Summaries of select research projects by graduates of the MIT-Zaragoza Masters
of Engineering in Logistics and Supply Chain Management

Network Capacity Planning
Team: Pilar Albar Bello, Bruna Fernandes Basile, Fernanda Caropresso
Advisor: Dr. Rafael Diaz & Dr. Spyridon Lekkas

Scenario Planning to Offset Supply Chain Disruptions
Team: Lokesh Deivasigamani, Carmen Gomez Sanchez, Luis Jose Racca
Advisor: Dr. Susana Val

Supply Chain Segmentation in Beverage Industry
Team: Javier Barros, Harrison Dow, Melissa Treviño
Advisor: Dr. Spyridon Lekkas

Hub and Spoke Network Design for a Fast-Growth Company
Team: Daniel Golenbock, Can Phan Xuan, Benjamin Sanford
Advisor: Dr. Rafael Diaz

Effective Forecasting and Inventory Allocation Strategies
Team: Amir Khan, Carlos Mira, Dmytro Rizdvanetskyi
Advisor: Dr. Çagri Gürbüz
Introduction

Welcome to the 2018 MIT Zaragoza Masters of Engineering in Logistics and Supply Chain Management Research Journal!

The five papers included in this journal were chosen from the sixteen projects submitted by the class of 2018 at the Zaragoza Logistics Center. The articles are written as executive summaries and are intended for a business, rather than an academic audience.

The purpose of the executive summaries is to give the reader a sense of the business problem being addressed, the methods used to analyze the problem, and the relevant results, conclusions and insights gained. The complete projects are, of course, much more detailed. We have also included a complete list of this year’s projects with short descriptions at the end of this journal.

The articles in this publication cover a wide range of interests, approaches, and industries. This variety of topics illustrates one of the hallmarks of the MIT Zaragoza program: the students’ ability to focus their course work and research on topics that most interest them.

Some projects are conducted in conjunction with the Zaragoza Academic Partner (ZAP) Program, an initiative to enhance applied research and closer industry-academia relationships in the field of supply chain management.

The ZAP Program gives MIT Zaragoza program students the opportunity to work closely with industry professionals on actual supply chain problems, and gives companies an opportunity to interact with a student or student team along with a professor as expert thesis advisor who together bring new insights and approaches to a current supply chain project.

We hope you enjoy the articles. If you wish to discuss any other aspect of the program or wish to find out how your company can interact with our students, please do not hesitate to contact me directly.

Happy reading!

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Network Capacity Planning

By Pilar Albar Bello, Bruna Fernandes Basile and Fernanda Caropresso
Thesis Advisors: Rafael Diaz, PhD and Spyridon Lekkakos, PhD

Summary:
This thesis addresses the lot sizing and capacity allocation problem of a leading pharmaceutical company. The key question addresses was: how products should be assigned to each production line in order to utilize existing capacity in the best way possible while reducing costs.

Our sponsor company is a large multinational firm, leader of its sector, with significant investments in R&D. It operates a global manufacturing network consisting of 31 sites that incorporates 3 different production stages – drug substance, drug product and packaging – involving 14 different technologies and 42 product families. The combination of all these elements results in more than 3,000 SKUs.

The sponsor company wanted to investigate the current processes for capacity allocation and batch sizing, in order to explore ways for delivering value through supply chain optimization. The question proposed by the firm was: How should products be assigned to each production line to utilize existing capacity in the best possible way while reducing costs? Due to the network complexity and the lack of adequate decision-support tools, assigning manufacturing capacity to different products is a challenge. Currently, allocation decisions occur at the product level with limited overview of interdependencies across products and sites.

In the biological pharmaceutical industry, the size of the batches is determined according to the manufacturing procedures that would result in the best yield, balancing cost components but also technological and quality restrictions. However, when planning the

KEY INSIGHTS

1. The final method selected was largely driven by the fixed nature of the company’s cost structure.

2. This method builds on the idea that by rationalizing the campaign size allocations within its network, the company can reduce its cycle stock, and consequently, its investment in working capital.

3. Campaign sizing and network capacity allocation decisions should be supported by the tool.

Introduction

Over the last few decades, changes in market conditions have imposed new challenges on the pharmaceutical industry. Tighter regulatory constraints and the maturity of the markets have led to lengthy drug approval processes and higher costs for R&D. In this new context, capacity and management attention that were concentrated almost exclusively on R&D, sales and marketing, have started to change their focus to supply chain, as an opportunity to create value through optimization (Shah, 2004).
production of a given SKU, the company usually schedules not only one run (i.e., a single batch), but several continuous runs, called a campaign.

Since there is no established methodology for capacity planning, the usual practice has been maximizing the campaigns size to reach economies of scale in the utilization of highly expensive and specialized equipment. This ad-hoc criterion of large campaign-sizing, however, has a direct impact on inventory performance: some products have excess of inventory while others are not being produced on time to be used in the next manufacturing step.

Different approaches were investigated to solve the problem, including network optimization and standard economic lot sizing. However, due to the fixed nature of the costs in this company, the application of these methods had serious limitations. The proposed solution aims to rationalize the campaign size, decreasing cycle stock, and as consequence, the investment in working capital.

To achieve this objective, two tools were developed. First, the campaign sizing module uses Nonlinear Mixed Integer Programming to define the size of the campaigns and allocate production within the existing network. The scheduling module then recommends how to sequence the order of the manufacturing process for each line to minimize the average inventory. An inventory report provides the view of different scenarios to support the decision process.

Addressing the problem

According to Chopra & Meindl (2013), there are two types of problems where a network optimization approach is a relevant methodology for analysis. First, when a company needs to determine the location and capacity of production and distribution workcenters, the so-called network design (a long-term decision). Second, when a company needs to allocate products (and demand) to existing plants or distribution facilities (a short to mid-term decision). The standard approach in both cases is to formulate the problem as a profit maximization LP program subject to satisfying demand and problem-specific constraints.

As the thesis problem naturally falls under the umbrella of network optimization, this was the first approach followed in our investigation. However, in our attempt to identify and quantify the relevant cost parameters for applying this methodology, and after several rounds of discussion with the sponsor company, we came to the realization that most of the costs involved are fixed in nature. That is, any decision that would rearrange production among the existing production network would have zero impact in the firm’s profit and loss statement.

The fixed nature of the firm’s production costs – particularly of set-up costs that primarily consist of salaries—reduce also the applicability of an economic lot sizing approach to our problem.

Faced with this deadlock in the applicability of established operations management methods in the thesis question, we shifted our attention from profitability to working capital optimization. To that end, the relationship between cycle stock (i.e., batch size) and working capital investment is straightforward: the smaller the batch sizes are, the lower (on average) the value in the inventory account in the firm’s balance sheet.

Therefore, there might be an opportunity to rationalize campaigns size, allowing the production network to produce smaller batches –therefore, decreasing stock—subject to network capacity constraints. The challenge, then, is how to develop a model that is not driven by a cost minimization goal.

A suitable approach would be for the model to maximize capacity utilization. Capacity is defined as the maximum output a resource can produce, in a given period of time, considering ideal conditions. Capacity utilization would be the measure of how much the process actually produces dived by how much it could produce, if running at full speed (Cachon & Terwiesch, 2013).

In the context of this thesis, a different definition is used. First, we consider as utilization all the time associated with these tasks: shutdowns, change-overs, and production. The capacity utilization is then the ratio of the time used in these tasks divided by available time. We do this because we needed a metric to be used in our model, the optimization of which would provide campaigns size aligned with the idea discussed above. The application of this logic will allow the maximum number of production runs
until the capacity limit of the work centre is met (up to some pre-specified level).

This solution was designed to create a real impact on the company balance sheet through working capital management by inventory reduction. To the best of our knowledge, our work is the first attempt to address this type of problem by using a joint working capital-capacity utilization approach.

**Methodology**

In our work, we followed the basic principles of Operations research as a methodology for solving business problems by harmonizing apparently conflicting goals and bringing the optimal solution in the company’s perspective. The first step is formulating the problem and collecting the information. The second phase is developing a mathematical model and a computer based solution for deriving the solutions. In this case, a non-linear mixed integer programming was developed using Excel solver. The third phase is to test the model and refine it accordingly (Hillier & Lieberman, 2005).

Having agreed with the solution approach, the next step was to finalize the scope review. It was agreed that a prototype with reduced scope would be built, focused on the drug substance process. This stage is responsible for manufacturing the active ingredient and it is the most important economically for the process, presenting the biggest challenges in terms of allocation. Revisiting Shah (2004), "needless to say, this node of operation does not lend itself well to responsiveness, and significantly contributes to some of the poor supply chain metrics exhibited by this industry."

