
If a metric is not critical to fulfilling an organization’s core strategy, it should not be included on the scorecard. There is a tendency when designing performance measurement systems that “more is better,” but if too many metrics are selected, the scorecard can become too cluttered, preventing individuals from truly gauging performance.

Understand the dynamics of how performance is driven (Caplice & Sheffi, 1994). The faster that goods are delivered to beneficiaries after a disaster, the less likely these goods are accurately meeting the needs of the beneficiaries, and the more likely the operation will be costly. The organization responding must decide in advance how it wants to align itself along the dimensions of speed, accuracy, and cost.

Review the metrics periodically as performance improves (Meyer, 2005). The goal of implementing metrics is to improve performance over time, and as goals are achieved, targets must be re-evaluated and revised as necessary to ensure continuous improvement in the organization’s supply chain.

### Framework of Four Performance Indicators

To develop our framework of four performance indicators, we first conducted interviews with the professionals at the IFRC in order to understand their supply chain and their organization’s strategic goals. We then examined the data for the 2005 South Asia earthquake operation that was captured in Humanitarian Logistics Software (HLS). This software was implemented by the IFRC in 2003, to track information relating to the procurement and distribution of goods for all major emergency operations. Using the organization’s goals of how they strive to deliver goods to beneficiaries and using the data available from HLS, we developed a set of four indicators: appeal coverage, donation-to-delivery time, financial efficiency, and assessment accuracy. These indicators do not represent pure index calculations, but rather they serve to help the logisticians get a sense of how well they are achieving their goals related to each “appeal,” the term which refers to the list of items recorded on an operation’s total budget.

1. **Appeal Coverage**: This indicator is comprised of two specific metrics: 1) percent of appeal coverage and 2) percent of items delivered. The first metric is the quantity of items that have been pledged by donors out of the total number of items requested for the operation. Its purpose is to indicate how well and how quickly the organization is finding pledges for the requested items. The second metric is the percentage of items that have actually been delivered on-site out of the total number of items requested for the operation. Together, these two metrics indicate how well the organization is meeting its appeal for an operation in terms of both finding donors and delivering items.

2. **Donation-to-Delivery Time**: This indicator is a measure of how long it takes for an item to be delivered to the destination country after a donor has pledged to donate it. Both the mean and median number of days are reported on the scorecard, which is a practice used in the U.S. Army’s performance measurement system (Dumond, 2000). These two metrics help gauge both the average and the consistency of the delivery lead times.

3. **Financial Efficiency**: Three metrics comprise the indicator of financial efficiency. The first two metrics use two methods (one relative and one absolute) to compare the budgeted prices to the actual prices paid for items delivered in the operation. The third financial efficiency metric incorporates the transportation cost of delivering the goods to the beneficiaries. This metric is expressed as a ratio of the total transportation costs incurred over the total costs for delivered items at a point in time. The value of this ratio should decrease over time, as less expensive transport methods are used after the initial delivery phase and as more items are delivered on-site.

4. **Assessment Accuracy**: How quickly donations are pledged and goods are delivered to beneficiaries relies on how accurately the field personnel assessed the needs of the population affected after a disaster. Assessment accuracy therefore indicates how much the operation’s final budget changed over time from the original budget. This metric contextualizes the values of the other metrics on the scorecard. For example, if it appears on the scorecard that the delivery lead time of a specific type of item was longer than average in an operation, the assessment accuracy metric will indicate if the long lead time of that item was caused by an initially low estimation of the quantity needed.

### Using the Framework in an IFRC Operation

The metrics described above have been combined to form a scorecard as shown in Figure 1. To implement this system and determine if the organization is meeting its goals for the operation, the logistics department would analyze these scorecards at different points in time after the operation’s original appeal date. Figure 1 shows what the “Week 1 Scorecard” would have looked like for the 2005 South Asia earthquake operation, had this system been used by the IFRC during that operation. Only the metrics for Appeal Coverage and Donation-to-Delivery Time are included in the Week 1 Scorecard. The financial efficiency metrics are not added until the Month 1 Scorecard, because the IFRC focuses primarily on procurement and delivery during the operation’s initial phase immediately after a disaster. Assessment Accuracy is not included on the Week 1 Scorecard, because the Week 1 budget is what will serve on the future scorecards as the “baseline” budget for the operation.

