Master of Engineering in Logistics and Supply Chain Management

RESEARCH JOURNAL

CLASS OF 2015

Summaries of select research projects by graduates of the MIT-Zaragoza Master of Engineering in Logistics and Supply Chain Management (ZLOG)

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Introduction

Welcome to the 2015 MIT Zaragoza Master of Engineering in Logistics and Supply Chain Management (ZLOG) Research Journal!

The five papers included in this journal were chosen from the thirteen theses submitted by the ZLOG class of 2015 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 theses are, of course, much more detailed. We have also included a complete list of this year's ZLOG theses with short descriptions at the end of this journal.

The articles in this publication cover a wide range of interests, approaches, and industries. The topics include: portfolio analysis and optimization, product distribution cost savings, network design, supply chain risk service disruptions and strategic sourcing. This variety of topics illustrates one of the hallmarks of the ZLOG program: the students' ability to focus their course work and research on topics that most interest them.

The ZLOG program 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 projects highlighted in this journal reflect the variety of ZLOG student interests. All 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 ZLOG 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 ZLOG program or wish to find out how your company can interact with ZLOG students, please do not hesitate to contact me directly.

Happy reading!

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Product Portfolio Analysis & Evaluation of Technical Criteria for Product Phase Out

By Aram Aharonian & Diana Carolina García Meléndez

Thesis Advisor: Professor Mustafa Çagri Gürbüz, Ph.D.

Summary:
This thesis provides a structured approach with the goal of reducing product complexity. This includes a thorough product portfolio analysis and subsequent optimization recommendations. Based on these findings, the analysis of soft and technical factors is conducted, evaluating the feasibility of the aforementioned proposals. Lastly, the supply chain impact is determined if the recommendations were to be put in place.

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KEY INSIGHTS

1. Product portfolio complexity can be considered as “positive” as long as it contributes to overall performance. Nonetheless, an uncontrolled portfolio growth can result in cost increments
2. Reducing portfolio complexity could have a negative impact on sales but at the same time lead to increased profitability.

Introduction

While product introduction to markets is a topic that has been discussed and researched extensively, product phase out, or discontinuation of products, is still a less analyzed field. While the strategy of the future phase out typically should be set upon product launch, it is important to periodically analyze the performance of product families and each variety offered on the market, in order not only to better understand product behavior, but also identify optimization potential. Product variety within product portfolios of companies is often considered to be a necessity, in order to serve different types of demand, thus enabling companies to gain and retain their market share.

These varieties have typically grown as part of a product’s evolution, based on local needs or regulatory statutes that needed to fulfilled when entering new markets. While having a wide array of services of products to offer of the same category enables capturing sales and meeting market demand, it also comes at a monetary cost. In order to provide said products or services, a company needs to have flexibility throughout the supply and value chain. This has become even more important in recent years, as product life cycles and the time from research to the shelf have been drastically shortened. Being able to adapt and navigate in such a rapid-paced environment opens opportunities for companies to establish competitive advantages. This becomes very evident when observing the electronics companies offering mobile phones, where life cycles of the high end products have been shortened to as little as one year. In this industry, it has become evident that providers with less variety are more flexible in reacting in time to demand. The planning of the product lifecycle can be vastly different, depending on the observed industry.

In the Pharmaceutical industry and in our particular example, we are looking at the streamlining possibilities within an entire product. This means, that the goal is to reduce the amount of **presentations**, which represent a single variety, based on **package size**, **dosage form** and **dosage**.

Additionally, pharmaceuticals are subject to a multitude of regulatory constraints, and therefore require a slightly different approach. Here, a managerial decision to phase out a product or discontinue particular varieties are not always possible to execute. The regulatory environment in particular will have a strong weight in decision making in terms of feasibility and actual possibility. A holistic product portfolio analysis thus is required to consider and evaluate all these different angles.