Data collection and analysis were done in parallel with the scope discussions, and consisted in analyzing demand, inventory and production data, as well as detailed information about regulatory constrains, to assure consistency when developing the tool. The other milestones will be discussed in next sessions.

**The Model**

The figure below illustrates the framework used for developing our model:

1. **Campaign Sizing:** optimization model that recommends how many runs of each product should be allocated in which work centre, according to the resource availability, regulatory, capacity and demand constrains. See Appendix for the mathematical model.

2. **Campaign Scheduling:** the number of runs and resource allocation recommended in the optimization are translated into a detailed production scheduling. A macro developed in Excel executes different combinations of production orders and recommends the solution that minimizes average cycle inventory over the year.

3. **Inventory Report:** this spreadsheet plots both the demand and the optimized production, providing the view of beginning, average and maximum inventory. A second scenario is provided, communicating to the company what would be the impact in the inventory if the production of the next stage was smoothed.

Sensitivity analysis capabilities are embedded in the system for simulating different what-if scenarios.

**Results and Conclusions**

The optimization model developed will allow the firm to improve the planning process, having a clear view of the impact of sourcing decisions in the inventory and in the feasibility of their production plans.

The campaign sizing tool brings the optimal decision in terms of allocation of capacity and quantity of runs that have to be performed. The campaign scheduling tool will allow the firm to have a detailed production plan, as shown in the picture below.
The inventory report will allow the company to compare the current versus optimized plan, with dashboards that summarizes the results:

The results brought when comparing the scenarios with and without the optimization were really expressive: a reduction of 13,6% in the average inventory only by rationalizing the campaign sizing and scheduling, 23,8% when smoothing the drug substance production and 19,1% when changing the drug substance production according to the drug product demand.

During the discussions on how to use the model, it was noticed that currently the planners divided by product type –drug substance, drug product or finish goods, and product families– and have to schedule production in common machines, which makes the allocation even more challenging. The company has already realized that and has created the role of drug substance and drug product business partner.

Our recommendation is that the business partner for drug substance should be in charge of consolidating all the information needed and run the model in a periodic basis. By centralized this task, the planner can realize synergy opportunities for different drug substance that share the same resources that could not be realized when making a decentralized plan.

A standard procedure, with detailed explanation about the model assumptions and formulas was develop not only to speed up implementation but assure that new people can be easily trained, guaranteeing the process continuity, as well as the extension of the model to the next node – drug substance production.

It is important to emphasize that the methodology and tools developed not only serve as a base to the planning process. The tool can also be used to simulate different what-if scenarios considering different types of projects – temporarily shutdown of a work center, closing of a plant, adding more capacity or getting new regulatory approvals. It will be able to calculate the impact in the current capacity and quickly answer important questions such as:

- Are we going to be able to supply all the demand?
- What the capacity utilization would be in this case?
- How much cycle inventory would be generated?

The model was developed to support the planning decisions with different dimensions such as day by day operations or projects, short or medium terms, using the scientific approach to create a robust innovative solution, with immediate applicability. The results shown and the decision to proceed with the tests confirm that it is possible to make a real impact when business decisions are aligned with a solid academic approach.

**Cited Sources**


Appendix: The Mathematical Model

### Indices

<table>
<thead>
<tr>
<th>Indices</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>Multi-source product in DS workcenters (API)</td>
<td>[1, ..., I]</td>
</tr>
<tr>
<td>j</td>
<td>Single-source product in DS workcenters (API)</td>
<td>[1, ..., J]</td>
</tr>
<tr>
<td>R</td>
<td>End customers (clusters of countries)</td>
<td>[1, ..., R]</td>
</tr>
<tr>
<td>K</td>
<td>DS workcenters</td>
<td>[1, ..., K]</td>
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### Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>X_{ijr}</td>
<td>Volume of multi-source product produced in workcenter k for customer r</td>
<td>Kgs</td>
</tr>
<tr>
<td>Y_{ik}</td>
<td>Total number of runs of product i in workcenter k if 0; else total number of runs of product i in workcenter k is more than 0</td>
<td>1 or 0</td>
</tr>
<tr>
<td>M_{ik}</td>
<td>If no multi-source product produced in workcenter k; otherwise variables needed for calculating the total number of campaigns</td>
<td>1 or 0</td>
</tr>
<tr>
<td>V_{ik}</td>
<td>If no single-source product produced in workcenter k; otherwise variables needed for calculating the total number of campaigns</td>
<td>1 or 0</td>
</tr>
<tr>
<td>X_{ijk}</td>
<td>Number of campaigns (and, therefore, campaigns) of single-source product i in workcenter k</td>
<td>product in DS workcenter k</td>
</tr>
<tr>
<td>M_{ijk}</td>
<td>Number of campaigns (and, therefore, campaigns) of single-source product i in workcenter k</td>
<td>product in DS workcenter k</td>
</tr>
<tr>
<td>R_{ijk}</td>
<td></td>
<td></td>
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</tbody>
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### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAP_{ik}</td>
<td>Production capacity in DS workcenter k</td>
<td>Weeks</td>
</tr>
<tr>
<td>BAS_{ijr}</td>
<td>Baseline volume (budget file) of product i for customer r</td>
<td>Kgs</td>
</tr>
<tr>
<td>KOP_{ik}</td>
<td>Kilo product per run in workcenter k (CP assumption)</td>
<td>Kgs/run</td>
</tr>
<tr>
<td>RunWeek_{ik}</td>
<td>Runs of product per week in workcenter k</td>
<td>Runs/week</td>
</tr>
<tr>
<td>CHOP_{ik}</td>
<td>Time of a changeover in DS workcenter k</td>
<td>Weeks</td>
</tr>
<tr>
<td>MA_{ik}</td>
<td>Maintenance and shutdowns of DS workcenter k</td>
<td>Weeks</td>
</tr>
<tr>
<td>Dth_{ik}</td>
<td>Maximum capacity utilization of DS workcenter k</td>
<td>%</td>
</tr>
<tr>
<td>MinRuns_{ik}</td>
<td>Minimum number of runs per campaign for product i</td>
<td>Runs</td>
</tr>
<tr>
<td>MinRuns_{ik}</td>
<td>Minimum number of runs per campaign for product i</td>
<td>Runs</td>
</tr>
<tr>
<td>WorkFixed_{ik}</td>
<td>Volume in weeks of the baseline of single-source product i produced in workcenter k</td>
<td>Weeks</td>
</tr>
<tr>
<td>RunFixed_{ik}</td>
<td>Runs of the baseline of single-source product i produced in workcenter k</td>
<td>Runs</td>
</tr>
<tr>
<td>X_{ik}</td>
<td>1,000,000 (big number) if product i produced in workcenter k according to regulations; 0 otherwise</td>
<td>1,000,000 or 0</td>
</tr>
</tbody>
</table>

### Objective Function

Maximize

\[ Z = \sum_{i} \sum_{j} (M & S_{ij} + \sum_{r} (N_{ij} \times CHOP_{ij} )) + \sum_{i} \sum_{j} \sum_{k} (K_{ijk} \times WorkFixed_{ik}) ] + \sum_{i} \sum_{j} \sum_{k} \sum_{r} (R_{ijk} \times RunFixed_{ik}) ] + \sum_{i} \sum_{j} \sum_{k} \sum_{r} (D_{ijk} \times CAP_{ik}) ] \]

Subject to:

1. Available capacity of DS workcenters (in weeks)
   \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{CAP}_{ik} \quad \forall k \in K \]

2. Baseline demand fulfillment of DS each product for each customer
   \[ \sum_{i} \sum_{j} \sum_{r} X_{ijk} = \text{BT}_{ijr} \quad \forall i \in I, j \in J, r \in R \]

3. Regulatory constraints of the different clusters
   \[ X_{ijk} \leq \text{LTE}_{ij} \quad \forall i \in I, j \in J, r \in R \]

4. Needed to calculate the # of campaigns (multi-source)
   \[ \sum_{i} \sum_{j} R_{ijk} \geq \text{MinBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

5. Needed to calculate the # of campaigns (multi-source)
   \[ \sum_{i} \sum_{j} \sum_{r} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

6. Needed to calculate the 4th campaigns (multi-source)
   \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

7. Needed to calculate the 4th campaigns (multi-source)
   \[ \sum_{i} \sum_{j} \sum_{r} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