Similar scorecards would be created after Week 2, Month
donors who need to know what to donate, field personnel who need to know what they are receiving, and the logistics department which links these two parties together. The prioritized items are prominently displayed on the scorecard so that the organization can easily see how quickly and efficiently these goods are being delivered to the field.

In order to apply this framework for use in other non-profit humanitarian organizations, the IFRC’s framework should be modified, since it was designed in keeping with their specific business processes and strategic goals. For example, the IFRC accepts both cash and in-kind donations (donations of goods), while many other relief organizations only accept cash donations. When only cash is accepted, there is an additional step in the supply chain. First, the organization raises the funds that are needed from donors. Next, they procure the goods from suppliers, and finally, they deliver the goods to beneficiaries. To account for this additional step of fundraising, a metric should be added which captures how quickly the organization raises funds from donors out of the total amount of money that has been requested for the operation.

Next Steps – The Cultural Change Required to Implement the Framework

The “Total Op Target” column has been left blank in Figures 1-3; an organization actually using this system must first define these values in order to compare targets to actual results. Defining quantitative goals is a critical success factor to the implementation of a performance measurement system.

A key feature to highlight from the scorecard is the systematic use of designating “priority items” in each operation. If an organization determines at the beginning of an operation what the most important items are to deliver to beneficiaries, this will facilitate communication between donors who need to know what to donate, field personnel who need to know what they are receiving, and the logistics department which links these two parties together. The prioritized items are prominently displayed on the scorecard so that the organization can easily see how quickly and efficiently these goods are being delivered to the field.

In order to apply this framework for use in other non-profit humanitarian organizations, the IFRC’s framework should be modified, since it was designed in keeping with their specific business processes and strategic goals. For example, the IFRC accepts both cash and in-kind donations (donations of goods), while many other relief organizations only accept cash donations. When only cash is accepted, there is an additional step in the supply chain. First, the organization raises the funds that are needed from donors. Next, they procure the goods from suppliers, and finally, they deliver the goods to beneficiaries. To account for this additional step of fundraising, a metric should be added which captures how quickly the organization raises funds from donors out of the total amount of money that has been requested for the operation.

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ment Metrics

The system of scorecards and metrics designed as part of this research is an initial attempt to place a framework around the long-standing question of how to measure supply chain performance of relief operations. While there is clearly room for further research on this topic, this system is a first step towards relief organizations being able to gauge “how well” their supply chains are performing and how quickly beneficiaries are reached with aid. Some improvements to the system itself may not be discovered until an organization implements a measurement system; their logisticians may determine more efficient ways to present the information they need in order to take corrective action during an operation. Implementing a measurement system will also create additional challenges for a relief organization, because the humanitarian sector is not accustomed to measuring logistical performance. Hence, the implementation of a performance measurement system will require a change in culture. Managing this culture change is critical, because success will require support from people in various departments within an organization, particularly the organization’s top management.

Although there will always be elements of chaos in the immediate days after a sudden-onset disaster, there is reason to look to the future with optimism. The development of information technology systems that can provide visibility to the disaster relief supply chain is a huge step forward for the humanitarian sector as a whole. As more organizations begin to adopt and implement these systems and this visibility is established, the use of key performance indicators will then become essential to further enhance the efficiency and effectiveness of these supply chains. By clearly defining operational targets and measuring actual performance to these targets, organizations will be better able to retain the lessons they learn from each operation and provide a higher level of service to their beneficiaries in the future.

Bibliography


Vendor Managed Inventory vs. Order Based Fulfillment in a Specialty Chemical Company

By Dimitrios Andritsos and Anthony Craig
Thesis Advisor: Dr. Stephen C. Graves

Introduction

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

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

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

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

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

**Current System**

Our initial goal was to understand the operation of the current system. Towards this direction we tried to identify how each customer location contributes to the total sales volume as well as how this volume is distributed across the various products. Analysis of the order history revealed that out of the 289 customer sites served during the year under study, 13% account for 51% of total sales and 31% account for 80% of total sales. It is important to note that the majority of the high volume customer sites are closely located to the facility despite the high overall dispersion of the total number of customer sites.

On the other hand, distribution of total sales volume across products is not as highly fragmented. From the 25 distinct products that were delivered from the facility, the top product accounts for 60% of the total sales volume and the top 4 products account for 81% of total sales.

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

In order to determine the effectiveness of the existing dispatching practice, our analysis subsequently turned to the delivery history. Truck utilization averaged 84%, indicating that there exists some room for improvement in this respect. In addition, 81% of all trips had between two and four intermediate. In most trips, three or fewer products were delivered with most stops on a trip entailing the replenishment of a single product.