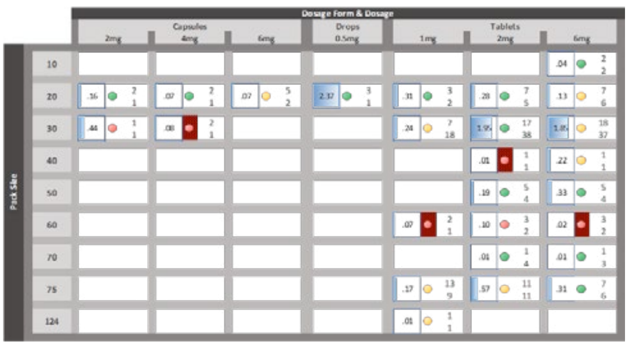
Approach

Phase 1: Visualization and proposal of streamlining candidates

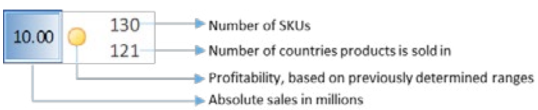
In this first phase, a sample product is analyzed in terms of its financial performance. For this thesis, the complete portfolio of established portfolios was considered and served as the basis for the streamlining recommendations. At this stage, it is evident that streamlining candidates might have a multitude of factors influencing a final decision on streamlining. However, for the initial mass analysis, it is important to simply identify these candidates in order to conduct a subsequent more thorough analysis on the actual streamlining possibilities.

The visualization of the initial stage was performed via product matrix, pointing out key facts about each offered presentation of an entire product:

- Sales
- Profitability
- Number of SKUs
- Number of Markets



Each presentation represents these key figures in a particular format:



The profitability ranges were defined based on an analysis of the entire product portfolio:

	Negative Profitability	< 0% Profitability
	Low Profitability	< 36% Profitability
	Medium Profitability	36% - 72% Profitability
	High Profitability	> 72% Profitability

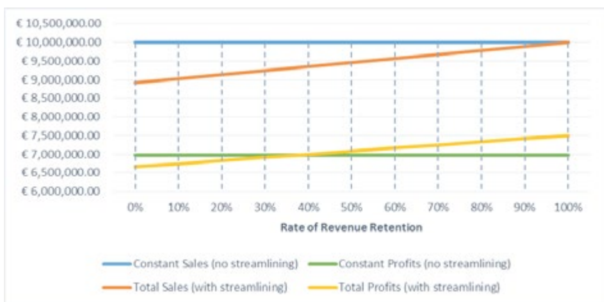
Based on discussions with matter experts, a ruling engine is set up to identify streamlining candidates. For this purpose, all established products have been analyzed, constituting more than 500 presentations all together. The ruling applied can be seen as follows:

- Candidate generates less than 5% of the whole product's sales
- Candidate generates less than 50,000€ in sales
- Candidate is sold in fewer than 5 countries

Whenever a presentation fulfills one of these rules, it will be flagged as criteria fulfilled (1 = yes, 0 = no). Adding up all fulfilled rules finally decides whether a presentation should be proposed for streamlining. How many of these criteria need to be fulfilled finally depends on the profitability of a presentation:

Negative Profitability	Always proposed for streamlining
Low Profitability	At least 1 out of 3 criteria fulfilled
Medium Profitability	At least 2 out of 3 criteria fulfilled
High Profitability	All 3 criteria fulfilled

While there are a multitude of factors influencing the decision on streamlining these candidates, in this particular phase, the focus is on the financial performance and the reach of a product in terms of the number of markets it is promoted in. Therefore, with the goal to set up proposals for the next step, these external factors are not yet considered in this part of the evaluation.



If the proposed presentations, based on this ruling engine, were to be merged into the continued ones, it would depend on the retention rate of sales how profitability could evolve. If it is possible to further retain the costs of goods sold, the loss of sales could be compensated by gains in profits. In this particular example, if approximately 40% of sales can be retained, the profits would be identical.

With these considerations, it is important to further understand which of these streamlining proposals are not subject constraints that will hinder a presentations merger. Also, it is important to further analyze how to better understand what the impact of the COGS will be by looking at the supply chain implications.

Phase 2: Analysis of proposed candidates for streamlining possibility (soft + technical factors)

The second phase is looking at factors outside the financial field that can significantly impact the decision on streamlining products. At this stage, the impact of soft and technical factors can mean both an increased difficulty in streamlining products, but also an impossibility (in most cases due to regulatory restrictions).