8. Needed to calculate the 4th campaigns (multi-source)
   \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

9. Needed to calculate the 4th campaigns (multi-source)
   \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

10. Needed to calculate the 4th campaigns (multi-source)
    \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

11. Needed to calculate the 4th campaigns (multi-source)
    \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

12. Needed to calculate the 4th campaigns (multi-source)
    \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

13. Needed to calculate the 4th campaigns (multi-source)
    \[ \sum_{i} \sum_{j} X_{ijk} \leq \text{MaxBT}_{ij} \quad \forall i \in I, j \in J, r \in R \]

14. Non-negativity constraints
    \[ X_{ijk}, N_{ik}, Y_{ij}, M_{ik}, V_{ijk} \geq 0 \quad \forall i \in I, j \in J, r \in R, f \in F \]

15. Binary constraints
    \[ Y_{ij}, N_{ik}, M_{ik} \text{ are binary} \quad \forall i \in I, j \in J, f \in F \]

16. Integer constraints
    \[ N_{ik}, M_{ik} \text{ are integer} \quad \forall i \in I, j \in J, f \in F \]
Scenario Planning to Offset Supply Chain Disruptions

By Lokesh Deivasigamani, Carmen Gómez Sánchez and Luis José Racca
Thesis Advisor: Dr. Susana Val

Summary: This thesis proposes a methodological framework so as to capitalize the utilization of S&OP scenario planning tools by our sponsor company and other firms within the medical device industry in their commitment to provide high levels of customer service while dealing with the uncertainty given from the most critical disruptions in their supply chains.

KEY INSIGHTS

1. S&OP scenario-based planning appears as a powerful tool to build supply chain agility in companies within the medical device industry: committed to high customer service levels, constrained by strict regulations and continuously challenged by uncertain situations.

2. Software vendors have developed S&OP tools to support scenario planning in an integrated way. The successful performance of scenario planning will therefore rely both on the planner’s expertise and on the quality of enabling software.

3. This research has allowed determining the most critical scenarios for a company within the medical device industry, evaluating the top software vendors solutions and providing a utilization framework that will serve as a guide to planners during their familiarization with the S&OP scenario planning tool.

Introduction

The sponsor company is a global leading manufacturer of medical devices highly committed to ensure the maximum availability of its products, given their importance in surgical operations across the world. The company has about 60% of the global market share with a family of products, which means that six out of ten surgeries around the world may require one of these medical devices.

For these reasons, the company has been implementing different solutions to improve their planning process and guarantee the highest customer service level. These initiatives are not only a way to reinforce their social commitment but also a strategic move to avoid ceding space to competitors and losing their privileged position in the market.

However, maintaining a high customer service level becomes challenging when dealing with uncertain scenarios such as new product introductions and big tenders; or simply overcoming unforeseen disruptions within the supply chain that could jeopardize supply and production capacities.

For dealing better with uncertainty and anticipating the impact of planning decisions in the long-term, the firm is implementing a new Integrated Business Planning (IBP) software. This implementation is intended to integrate information along their vertical operations.
Furthermore, this system has some powerful scenario planning capabilities that the company would like to take advantage of. During the development of this project, we have considered scenario planning capabilities as a replica of what-if-analysis tools, which will provide users a comparison of different scenarios with a base scenario.

By performing an internal analysis within the sponsor company, most disruptive supply and demand scenarios have been identified. It is intended to use this list as a helpful compilation for the sponsor company as well as for other players within the healthcare field.

Additionally, this thesis provides a benchmarking analysis of IBP software solutions available in the market with scenario planning capabilities and experience in the medical device field. This study is framed with the purpose of defining most relevant software capabilities to model specific characteristics within the industry.

Finally, a methodological framework is proposed with the intention to serve as a guide on the modeling, interpretation and reporting of scenarios within an S&OP process context.

**Methodology**

The methodology applied relies first on an internal analysis within the sponsor organization, allowing us to determine key scenarios for the company; and second, on a study among IBP software vendors and healthcare competitors to determine additional features and relevant uses from an industry perspective. Both analysis have entitled us to recommend an approach on how to utilize S&OP scenario planning tools. Figure 1 details the process followed with each of the parties.

**Identifying Key Scenarios – Internal Analysis**

The internal analysis was initially launched following the classical scenario planning methodology developed by Schwartz (1996) and based on the identification of local factors and driving forces capturing the higher uncertainties from a supply chain disruptions’ point of view.

Personal interviews with sponsor company’s stakeholders and additional literature review have allowed us establishing a list of local factors and driving forces that can be accessed in the text of the thesis.

In order to adapt classical scenario planning approach (aimed at long term strategic decisions) to S&OP what-if analysis objectives (targeting medium to short term tactical decisions) local factors and driving forces were converted into specific demand and supply scenarios listed on the tables below.

<table>
<thead>
<tr>
<th>Table 1: Initial Demand Scenarios List</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Demand Scenarios</strong></td>
</tr>
<tr>
<td>A new product is cannibalizing an established product</td>
</tr>
<tr>
<td>A new product is selling much faster than expected</td>
</tr>
<tr>
<td>A product needs to be urgently recalled</td>
</tr>
<tr>
<td>Demand increases suddenly due to a big tender contract</td>
</tr>
<tr>
<td>Fluctuations in demand due to changes in health care insurance policies</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2: Initial Supply Scenarios List</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply Scenarios</strong></td>
</tr>
<tr>
<td>A facility is temporarily not operating due to a natural disaster or labor strike</td>
</tr>
<tr>
<td>A new inventory policy change is going to be applied</td>
</tr>
<tr>
<td>A planned maintenance shutdown at a production or warehouse facility has been unexpectedly rescheduled</td>
</tr>
<tr>
<td>A shipping lane becomes unavailable</td>
</tr>
<tr>
<td>Defective batch recognized and rework claimed</td>
</tr>
<tr>
<td>Production capacity is unexpectedly reduced due to a machine breakdown</td>
</tr>
<tr>
<td>Supplier communicates on non-ability to supply for long term</td>
</tr>
<tr>
<td>Supplier communicates on non-ability to supply for short term</td>
</tr>
<tr>
<td>Variation on the flow of goods through the supply chain due to tax changes</td>
</tr>
<tr>
<td>Variation on the flow of products (or raw materials) due to regulatory changes</td>
</tr>
</tbody>
</table>

Then, stakeholders were asked to fulfill an online survey so as to rank scenarios by impact and likelihood. The simple average of results allowed building a matrix representation of demand and supply scenarios based on the vulnerability framework provided by Sheffi & Rice (2005).

Matrix representation allows classifying scenarios in 4 main groups or quadrants based on vulnerability matrix classification described by Sheffi (2005):

- **Quadrant 1**: scenarios in this quadrant have high probability of occurrence and high impact on the company’s performance, justifying a recurring scenario planning analysis on several S&OP cycles as those situations may occur several times in a year.
• **Quadrant 2**: scenarios in this quadrant have high probability of occurrence but low impact on the company’s performance. The resolution of this kind of situations are part of the scope of a daily supply chain management in the normal operation of the business and would not require further study within S&OP meetings.

• **Quadrant 3**: scenarios in this quadrant have low probability of occurrence and low impact on the company’s performance which would not require attention in S&OP meetings.

• **Quadrant 4**: scenarios in this quadrant have low probability of occurrence but high impact on the company’s performance, that is to say, the “black swans” quadrant according to Sheffi (2005). In fact, this kind of scenarios could represent a significant risk as usually companies do not prepare to face such unexpected situations (e.g. hurricane, massive recall).

Therefore, we consider these scenarios should be evaluated within S&OP meetings although they might not require a recurring analysis in several S&OP cycles since these situations would occur at most once in a year.

Considering the type of scenarios that are more prone to be analyzed during S&OP meetings, the sponsor company agreed on providing focus on quadrants 1 and 4. Then, using subject-matter-expert opinion from the firm, results were pondered with a weighted average depending on the different departments that participated in the survey.

Previous considerations about demand and supply scenarios and other scenarios pointed by stakeholders are represented in the matrices (Figure 2 and Figure 33) that provides a complete picture of the disruptive situations considered in the study.

Based on author’s recommendation, the sponsor representatives decided to establish two rankings of the most critical scenarios: one considering scenarios from quadrant 1 and another that would consider scenarios from quadrant 4. In this way, it would be possible to make the difference between recurring scenarios to be evaluated at several S&OP cycles per year from unlikely scenarios which would only require to be analyzed once every one or two years.

**IBP Software Solution – Benchmarking analysis**

A benchmarking analysis was carried out to measure the vendor’s products in terms of S&OP scenario features among all the competitors mentioned in the Gartner’s Magic Quadrant for S&OP System of Differentiation (SOD) published in May 2017.