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

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

**Replenishment via Dedicated Trucks**

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

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

**Maximizing Truck Utilization through VMI**

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

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

In order to limit the number of tanks considered for VMI we examined the order history for all tanks. We sorted the tanks in decreasing order of total delivered volume and added them to the VMI group until 80% of total delivered volume was reached. This produced a set of 248 tanks at 163 separate customer locations. Though this represented only 26% of the total number of tanks they accounted for 80% of the volume and 67% of the orders.

Customer locations were placed into delivery clusters through the use of a K-means clustering algorithm. The K-means clustering algorithm works by assigning each location to a cluster such that the total sum of the dis-
tances between each customer location and the center of its cluster is minimized. We created a set of five delivery regions, consisting of as few as 22 and as many as 78 tanks. This reduced the complexity of the problem such that we were able to construct a mathematical program to create routes for the VMI tanks within each cluster.

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

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

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

Table 1: Comparison of Systems

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

**Conclusion**

Using the methodology we described the calculated reduction in vehicle mileage achieved through VMI was 6%. Given the limitations and the assumptions of the model, it is difficult to determine how accurate this figure is, or how much it could be improved. This research did produce several key findings, however.

First, attempting to serve customers by sending dedicated trucks to each location does not appear to be a viable strategy given the high variation in demand rates between products. Second, by focusing on improved truck capacity utilization the total number of trips can be reduced, and this reduction in number of trips outweighs the increased mileage required to visit more customers on a single delivery. Finally, the major factor in many of the routing issues encountered was the size of the tank at the customer site, not the demand rate of the product usage. Many tanks were simply sized too small, requiring frequent deliveries and limiting opportunities for efficiently combining multiple products in one trip to the customer.

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

By Jin Namkoong and Ying-Lai See
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Introduction

Traditionally, product proliferation is perceived as an instrument for competitive advantage since it allows companies to better match their products to customers’ requirements. However, this view is narrow because its implications on various operations have been largely ignored. In production, product proliferation will lead to a higher frequency of line setups and switching, degrading overall manufacturing efficiency. With a deluge of similar products, forecasting becomes difficult. As a result of missed forecasts which in turn call for freight expediting, transportation cost is likely to be affected as well.

While the ramifications of product proliferation are extensive, the scope of this study is limited to the impact of product complexity on inventory holding levels. This research examines SKU proliferation of a specific product line, which we will call Formax, produced by a company that we will refer to as Emanon Inc. Due to customers’ varied requirements, Emanon produces Formax in a variety of widths, lengths, colors, to list a few. The width, in particular, goes from a narrow 4 cm to a wide 322 cm, and is in increments of 1 cm for most of the range. The total number of possible combinations of attributes is in the order of billions.

In the remainder of this section, we present an overview of the product’s supply chain. In Section 2, we construct a model that represents the relevant characteristics of the supply chain and state our key assumptions. Using the results obtained in Section 2 as the empirical basis, we evaluate an alternative involving width offerings reduction in Section 3. In Section 4, we optimize the model constructed in Section 2. Finally, we present our conclusions in Section 5.

Formax’s Supply Chain Overview

The manufacture of Formax begins with the mixing of two key ingredients: core and additive. Subsequently, the compound is forced through a nozzle to produce a continuous, uniform sheet that is immediately slit into rolls of desired width.

In general, Emanon adopts a make-to-stock policy for Formax’s production. It holds the product in finished goods inventory at multiple warehouses and satisfies demand from that inventory as orders come in. Thus, the warehouses can be perceived as the push-pull boundary within the supply chain. Between the manufacturing and warehousing facilities, goods are normally shipped by trucks or ocean carriers. As a result of long transportation lead time, a significant amount of inventory is in transit all the time.
As a result of process limitations, a small portion of Formax is trimmed away by customers during their manufacturing stage. Currently, Emanon provides trim tubs to the customers and buys the discarded material back for re-extrusion.

Model Construction

To keep the scale of the model in check, we focus our analysis on a group of SKUs with all attributes being equal except for the width. Figure 1 shows the overall architecture of the model constructed using PowerChain Inventory software from Optiant. Following a three-tiered structure, the supply chain begins with the procurement of raw materials, followed by the manufacturing processes, and ends with the shipping stages. By design of the software, inventory accumulates at the end of every single node.