The soft factors to be considered in this phase are presented as follows:

Streamlining Feasibility:

- Government policies and regulations
- Changes in third party specifications
- Decline in market potential
- Parent organization decisions and policies
- Poor product performance (despite a generally viable market)
- Development of new products
- Rationalization brought about by mergers and acquisitions
- Development of an active variety reduction policy

Streamlining Impact:

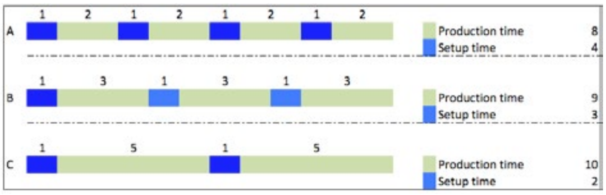
- Product's elimination effect on sales of other products
- Product's elimination effect on customer relationships
- Product's elimination effect on profitability of other products
- Reallocation of capital and facilities to other opportunities
- Release of executive time spent on the product
- Existence of substitutes to satisfy the customer
- Product's elimination effect on corporate image
- Competitive moves in case the product is eliminated
- Product's elimination effect on employee relationships

Phase 3: Analysis of the accepted proposals' streamlining effort on supply chain performance

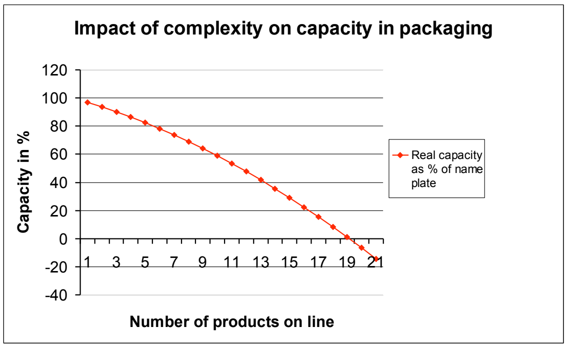
Once presentations have been deemed feasible for streamlining, not only from a financial impact, but also a technical and soft factor point of view, it is important to understand how operations in fact will be affected. This is important, as Phase 1 points out a roadmap built on significant assumptions. Therefore, certain supply chain related points of impact will be examined, in order to understand the benefits/complications that can occur through product streamlining.

- Production and packaging

In manufacturing, the setup time is an important topic regarding the optimization of the capacity utilization; it is intuitive to say that as the frequency of the setups increase, the capacity utilization declines, as shown in the next figure:



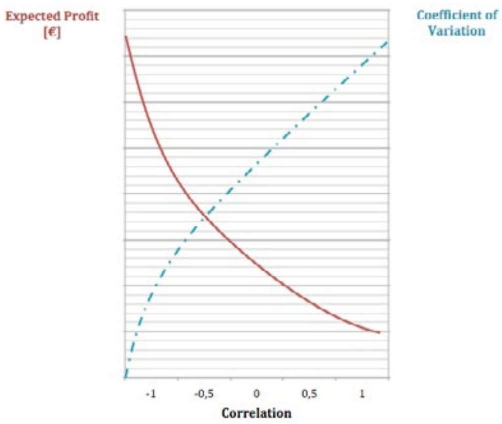
In this example, the impact of complexity in the packing line is such that for each additional dosage form is a capacity loss of between 3% and 6% per dosage form.



- Warehousing

By merging different products into a single one that can satisfy the requirements of the demand (product pooling), the demand uncertainty is decreased, impacting directly the level of inventory necessary.

The efficiency of the pooling effect over the inventory level, and thus over the profitability, is directly related to the coefficient of variation of the pooled demand.



- Planning process (supply and demand)

Both planning roles, supply and demand, may be affected by product streamlining, given the nature of their responsibilities. In the case of the supply planners, the main objective is to set up the master plan at a SKU level as well as the resources and capacity. The way in which the supply planning team is organized is by product, every product is the responsibility of one particular planner. Considering the average workload of a supply planner and the time dedicated to plan each SKU, an analysis of the time reduction in the workload was done in order to determine the benefits from the streamlining proposals. The same analysis was done for the demand planner role, considering that the main difference compared to the supply planner role is that the demand planning team is organized by country. So one product is analyzed by more than one planner, meaning that the decision of streamlining a given SKU may affect more than one person according to the number of countries in which the SKU is sold.