To make the analysis feasible and aligned with the sponsors’ software’s preference, the study was focused on the software vendors falling in the leader and visionaries’ quadrants. As it is shown in Figure 2, this selection was restricted to two quadrants considering market scope and matching with the sponsor’s business strategy.

**Figure 2: Software Vendors Classification - Source: Own based on Gartner 2017**

Despite several efforts made, the research team could only schedule demo sessions with four vendors. Two were classified as leaders: OM Partners & River Logic;
and other two were classified as visionaries: Llamasoft and Toolsgroup. Evaluation parameters were chosen such that it meets the capability requirements as per Singh and Lee (2013). Based on feedback from demos and evaluation from other sources of information, a score on a scale of one to eight was provided to each vendor tools as shown on Table 3.

**Table 3: Software Vendors Evaluation Grid**

<table>
<thead>
<tr>
<th>Evaluation Item</th>
<th>Llamasoft</th>
<th>River Logic</th>
<th>Toolsgroup</th>
<th>OM Partners</th>
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<td><strong>6.64</strong></td>
<td><strong>6.36</strong></td>
<td><strong>7.45</strong></td>
</tr>
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</table>

Framework Creation

For updating and executing scenario-based planning, the authors have proposed the following framework for creation and management of different scenarios within an S&OP process context:

![Figure 3: Framework Diagram](image)

Conclusions

The use of scenario planning software capabilities provides valuable information to deal with embedded uncertainty and support the decision-making during the S&OP process. This thesis sets the basis to simplify learning about the use of scenario software capabilities for planners in the medical device industry. The main insights gained from this research can be summarized as follows:

- The selection of scenarios should rely on the identification of the most relevant tactical uncertainties, their conversion into specific disruptive situations and their ranking by impact and likelihood. Only high impact scenarios should be evaluated within an S&OP process adjusting the frequency of analysis to the scenario probability of occurrence.
  - A complete portfolio of high impact scenarios has been provided to the sponsor company, although the list will have to be periodically updated as risk evolves with both the company and the industry.
  - The benchmarking analysis allowed measuring the scenario planning capabilities among the top software providers. Software vendors who participated in the study have proved to have powerful applications although results point out OM Partners (our sponsor’s tool of choice) as the most recommendable solution within the medical device industry.
  - A methodological framework has finally been proposed providing planners with guidance on the selection, modeling and interpretation of scenarios for an S&OP process. The analysis should foster discussion, propose solutions and enhance consensus decision-making.

This research outcomes will help the medical device industry and our sponsor company to leverage their supply chain by tackling disruptions in a more efficient and responsive manner.

Cited Sources


Supply Chain Segmentation in the Fast-Moving Consumer Goods Industry

By Javier Barros, Harrison Dow, Melissa Treviño
Thesis Advisors: Dr. Spyridon Lekkakos

Summary:
This thesis investigates supply chain segmentation in the context of the fast-moving consumer goods industry. A tailored tool has been developed, which provides 3D analysis capabilities at the SKU-level and 2D at the customer-level, along with other value-adding features.

KEY INSIGHTS
1. Supply Chain Segmentation is feasible in the fast moving consumer goods (FMCG) industry.
2. 3D Segmentation: Volume-Volatility-Value as the dimensions.
4. Tailored tool for easy visualization and analysis of segmentation.

Introduction
In a market environment that is continuously evolving, modern supply chains are characterized by high complexity due to the speed of changes in consumers’ preferences, but also due to intensive competition among industry players. Customers are being offered more customized versions and also, firms are introducing new channels to fulfill demand. The product and channel proliferation pose challenges to companies to remain competitive and profitable. Supply Chain Segmentation can be a valuable tool in helping companies reconfigure their supply chain strategies.

To use it though, a company needs to have a deep understanding of: different processes in the SC, characteristics of the products, types of markets and customers, distribution channels, and company dynamics. SC Segmentation shall be seen as an ongoing process that needs to be reevaluated periodically in this ever-changing environment.

The sponsor company, AbcCo, is a fast-moving consumer goods company. The company has many brands, making its portfolio diverse and unique, but also very complex. To meet the strategic goals while maintaining its current profitability, AbcCo seeks to see if SC Segmentation can provide direction the firm’s SC for meeting efficiency and responsiveness targets well into the future.

Methodology
The first step was to review different sources of literature in order to understand: (a) the importance, concepts and different types of segmentation; and (b) the key findings from real cases of companies that have already implemented segmentation to restructure their supply chains. The second step was to map current situation of the company to
understand the SC processes, product characteristics, the different demand channels, the company dynamic, and key performance indicators. During this step, meetings with AbcCo’s representatives from various departments are also held.

Steps 3 and 4 were executed simultaneously in close collaboration with the company. To decide the segmentation approach and select the most suitable models, an iterative process was followed where sample data was provided by the company, analyzed by the team and discussed again with the company. This process took place several times until the segmentation dimensions were finally selected and the model was finalized. Once the model was decided, it was fed with available data in collaboration with the sponsor for making sure that the data was interpreted correctly and was aligned with the company context.

To make the model practical, a tool was developed in which all the dimensions and segments were stated, along with the SKU data, customers, type of packaging, type of markets, and other relevant quantitative information that will be discussed later in this document. When this tool reaches maturity, a large-scale workshop with the sponsor’s top SC managers took place to validate the tool performance, but also identify opportunities for using the insights provided for realigning the company’s operational strategies.

The industries of the existing cases operate much different than a FMCG company and that the segmentation results cannot be duplicated without modifying the variables. To the best of our knowledge, this is the first study that attempts to apply a hybrid segmentation approach into the fast moving consumer goods industry A segmentation model using three different variables, inspired by Olvason et al (2010), was chosen as the foundation of building the new model.

**Analysis and Model building**

Our approach to SC Segmentation for AbcCo is driven by the fact that different stages in the supply chain are faced with different types of complexities. Also, there is a decoupling point in the SC segmentation, which is at the warehouse. The three variables that will be focused on are volatility, volume, and value. Furthermore, each of these three variables will be divided in another two segments – high and low.

Two types of Coefficient of Variation (CV) were considered: CV of sales and CV of sales forecast. CV of Sales was chosen due to the high correlation with the CV of forecast and the fully availability of the info. Figure 1 shows the cutoff for Volume and Volatility’s high and low threshold. Figure 2 shows the VALUE threshold.

**Literature Review**

From Academic scholars Protopappa and Thonemann (2017), it becomes clear that segmentation on its own has little value, if not associated with particular set of operational actions that will lead to some type of differentiation in the way individual segments are served. There are three main segmentation techniques in these academic studies: market-driven, product-driven, and hybrid product-market segmentation.

![Table 1: Methodology diagram](image)

![Figure 1: High and Low levels for Volume and Volatility per SKU](image)

![Figure 2: High and Low levels for VALUE per SKU](image)
A 3D cube was defined (Figure 3) where each segment was characterized to make it easier for the stakeholders to understand and relate each box to the behavior of SKUs inside. Each animal represents a type of behavior and the color is related to the value variable (green for high margin and red for low). The animals and colors match well with AbcCo’s existing segmentation, which made it easier for them to understand and analyze.

![Figure 3: Final 3d model cube](image)

After the decoupling point, the segmentation is focused on the customer side since service requirements per customer are not the same and this type of segmentation might reveal well-functioning relationships and challenging customers.

For analyzing the volatility dimension at the customer level, we base our analysis on the relative size of stable SKUs within each customer’s portfolio. This percentage of volume built by SKUs with high volatility (CV) was calculated for each customer to segment the customers into two groups: One group with highly volatile SKU content and the other with low volatility SKU content. The SKU threshold was set.

Having analyzed the customers on the basis of the (redefined) value and volatility dimensions, four segments emerge, which we characterize by using 4 medals: Gold, Silver, Bronze and Wooden, from most desirable to the least (Figure 4). The gold segment represents the customers who have high value (VALUE) and low % of high-volatility SKUs.

![Figure 4: Customer Segmentation](image)

Segmentation tool and Strategic Alignment

The segmentation tool (Figure 5) developed in this thesis allows the user to visualize the SKU and customer segments along with the interrelationships within by changing the tool options and parameters.

![Figure 5: View of the Dashboard](image)

The tool was developed in excel and it has 2 main views: a pivot table and a dashboard. The dashboard allows a quick visualization of huge sets of information which can be understood in an easier way than abstract or complex contents. It is very useful when comparing markets or customers (Table 3). Relevant questions are raised from this data visualization. What are the main differences between two different customers? What kind of SC Strategies should be applied to reduce the differences between a wooden and a golden customer?