Master-Sizing

Master-sizing is a form of width rationalization in which rolls would only be offered in increments of a larger value. On one hand, it has the advantage of pooling risks together to reduce inventory requirements. On the other hand, it forces the company to hold wider rolls in inventory. These two counteracting effects jointly determine the net impact of this initiative on total inventory investment.

In this research, we examine four specific width interval values, namely 5 cm, 10 cm, 15 cm, and 20 cm. The model has the same structure as before except that certain manufacturing stages have to be combined together.

Results

On the premise that demand is inelastic, the blue curve in Figure 2 shows the impact of master-sizing on total inventory investment. The curve shows that total inventory investment should reduce by roughly 10% when the interval value is widened to 5 cm. By stretching the interval to 20 cm wide, we can expect total inventory investment to further reduce to around 74% of its original value.

The fact that the curve stays below the level of 100% indicates that the value of pooling more than outweighs the wider-roll effect within the range of tested interval values. However, the relative strengths of the two counteracting effects do not stay unchanged across the range. To illustrate that, we decompose the results above and show the two effects separately. The yellow curve in the figure shows the impact of the wider-roll effect alone on total inventory investment. As depicted, the wider-roll effect causes total inventory investment to rise linearly with respect to the width interval. The purple curve, on the other hand, shows the impact of the pooling effect alone on total inventory investment. The curve slopes downwards almost linearly initially but begins to flatten as the interval value widens, indicating an eventual wane in strength of the pooling effect.

Judging from the trends of the two separate effects, the blue curve in Figure 2 is likely to pick up when the interval value goes beyond 20 cm. In other words, the maximum achievable savings in total inventory investment by means of master-sizing is around 26%.

Model Optimization

The software comes with the capability of minimizing total inventory investment by treating the service time parameters between nodes as decision variables of an optimization problem. By using this feature, we see a 14.5% reduction in the total inventory investment, and the only change involved is that the service time of the manufacturing stages has to increase from 2 to 5 days.

Increasing the service time implies a shorter exposure period for the manufacturing stages but a longer exposure period for the shipping stages. Implicitly, the optimization
mechanism pushes the finished good inventory down the supply chain. In other words, it is more cost-effective for the finished goods to be held at the external warehouses than at the manufacturing site.

The appeal of this approach is that it reduces total inventory investment without introducing the wider-roll effect at all. However, it brings about the issue of inconsistency. Take note that the manufacturing site does serve domestic customers directly, so a service time of 5 days basically means a promised delivery lead time of 5 days for the domestic customers. On the other hand, since the service time of the shipping stages stays unchanged at 2 days after optimization, the international customers have the privilege of getting the goods sooner. This could be an issue if some of the domestic and international customers belong to the same company.

Conclusions

In this research we have constructed a supply chain model for determining the effect of width rationalization on inventory levels. We find that the value of pooling diminishes as the width interval widens. Because the product is available in rolls and its value is determined by the surface area, there exists a wider-roll effect that offsets the pooling advantage. Although the total number of rolls held in inventory decreases as a result of width rationalization, the total worth of the inventory does not necessarily reduce accordingly. In other words, there is a definite range of width interval within which the rationalization effort is favorable in terms of total inventory investment. Beyond that range, the reverse is true.

The managerial implications of the wider-roll effect are significant. On top of causing a larger degree of mismatch between customers’ needs and supply, master-sizing also creates more wastage of resources because a higher percentage of the product will traverse the supply chain back and forth without getting to serve any demand. Such inefficiency comes at a price which neither the manufacturer nor its customers want to pay. Consequently, the real challenge of the rationalization program not only lies in the selection of an appropriate width interval value, but also in preventing the perception that customers are footing the cost of increased wastage. Two readily available options accomplish that: reduce the product price or increase the buy-back price. Properly wielded, master-sizing can be a winning proposition for both parties.