Our discussion on operational reconfiguration follows the segmentation approach and is organized in three parts (Figure 6): Pre-decoupling, Post-decoupling and end-to-end strategic actions.
Pre-decoupling point

Production
The use of the animal characterization of the segments can guide to Production planners to set the SKU’s prioritization according to Volume, Volatility, and Value classifications. Once the low-volume high volatility products have been identified, decisions such as introducing low-capacity responsive lines and allocating the SKUs accordingly, can be supported by reliable quantitative data and be made in a systematic way.

Inventory policies/ Forecasting at SKU level
The segmentation tool allows identify in a simple way the products that might need different forecasting techniques based on the segment where they are categorized. The segmentation tool allows taking targeted forecasting investment decisions on the basis of the colored animal segments and their characteristics.

Post-decoupling point

Distribution
As the tool allows users to visualize the profitability and volatility profile of the different customers (both at the individual and aggregate SKU level), distributors can be segmented into two group: one group to low volatility customers using efficient distribution whereas the high volatility customers will have a more responsive setup.

Customer Service Level
The tool can help by creating opportunities for differentiation and prioritization of the efforts in building customer relations. By providing disaggregate information per customer, the tool can help systematize the understanding of the value that each customer brings, but also the identification of areas for improvement in the relationship.

Stock rationing policy
Tradeoffs are unavoidable when inventory levels are low and capacity is restricted. The tool gives a clear customer segmentation that combined with the market and customer knowledge inside the company that can be translated in better decisions on how to prioritize which customers are going to be served (high priority) and which will be rejected.

End-to end

Product penetration
The tool provides a systematic way for tracking the progress of the product. Figure 7 shows the growth a product follows. Several courses of actions can be done through the study of growth patterns, best and worst performing customer/channels. Also, the tool can support product elimination decisions.

Reflections and Limitations
This thesis is the summary of a journey between the research team and the sponsor Company where the state of knowledge was pushed by applying a hybrid approach to a manufacturer of FMCG (Fast Moving Consumer Goods), realizing that there was no documented methodology or strategy to approach Supply Chain Segmentation that fits with AbcCo’s necessities for segmentation.

This thesis has also obvious limitations, mainly in our discussion of the strategic alignment. This is the implication of the fact that two important actors are missing from our analysis: customer and producer. However, to understand the main points in production and the customer profile and needs, the scope will be increased greatly.

Cited Sources


Hub and Spoke Network Design for a Fast-Growth Company

By Canh Phan Xuan, Benjamin Sanford, and Daniel Golenbock.
Thesis Advisor: Rafael Diaz

Summary
This research project addresses hub network design for a fast-growth express delivery company in the largest city of Vietnam. Multiple techniques were applied to explore potential hub locations including multiperiod mixed-integer programming, driving distance clustering, and simulation to validate the robustness of the solution.

KEY INSIGHTS

1. It is necessary to account for the difference between Cartesian and driving distances when clustering spatial constrained data in order to approximate the true physical geographical distance and efficiency of the network.

2. Although ideal hub locations have been determined, the optimal time in which to open the hubs as well as the hubs’ size needed to meet increased demand must be confirmed by implementing a MIP with multi-period extension.

3. By running a simulation that varies both cost and demand parameters, a planner can reflect on not only which hubs are being opened most frequently but on how efficiently they are being utilized.

Introduction
In meeting the demands of a fast-growing industry, the number and location of a firm’s facilities is a critical factor in its long-term strategic and competitive advantage (Daskin, 2013). Placing distribution centers in suboptimal locations invariably leads to under or inefficient utilization of the resources of these locations. By accurately forecasting demand and tying projections to network design decisions, companies can optimize the utilization of their resources. In many cases companies make network design decisions based on accessibility or intuition. By first evaluating these important choices with a relatively simple framework, companies can position themselves to make strategic decisions based on sound reasoning, allowing them to defend their capital expenses to stakeholders.

A common drawback when making network design decisions derives from the fact that traditional clustering algorithms do not reflect real world conditions. When designing a network within a relatively small radius, straight line and curved distances do not approximate the true physical geographical distance and efficiency of the network. When physical boundaries and urban features such as traffic are taken into account what was ostensibly an optimal distribution network is revealed to be counterproductive. For these reasons, it is critical...
that driving distance between distribution centers and demand clusters (and by extension the circuity of the region) be considered.

After the hub locations have been selected a simulation can be performed highlighting the effects that demand variability has on the network. Although the ideal hub locations have been determined, the optimal time to open a new hub to meet increased demand must still be confirmed. By running a simulation that varies both cost and demand parameters, the company will be able to reflect on not only which hubs are being opened most frequently but on how efficiently they are being utilized.

Methodology
Our methodology consisted of six steps and is summarized in Figure 1:

1. Data collection & cleaning
2. Customer demand (Creating Tolls)
3. Building baseline model
4. Analysis, interpretation, and simulation
5. Multi-period optimization: greenfield and brownfield - Model to support an optimal size of each hub
6. Optimization model, comparison to current network configure

Figure 1: Methodology summary

Customer Demand Aggregation
Due to the size of the data - up to 700,000 transactional data points in a month - querying and validating is a very time-consuming process. Consequently, it was determined that taking a representative random sample from the population would save on processing time while still giving accurate results.

We used the below formula for calculating sample size n:

\[ n = \frac{N \times X}{(X + N - 1)} \]

where,

\[ X = Z_{a/2}^2 \times \frac{p \times (1 - p)}{MOE^2} \]

and \( Z_{a/2} \) is the critical value of the Normal distribution at \( a/2 \) (e.g. for a confidence level of 95%, \( a = 0.05 \) and the critical value is 1.96), MOE is the margin of error, \( p \) is the sample proportion, and \( N \) is the population size.

A two-pronged approach was essayed. The first method took equal size samples of package deliveries from each district. We set our sample size at \( n = 400 \). This gives a 95% confidence interval while maintaining a 5% margin of error. Each of the 400 samples from the 19 districts were then geocoded using Google API and a VBA code in Microsoft Excel. This provided the latitude and longitude of each delivery address to determine the center of gravity (CoG).

Below are the formulas used to calculate CoG.

- \( C_x = \frac{\sum x_i \times w_i}{\sum w_i} \)
- \( C_y = \frac{\sum y_i \times w_i}{\sum w_i} \)

These calculations were performed for each district in order to determine that district’s optimal COG based on historical shipment data. Below are the 7,600 shipments (400 from each 19 districts) plotted with the size of the point commensurate with the package weight. In Figure 4 are CoGs plotted on a map of Ho Chi Minh City with labels designating each district.

The next method obtained a data sample using a random sample from the total number of shipments. Some districts have as many as five times the shipment volume of other districts. These higher shipment densities affect where the CoGs are generated when using clustering methods as discussed below. To obtain this random sample the “=Rand()” function was once again used and the results were sorted from smallest to largest as before. A sample of \( n=5,000 \) was taken. All of these addresses were geocoded and stacked for further analysis (Figure 3).
In order to determine the optimality of the current network configuration, center of gravity was applied to the 19 districts based on volume during a period of peak demand. Center of gravity was selected as it is a very useful heuristic for approximations when dealing with limited data. Nevertheless, in order to remove the constraints imposed by the city’s administrative divisions, we applied clustering techniques to the aggregation starting with k-means. As a centroid-based clustering technique, k-means can quantify inter-location distances in order to associate locations with clusters, decreasing the number of interactions between entities. In this case, we also needed to account for the difference between driving distance and Euclidean distance. This is because our coordinates were composed of latitude and longitude and there exist numerous physical geographical boundaries and obstacles between them. As a result, we implemented a more recently published methodology entitled “Facility Location Decisions Based on Driving Distances on Spherical Surface” (Han, 2015). Han’s work bases its approach on optimal driving distances generated from Google Maps. Using Google API, driving distance (from Google Maps) between each input location and every other location is queried and input in a matrix which is then used to generate the clusters. The algorithm allowed us to account for both shipment density as well as precise driving distance.

Working with 19 CoG weighted locations and 400 random variable locations, we applied Han’s driving distance matrix using Google API. The clustering algorithm we employed took the 7600 (19 X 400) distances generated by the matrix and clustered each of the 19 rows of distances (for example, the distance from location 1 to each of the other 400 locations). The clustering was computed based on the distance with shipment volume weighted on the 19 X 400 dimensional location data while the actual clustering was done on the location coordinates. The resulting output was 19 clusters of locations with x, y coordinates. The following is a summary of the algorithm implemented:

1. Using Google API’s distance-matrix platform, input GPS coordinates data representing the centers of gravity for the volume of shipments of each of the 19 districts in Ho Chi Minh City as well as data representing 400 randomly selected coordinates.
2. Parsed returned data to get distance values, creating a 19*400 matrix of distances in meters.
3. Input weight data representing the volume of shipments of the 19 COGs.
4. Set parameter of the minimum distance that the algorithm needs to find between a centroid and its corresponding location. min_distance = 20000; num_clusters = 19
5. Performed k-means clustering on the matrix_data; calculated coordinates, distances, and centroids
6. Initialized Cartesian coordinates, calculated x, y, z using GPS coordinates, calculated centroid coordinates, translated centroid coordinates from Cartesian back to degrees.
7. Passed through each location in the cluster and calculated its distance from the centroid using Google API.
8. Exported the GPS coordinates based on the cluster #, exported distances from centroid to each location in the cluster and center locations for each cluster.
Mathematical Model

Hub network optimization

As previously mentioned, our objective was to find an optimal network configuration that includes (1) optimal flow for orders throughout the hub network; (2) a roadmap of open hubs corresponding with demand growth. To accomplish this task, we developed a multi-period optimization model over a three-year planning horizon (12 quarters).

The mixed integer linear program aims to answer the following questions:

- How much cost savings can be realized by designing a new network?
- How much more efficient, in terms of cost, is clustering vs. CoG?
- Can demand be met with the facilities selected?
- At what time should each hub be opened to minimize cost?

Indices:

<table>
<thead>
<tr>
<th>I</th>
<th>set of hub facilities i ∈ I</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>set of forecasting period t ∈ T</td>
</tr>
<tr>
<td>J</td>
<td>set of demand points j ∈ J</td>
</tr>
</tbody>
</table>

Variables:

- $x_{ijt}$ : Quantity of parcel X flow through Hub i to customer j in period t, unit: parcel
- $y_{it}$ : 1 if hub i is recommended by the model to open in period t, 0 otherwise

Parameters:

- $\varphi_{ijt}$: Fixed outbound last-leg transportation cost from hub i to customer demand point j in period t, unit: USD/parcel
- $\theta_i$ : Fixed hub cost is defined by the default size of each hub multiplied times the renting cost/ sqm in location i, unit: USD/sqm
- $vo$ : Variable outbound last-leg transportation cost, unit: USD/mile
- $d_{ij}$ : Distance from hub i to customer demand point j, unit: mile
- $K_i$ : Delivery capacity of Hub i, unit: parcel
- $D_{jt}$ : Demand of customer j in period t, unit: parcel

Minimize (z)

\[
\min \sum_{i \in I} \sum_{t \in T} \theta_i y_{it} + \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} (\varphi_{ijt} + vo \cdot d_{ij}) \cdot x_{ijt} \tag{1}
\]

Subject to:

\[
\sum_{i \in I} x_{ijt} = D_{jt} \text{ for } \forall j \in J \quad \text{← (2) Demand constraint}
\]
\[
\sum_{j \in J} x_{ijt} - My_{it} \leq 0 \quad \text{← (3) Linking constraint}
\]
\[
\sum_{j \in J} x_{ijt} \leq K_i \text{ for } \forall i \in I \quad \text{← (4) Delivery capacity constraint}
\]
\[
y_{it} = \text{binary} \quad \text{← (5) Binary constraint}
\]
\[
x_{ijt} \geq 0 \quad \text{← (6) Non-negativity constraint}
\]
\[
y_{it} \geq y_{it-1} \quad \text{← (7) Constraint signaling once a hub is opened it will not be closed}
\]

Hub sizing optimization model

One drawback of the above approach is the universally assumed hub size of 1,500 m² suggested by the company. This approach can lead to underutilization of hubs as well as difficulty locating a hub within the specified range, particularly within the city center. To tackle this problem a hub size optimization model was developed.

Variables:

- $x_{ij}$ : Quantity of parcel X flow through Hub i to customer j, unit: parcel
- $s_i$ : Size of hub i, unit: square meter

Parameters:

- $\varphi_{ij}^c$: Fixed outbound last-leg transportation cost from hub i to customer demand point j in period t, unit: USD/parcel
- $y_{it}^c$: 1 if hub i is recommended to open in period t, 0 otherwise
- $vo^c$: Variable outbound last-leg transportation cost, unit: USD/mile
- $d_{ij}^c$: Distance from hub i to customer demand point j, unit: mile
- $K_i^c$: Delivery capacity of Hub i, unit: parcel
- $D_{jt}^c$: Demand of customer j in period t, unit: parcel
- $m_i^c$: Minimum space of hub i
- $M_i^c$: Maximum space of hub i

Minimize (z)

\[
\min \sum_{i \in I} \sum_{t \in T} \left( s_i \cdot r_i \cdot y_{it} \right) + \sum_{i \in I} \sum_{j \in J} \sum_{t \in T} \left( \varphi_{ijt}^c + vo^c \cdot d_{ij}^c \right) \cdot x_{ijt} \tag{8}
\]

Subject to:

\[
\sum_{i \in I} x_{ijt} = D_{jt}^c \text{ for } \forall j \in J \quad \text{← (9) Demand constraint}
\]
\[
\sum_{j \in J} x_{ijt} - My_{it} \leq 0 \quad \text{← (10) Linking constraint}
\]
**Interpretation & Results**

**Baseline result**

Our replicated model confirmed that excluding fixed costs, each order would cost the company $0.339, compared to the actual average cost per order of $0.340. In other words, the simulated cost per order was lower than the actual cost by 0.27%.

The model solution shows that the potential cost savings is $6,291 for week 51, equal to 8.42% of total cost, as described in the table below.

<table>
<thead>
<tr>
<th>Table 1: Optimal vs baseline</th>
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<tbody>
<tr>
<td>Cost structure</td>
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<tr>
<td>-------------------------------</td>
</tr>
<tr>
<td>Fixed cost</td>
</tr>
<tr>
<td>Outbound delivery cost</td>
</tr>
<tr>
<td>Total cost</td>
</tr>
<tr>
<td>Total # of hubs</td>
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</tbody>
</table>

**Model Result and Analysis**

The model was used to optimize the network based on one week of historical demand data in order to set a baseline to test the model. It was then run for four separate multi-period scenarios all with the same demand growth projection. The four scenarios were laid out as follows:

1. Center of Gravity Clustering – Greenfield
2. Center of Gravity Clustering – Brownfield
4. K-Means Clustering – Brownfield

To complete this model, we used Open Solver, an open source Excel add-in. One advantage of open source add-ins is that companies can easily install and integrate them into Excel. Any employee that needs access to this tool can do so without paying exorbitant licensing fees or undergoing extensive training.

As observed in the table below, the greenfield CoG proved to be the lowest cost network. We expected the greenfield clustering analysis to provide the lowest cost network, and although it was not the lowest it was within 1.3% of the greenfield CoG network cost. The initial explanation for this discrepancy is the sample size of shipments for the driving distance clustering. While we were able to run 400 data points, a sample of 1,000 or ideally 5,000 would produce a realistic picture of demand without the inherent risks of outliers in small-sized samples. The algorithm that was developed for the clustering relies on Google API calls. These are free of cost up to a limit of 2,000 queries per day. With 1,000 shipment points and 19 hubs (=19,000 distances), this analysis would be either time or cost prohibitive. With little time remaining, we decided to take a sample of 400 and analyze the results.

<table>
<thead>
<tr>
<th>Table 2: Matrix to compare the optimal solutions</th>
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<tbody>
<tr>
<td>Driving Distance Clustering</td>
</tr>
<tr>
<td>Greenfield</td>
</tr>
<tr>
<td>Brownfield</td>
</tr>
</tbody>
</table>

Below is the roadmap of the greenfield clustering network option. This table indicates when to open each hub along with the utilization of each hub at any given time. Within the model identical charts are developed for every combination of brownfield/greenfield and clustering/CoG.

| Table 3: Hub selection road map & utilization rate |

In Table 3, three hubs (Hub 3, 11, and 17) would be underutilized (less than 50%) from serving areas with relatively low demand. The result of the hub sizing optimization model suggests that at the end of the designated period, all of the opened hubs should be fully utilized. Moreover, we tested a “naive” solution to determine hub size by multiplying the default hub size (1,500 m²) by the maximum utilization rate of the entire period (2019-Q1 to 2021-
Q4). The hub size optimization model and “naïve” solution returned $287,525 and $302,609 respectively, resulting in a total fixed cost savings of 5.25% across the hub network over the entire period. This approach performs best in situations in which the decision maker is confronted with capacity constraints as well as variance in set-up cost across regions.