Through model optimization, we also find for a product chain like ours, it is more favorable to push the finished goods inventory down the chain. In other words, having the external warehouses rather than the manufacturing plant hold the inventory can effectively reduce the inventory requirements without compromising the service level.
Promotional Forecasting in the Grocery Retail Business

By Pakawakul Koottatep and Jinqian Li
Thesis Advisor: Dr. Larry Lapide

Introduction
Predicting customer demand in the highly competitive grocery retail business has become extremely difficult, especially predicting demand for promotional items. The difficulty in promotional forecasting has resulted from numerous internal and external factors that affect the demand patterns. It has also resulted from multiple levels of forecasting hierarchy that involve different groups in the organization that employ different forecasting methods and systems. In the grocery retail business, promotional forecasting is conducted at three levels: the chain level, the distribution center level, and the store level. The groups involved in producing and using promotional forecasting include the merchandising group, the supply chain group, and individual stores. Moreover, judgments from the forecasters are critical to the accuracy of forecasts, though the value of tweaking forecast results has yet to be determined.

The main objective of this thesis is to analyze the effectiveness of promotional forecasting and identify factors contributing to the forecast accuracy. With regard to the main objective, we also aim to identify the best approaches to improve forecasting results. In this executive summary, we will first discuss the current practices and challenges in promotional forecasting in the grocery retail business. Next, the research methodology and analysis results will be described. Finally, we will discuss factors leading to high forecast errors based on the analysis results and suggest several approaches to improve forecasts.

Promotional Forecasting in the Grocery Retail Business

The unique organization and supply chain structure of the grocery retail business gives forecasting in this industry four characteristics. First, in the grocery retail business, where the cost of stock-out far exceeds the cost of holding inventory, forecasters generally have a high incentive to over-forecast in order to meet the corporate goal of maximizing customer satisfaction.

Second, because of the proliferation of SKUs and the number of customers that each store serves, the number of items on the shelves for each SKU is relatively low. Therefore, forecast accuracy measures that are used in other industries may not be applicable to the grocery retail industry at the store level.

Third, because of the broad range of products available in grocery retail stores, the complexity of the demand pattern varies for each product, and even for products in the same product group and category, depending on various factors such as seasonality, rate of new product introduction, product life cycle and availability of the products at the competitors’ stores. Therefore, some products
are more difficult to forecast than others. Especially for promotional forecasting, besides regular attributes and historical sales data that are the main inputs used for predicting the demand, there are other factors that need to be taken into account when predicting the demand. Some attributes are correlated to each other, resulting in higher forecasts than what they should be.

Fourth, because forecasting systems cannot take into account all situations, forecasters, based on their judgments, often need to tweak the forecasts generated by the systems, and this may either improve or degrade the forecast accuracy. On one hand, forecasters’ experience and familiarity with the products contributes tremendously to the accuracy of the forecast results. On the other hand, judgments tend to introduce bias and variations, and the impact of the judgments is difficult to quantify.

Forecast structures and objectives

In the grocery retail business, forecasting is conducted at three levels: the chain level, the distribution center level, and the store level. The objective of forecasting is specific for each of these levels. At the chain level, the merchandising team uses the forecasts to make promotion decisions. At the distribution center level, forecasts are provided by the supply chain group and used by the replenishment group to make purchase orders decisions. Finally, at the store level, which is the most detailed level, forecasting is conducted by the supply chain group and used by grocery retail stores as the basis of store replenishment. The purpose of forecasting at each level, as well as the responsibility and incentives of each group producing and using the forecasts are different, and they each use particular attributes, methods and systems to generate forecast results.

Methodology

We researched the operations and challenges in grocery retail promotional forecasting through fieldwork, visiting and interviewing personnel in the supply chain and merchandising groups of a midsized regional supermarket chain. Using this information as background, we analyzed and employed model simulations using forecast and demand data from September 2005 to February 2006 which covered three major holidays: Thanksgiving, Christmas, and New Year. We collected the forecast and demand data of the supermarket chain in three product categories: ice creams, ice cream novelties and cereals. The ice cream and ice cream novelty categories are comprised of products with seasonality patterns, while the cereal category comprises products with relatively stable demand. For each category, products with similar characteristics are further divided into groups. Data for each of the categories are organized in a variety of ways for the analysis of forecast performance.

Without understanding the current forecast performance, grocery retailers cannot improve their forecasting process, which is a critical step dictating the efficiency of their supply chain. Selecting the right measures for the business is also important because some measures may lead to misleading results. For example, although mean percent error (MPE) and mean absolute percent error (MAPE) are the most frequently used measures among retailers, they are meaningful only when the volume is large. Due to the low volume per item at each store of the grocery retail business, grocery retailers need measures that do not inflate the average error with high percent errors of low-volume items. Also, the measures need to be comparable across different SKUs. Therefore, we have used weighted mean percent error (WMPE) and weighted mean absolute percent error (WMAPE) that use the forecast unit to weight the error of each forecast. These measures not only retain the advantages of conventional MPE and MAPE, but they also reduce the incentive to over-forecast as the weighted error will be amplified if the forecast far exceeds the actual demand.

Analysis and Results

To begin, we conducted a forecast measurement analysis by organizing the forecast data in a variety of ways: levels of aggregation, product characteristics, promotional attributes, different time of forecasting, and different forecasting methods, to empirically determine factors contributing to forecast errors. The results of our analysis show that forecasts are more accurate as they are aggregated up from store to distribution center to chain, as well as from item to product group to product category because of the expected pooling effect. For the analysis of product category, we found that for ice creams and ice cream novelties, both with seasonal demand and frequent new product introductions, the forecasts are significantly less accurate than those for cereals, which represent products with constant demand and longer product life cycles. The analysis on holiday versus non-holiday periods also suggests that in general errors are higher for items promoted during holiday periods. For the impact of promotional attributes on accuracy, we found that the accuracy of forecasts for different offer types varies, and ad layout attributes do affect the forecast accuracy, but the exact effects are hard to capture using forecasting systems.

Interestingly, when ABC analysis was conducted to test the impact of promotional volume on the forecast accuracy, we found that with more experience and familiarity with the products, systems and forecasters are able to predict the demand significantly better. In order to achieve improved forecast accuracy while minimizing the efforts of forecasting, products should be classified based on accumulative sales value, which is one form of ABC classification. By applying ABC classification to the items, forecasters can prioritize their efforts based on the value of time spent providing judgments on the forecasts to the profitability of the company.

We also compared the forecasts generated four weeks ahead with the forecasts generated two weeks ahead...
on the same set of data, and found that the errors are decreased as the forecast decisions are made closer to the promotion week. This result suggests the opportunity to improve forecast accuracy by shifting the forecasting process for products with short replenishment lead times to a point closer to the promotion week.

As for different forecasting methods, we found that although in general the forecast results from the supply chain group are more accurate, sometimes the insight and experience of the merchandising team could be leveraged to achieve even better results.

We also conducted regression analysis to verify the correlation between different attributes and forecast accuracy. Although we could not find an exact mathematical relationship between the attributes and the accuracy, the result of the stepwise regression shows that holiday is the most significant attribute correlating to the forecast accuracy, followed by product category, front page of the weekly circular and promotion offer type. This could provide some insights to grocery retailers on how to plan their promotions without compromising forecast accuracy.

Improving Forecasts

From the analysis of forecast accuracy, we have identified several factors that lead to high forecast errors in this industry. To begin with, the relationship between forecasting attributes and demand uplift is difficult to quantify. Therefore, forecast results should be measured and forecasting systems should be updated constantly so that the effects from forecasting attributes can be better captured. Moreover, because of the collinearity of forecasting variables, systems and forecasters tend to add the uplift of one variable on top of the others, resulting in overestimated forecasts. Furthermore, although grocery retailers employ sophisticated forecasting software to assist with the forecasting process, it is not possible to take into account all relevant variables. This emphasizes the importance of the forecaster’s experience. However, performance of forecasters is rarely tracked and analyzed. The learning process of forecasters cannot be effective without constant accuracy measurement that provides information on the result of the judgments they made in order to improve future forecasts.

We have suggested several ways to improve forecasts. First, according to the results of the analysis, we see the opportunity to improve store forecasts so that the aggregated forecasts at higher forecasting levels can be substantially improved. We have proposed three models: the bias correction model, the adaptive bias correction model, and the regression model. By applying the bias correction model to the same set of data at the store level, the weighted mean absolute percent error decreased from 94% to 57%. Also, we have conducted an experiment on the combination of bottom-up and top-down approaches to improve replenishment forecasts, which was also proven effective. However, the practical use of these models in the grocery retailer industry is yet to be studied. The cost of improving forecasts should be justified by the benefits grocery retailers would receive.

Although forecasts can be improved using approaches described above, we believe that the key element of success in forecasting is measuring the accuracy and revising the systems and processes according to the current forecasting performance. Thus, we have suggested a framework for measuring accuracy that emphasizes the importance of comparing the accuracy of forecasts generated from systems and from judgments. It is important to note that forecasts from the systems and revisions from judgments should be recorded and analyzed separately so that the sources of forecast errors and the value of forecasters’ judgments could be better identified.
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