Simulation
To simulate variability in demand forecasting we employed Excel functions NORM.INV and RAND() to generate a random probability of demand. A VBA code was composed that inputs the values of the randomly generated demand into the model. The code then takes the results indicating which hub is to be open during each period and inputs it into a table. This data is then compiled after every simulation to show what percentage of the time that hub was selected.

In the model one can input how many simulations are to be run; the model then displays how many times the simulation has been executed. The figures below demonstrate an instance in which 1,000 simulations are performed with a 15% standard deviation of demand.

Table 4: Simulation Results

Table 5: Average Hub Capacity Utilization (%)

Conclusion
In clustering 19 city districts’ center of gravity as part of our greenfield analysis, we used driving distance to determine the ideal location of hubs while disregarding the current facilities in the network. The network optimization was performed on both the brownfield and greenfield sites for both standalone CoG and clustering, using both fixed and variable costs. The model determined the lowest cost to service the 19 clusters managing the tradeoff between facility and transportation as well as fixed and variable costs.

Simulating variable demand with an estimated 15% standard deviation confirmed that the models were robust against stochastic fluctuations over a 12-quarter period; that most hubs are to remain open under all scenarios; and that their utilization is maximized. Both greenfield scenarios proved cost-efficient compared to the brownfields. Moreover, both the CoG and clustering greenfield models were within approximately 1% of each other’s cost. However, because clustering is unconstrained by arbitrary administrative divisions and because it applies real-time driving distances, the clustering model far surpasses CoG for accuracy and distance efficiency.

It is for this reason above all that we recommended greenfield driving distance clustering to the sponsoring company. It now has a repeatable process for implementing similar analyses in its other markets using open source software that is easily accessible and user-friendly. The project proved that using this greenfield clustering technique produces a more optimal solution more quickly compared to the baseline, reducing administrative and software costs. The company can now change constraints to allow more involved services and costs, reduce its margin of error and rapidly implement many scenarios and cost models with one repeatable process.

Cited sources
Effective Forecasting and Inventory Allocation Strategies

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Summary:
This project tackles forecasting methodology for intermittent demand, pooling to reduce inventory and delaying stock allocation to reduce redistribution. We developed a robust tool capable of simulating forecasts, procurement, network design, transportation, and sales for 100M+ user-selected scenarios. Our recommended scenario attains 21% operational cost and 44% inventory reduction.

KEY INSIGHTS

1. Application of forecasts in simulation of procurement, inventory management, and distribution within network design yields actionable and pragmatic results.

2. Systematic classification for inventory pooling decreases stock levels and redistributions while mitigating risk exposure to obsolescence.

3. Transition to a hub and spoke network coupled with service level based inventory policy results in recurring operational cost reductions as well as a one-time large working capital recapture.

Introduction

Inventory is one of the cornerstones of Supply Chain, and without active management, it can rapidly turn from value-added to a massive drain. Order quantities and distribution are an important part of inventory management and primarily driven by forecasting. An effective forecasting methodology is key as forecast errors lead to mismatch of supply and demand, and consequently surplus. SCM researchers have developed various models to help forecast future needs based on statistical analysis of historical data. We exhaustively compared the performance of five time-series methodologies versus two modified “naïve” techniques used by the sponsor on a sample dataset to identify and recommend a model best-suited to the company.

We also addressed forecast accuracy beyond methodology. The existing distributed network and long order cycles significantly influence order quantities as well as forecast error. While all forecasts are wrong, aggregated forecasts are more accurate than dis-aggregated, and shorter horizon forecasts are more accurate than longer horizon. With this in mind, we recommended a “hub and spoke” network that allows aggregation of demand by locations and shortens the distribution forecast horizon by delaying inventory allocation. Rather than optimization, we took a simulation-based approach to network design. Simulation allows performance measurement of alternatives under considerable flexibility and a high degree of realism supplied by decision-makers – something we found essential for effective network re-design.

We developed a user-friendly scenario based “tool” that generates aggregated and dis-aggregated
forecasts, performs clustering, assigns locations to clusters, classifies inventory, simulates stock, transportation, and sales, and yields performance results for evaluation and conclusions.

Our recommended scenario combines an effective forecasting technique, optimal order cycle time, centralized pooling of select SKUs at co-located Pool Points, and deferred distribution of inventory to stores, netting double-digit percentage reduction in costs and average inventory. Furthermore, we found that the current inventory policy “protects” a significantly longer time period than needed, and a combination of network re-design and a shift in inventory strategy could yield a one-time recapture of $7m in working capital.

![Graph showing inventory growth and sales](image)

**Figure 1: Inventory in green and sales in blue over a 4-year period. Average inventory has grown and is protecting, 5 months on average.**

**Forecasting**

Using mathematical programming, we studied the forecasting performance of seven forecasting methods, using four separate error measurements on a 12 month test data set. Forecasts with up to 3 million data points were generated at store level for multiple order cycle times, using all methods.

To ensure a thorough analysis, we scrutinized results by filtering material groups, intermittent demand, and outliers by varying the order cycle length and by measuring against a custom designed error metric and benchmarking algorithm. By combining Mean Absolute Error (MAE) and price of the product, we introduced an error metric that provides relativity to the error in monetary value. It puts a price to the “mistake” (theoretically assuming that all over-forecasted products perish, and all understock are lost sales). To set a benchmark for forecast accuracy, we retroactively applied all techniques to each SKU, and summarized the error values of the method that yields the lowest overall error.

We found that “ratio forecast”, a relatively simple, modified naïve methodology fared best overall. We attribute this to negligible year-over-year change in overall sales for past four years, obvious seasonality, and aggregation via long order cycles.

The forecasting module in the tool allows the analyses of intermittency of sales, forecast generation and choice of error metric for comparison.

**Network Re-design**

The current distributed network leads to forecasting, ordering, and storing of all inventory at individual stores. The resulting duplicated and optimistically forecasted inventory implies larger order quantities, higher holding costs, and frequent rebalancing. Combined with 6+ month order cycles, due to a consolidating and seasonal industry driving “large buys” with quantity discounts in off-season periods, the risks and costs are even greater.

Based on our analysis and sponsor input, we performed a brownfield analysis to divide the region into smaller groups and create a hub and spoke network. To reap maximum benefit and allow ample flexibility we opt for a scenario-based approach rather than optimization. This “relaxed” tactic allows expert input from decision-makers to heavily influence the creation of realistic network scenarios.

The tool was used extensively to drive the findings of this project. Synonymous with the project, it is divided into three sections: clustering, classification, and simulation.

**Clustering**

Part of the hub and spoke strategy is to divide the region into clusters. In addition to the standard practice of clustering based on spatial proximity, we perform clustering based on redistributions and sales portfolio. **Distance** based clustering minimizes transportation, as closely located stores are grouped. **Sales portfolio**, which refers to the commonality of products sold across stores, minimizes inventory costs, as stores sharing similar inventory are clustered. **Redistribution** based clusters tackles both, as rebalancing data suggests

![Map showing clusters and individual store clusters](image)

**Figure 2: Mix of hub and spoke clusters and individual store clusters with lines representing redistributions.**
commonality of SKUs and close proximity. Stores were assigned to clusters using a combination of the three variables.

Recognizing that neither a fully distributed network, nor an exclusively hub and spoke network are optimal, we allow the development of a network with both hub and spoke clusters as well as distributed clusters with no Pooling Points (PP). Within clusters of multiple stores, PP are co-located with existing stores and are assigned by taking into account factors such as available space, relative location within the cluster, and access to highways.

The tool allows significant user-input and displays a real-time configuration of the network determined by the selections. Scenarios are created and saved for classification and simulation.

**Classification**

While pooling inventory in a hub and spoke network is beneficial, not all inventory needs be pooled. The current distribution policy of direct-to-store (DTS) is beneficial for certain products. To establish the classification of SKUs that would be pooled, and those not pooled, we proposed a forecast improvement threshold. If the forecast accuracy for a product is significantly improved when forecasted at cluster level, it should be pooled. Products with marginal improvement of forecast are better suited for DTS. Classification is at the cluster level, and SKUs may be classified differently in each cluster.

![Improvement Distribution](image)

**Figure 3:** Green dots represent SKUs that would be DTS, and blue dots are pooled based on significant forecast error reduction.

Within the tool, segmentation threshold is user selectable, and a graph displaying the percent of improvement captured is generated along with a scatterplot like figure 3 above. Saved cluster and classification settings are inputs for simulation.

**Simulation**

To evaluate the performance of each scenario, we modeled the procurement, distribution, transportation and sales of inventory. To mimic reality, distribution is executed via direct and milk-run routes, transportation costs are segmented into inbound, outbound and redistribution, gross margins and holding costs are sponsor provided, demand is random and sales service levels achieved are comparable. We further maintained credibility in the assumptions by ensuring ending inventory at the end of a six-month simulation was similar to recent historical data.

The outputs from the simulation of the complete scenario include sales realized and missed; inventory procurement, average inventory, and inventory holding cost; service levels pertaining to cycle stock and item fill-rate; transportation costs for inbound, outbound, and redistributions; operational costs of Pooling Points; and calculated metrics for average weighted cost and profit per pallet.

**Findings and Results**

We found that with a network re-design with 3 clusters in a North, South and West geographic segmentation, average inventory can be reduced by 15% while providing a similar sales service level. This inventory reduction equates to $2.3m in procurement savings. Additionally, even with increased operational cost related to hubs and outbound transportation to stores from PP, the recurring operational cost is reduced by $70k for a six-month period.

Furthermore, if the above scenario is combined with an appropriate Service Level based inventory policy, a recapture of $7m in working capital is plausible. Essentially, our simulation shows it is possible for the current average on-hand inventory of 5 months to be halved, while maintaining comparable service levels, backed by an effective hub and spoke distribution network.

![Additional Profit](image)

**Figure 4:** Results of our proposed solution 6 month simulation. Profit is calculated after accounting for lowered revenue.

**Reference**

Gary D. Eppen, Effects of Centralization on Expected Costs in a Multi-Location Newsboy Problem, Management Science, 1979
MIT ZARAGOZA PROGRAM - CLASS OF 2018

PROJECTS

Ad-Hoc versus Contractual Freight Rates
Team: Javid Abbasov, Mei Yang, Chunyan (Joris) Zhou
Advisor: Dr. Çagri Gürbüz

This thesis tackles the problem of using spot markets vs. contracts for procuring shipping rates through implementation of a mathematical model. The model will serve as a complementary tool in procuring the two different freight rates and optimizing the transportation costs for the shipper on each shipping lane.

Automated Store Replenishment impact on retail inventory management
Team: Pankaj Arya, Panagiotis Oikonomou
Advisor: Dr. Spyridon Lekkakos

This research offers insights related to the implementation and technical issues of Automated Replenishment Systems and indicates issues that force the user to bypass/override the system’s replenishment decisions. A framework is presented to ensure successful implementation throughout the whole network of the retailer.

Improved carrier performance and transport optimization for a Europe-based metal recycling company
Team: Nedim Begovic, Shailesh Gupta
Advisor: Dr. Çagri Gürbüz

This thesis tackles the dual question for a scrap metal recycling company to address decision-making on the choice of carriers and minimization of the procurement and transport costs to fulfil customer demand with the objective of reducing total costs for the company at optimum customer service. The Analytic Hierarchy Process and Multi Integer Linear Programming optimization models have been developed to answer these queries.

Distribution Network Optimization of Engine Spare Parts
Team: Ricardo Cabral, Soukaina Hamimoune, Byron Mendoza
Advisor: Dr. Rafael Diaz

This thesis project aims to determine the optimal materials flow into and between the various nodes of the distribution network that serves to improve costs and maintain a service level of 95%. The project identifies critical factors and outlines the various possible product flows along with determining the inventory investments and logistics costs.

Inventory Management of Humanitarian Medical Supplies
Team: Ignacio Castañeda, Rubchai Chinsuwan, Carolina González
Advisor: Dr. Spyridon Lekkakos

This thesis focuses on helping a humanitarian organization select the appropriate distribution system of medical goods to non-emergency missions. We used Arena software as a tool to evaluate distribution system performances of selected scenarios. The results will help the humanitarian organization improve their performance in existing missions and establish distribution system for future missions.
Resiliency and Sourcing Strategy in the Semiconductor Industry
Team: Ted Lynch, Scott Conner
Advisor: Dr. Rafael Díaz
This research quantifies the trade-off between the costs of additional inventory and qualifying a second source partner versus the benefits in supply chain resiliency during a supplier disruption. We use ROA and NPV analysis to evaluate the interaction between inventory levels, second source costs, risk potential, disruption length, service levels, and financial impact.

Defining Planning Parameters Values in the Pharma Industry
Team: Maria Inés Gallo, Lucas Lencina, Isabella Obediente
Advisor: Dr. Alejandro Serrano
This thesis tackles the question of what the planning parameter value is that minimizes cost of inventory in the different steps of the supply chain. The company is seeking to lower the four billion euros they hold in inventory without sacrificing their high service level to customers.

Pooling of Spare Parts Inventories in the Cement Industry
Team: Aleksandr Krasner, Igor Vilensky, Martin G. Wieser
Advisor: Dr. Spyridon Lekkakos
The principal target of our study was to develop an approach for prioritizing where the company should focus its efforts to identify the commonalities among spare parts. In that way, existing limited resources could be bundled to obtain the most advantageous cost-to-benefit ratio. As a subsequent objective, using the methodology for commonality identification, we evaluated if the pooling of spare parts (i.e. not holding inventory of each spare part at each point of demand) might provide business (financial) benefits and, therefore, should be further explored.

Spare parts management in the pharmaceutical industry
Team: Guadalupe Martinez de Aguirre Bengochea, José Miguel Martínez Fignoni, Kristence Voll
Advisor: Dr. Spyridon Lekkakos
This thesis studies the topic of spare parts management in the context of a multinational pharmaceutical company with the objective of reducing inventory costs and optimizing data collection processes. The result is a tool to standardize inventory policies across the different sites and a method to manage global information.

Exploring the Potential to Leverage Supply Chain Innovations of Anti-Counterfeit Pharmaceuticals
Team: Subir Paul, Lian Zhao
Advisor: Dr. Çağrı Gürbüz
This thesis investigates the problem-solving process of combating counterfeiting in Pharmaceutical Supply Chains. Adopting a design-thinking approach to evaluating existing and novel technologies in use in this field, this thesis posits a new three-pronged framework for creating solutions in the industry, also it considering the responsibilities of individual public and private agencies at play in this effort.
Network Capacity Planning
Team: Pilar Albar Bello, Bruna Fernandes Basile, Fernanda Caropresso
Advisor: Dr. Rafael Diaz and Dr.Spyridon Lekkakos

This thesis addresses the lot sizing and capacity allocation problem of a leading pharmaceutical company. The key question addresses was: how products should be assigned to each production line in order to utilize existing capacity in the best way possible while reducing costs.

Supply Chain Segmentation in the Fast-Moving Consumer Goods Industry
Team: Javier Barros, Harrison Dow, Melissa Treviño
Advisor: Dr. Spyridon Lekkakos

This thesis investigates supply chain segmentation in the context of the fast-moving consumer goods industry. A tailored tool has been developed, which provides 3D analysis capabilities at the SKU-level and 2D at the customer-level, along with other value-adding features.

Scenario Planning to Offset Supply Chain Disruptions
Team: Lokesh Devasigamani, Carmen Gómez Sánchez, Luis José Racca
Advisor: Dr. Susana Val

This thesis proposes a methodological framework so as to capitalize the utilization of S&OP scenario planning tools by our sponsor company and other firms within the medical device industry in their commitment to provide high levels of customer service while dealing with the uncertainty given from the most critical disruptions in their supply chains.

Hub and Spoke Network Design for a Fast-Growth Company
Team: Canh Phan Xuan, Benjamin Sanford, Daniel Golenbock.
Advisor: Dr. Rafael Diaz

This research project addresses hub network design for a fast-growth express delivery company in the largest city of Vietnam. Multiple techniques were applied to explore potential hub locations including multiperiod mixed-integer programming, driving distance clustering, and simulation to validate the robustness of the solution.

Effective Forecasting and Inventory Allocation Strategies
Team: Amir Khan, Carlos Mira, Dmytro Rizdvanetskyi
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This project tackles forecasting methodology for intermittent demand, pooling to reduce inventory and delaying stock allocation to reduce redistribution. We developed a robust tool capable of simulating forecasts, procurement, network design, transportation, and sales for 100M+ user-selected scenarios. Our recommended scenario attains 21% operational cost and 44% inventory reduction.