Conclusions

This thesis has established a procedure that helps to analyze the performance of product portfolios and recommend streamlining candidates. In the subsequent step, these proposals were evaluated from a feasibility point of view, to determine which presentations in fact can be streamlined. The final evaluation aimed at understanding the actual impact to be expected if the proposed presentations were in fact to be streamlined.

The key findings as part of the collaboration with the sponsoring company and the academic thesis advisor were following:

- The assumption that a presentation can achieve higher profitability by merging it into a better performing one might appear broad. Nevertheless, the fact that certain presentations are performing significantly stronger than others is proof that it is ultimately possible to improve performance. Based on the findings, presentations with a higher number of served markets typically were performing at higher profitability due to better use of economies of scale.
- The final figures in potential savings will be better predictable, when phase two is fully completed, thus indicating which presentations are in fact feasible for streamlining. Through expert interviews and sample evaluations, it became evident that the biggest measurable benefit would be in the reduction of cost in the packaging lines, as set-up times were drastically reduced the more presentations were streamlined.
- Of significant import to succeeding in the streamlining effort will depend on senior management buy-in and cross-department collaboration. Sales affiliates could force a strong counterweight, due to the nature of the incentive system and lack of data visibility.
- In the analysis, established products that had grown historically over a significant timespan were analyzed. Performance of current and future products could be improved, if regular reviews were conducted, looking at regulatory changes and sales trends. This could lead to improved performance throughout the entire product life cycle, if a continuous process is introduced.

From the collaboration with a multitude of representatives from the sponsoring company, we saw benefits that could be achieved by reducing complexity within the product portfolio. In order to do so, it is necessary to introduce appropriate processes that enable continuous data review and close collaboration with involved stakeholders in order to drive decisions faster and in accord. This ultimately can lead to better financial performance throughout the entire product portfolio.

Cited Sources

- Cachon & Terwiesch (2006). Matching supply with demand: 288 - 294
- Collinson, S. & Jay, M. From complexity to simplicity – unleash your organization's potential.
- Perumal, A. Waging War on Complexity Costs.

Innovating Flexible Distribution: Alternative Route-to-Market Models for the Beverage Industry

By Vincent H. Chong and Ricardo Salvatierra
Thesis Advisor: Prof. JianJun Xu, Ph.D.

Summary: The objective of this study is to quantify cost savings from introducing flexibility to product distribution. A simplified linear program was formulated to identify the optimal solution assuming a deterministic scenario, while simulations were developed to incorporate stochastic variables. Recommendations include an evaluation of alternative route-to-market models and insights on market characteristics where these models may be successfully implemented.

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KEY INSIGHTS

1. High demand variability in a cycle necessitates a larger yet possibly inefficient fleet size
2. Producers and manufacturers can leverage distribution flexibility to reduce operating costs
3. Low aggregated order volume from small stores minimizes improvements from flexibility

Introduction

Product distribution in developing markets involves challenges that stem from two primary reasons. First, the state of infrastructure such as roads and highways is inferior compared to developed countries as reported by The World Bank in its biannual Logistics Performance Index. Second, a significant portion of the volume is sold through small-format stores such as independent retailers and convenience stores in developing countries compared to developed countries, based on MarketLine's coverage of the global soft drinks industry. Both reasons negatively impact the efficiency of route-to-market models.

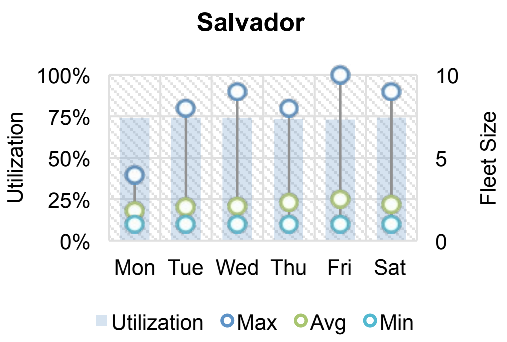
The objective of this thesis is to evaluate the impact on costs of adopting flexibility in the sales process and physical distribution. The authors utilized theoretical and analytical frameworks to measure this impact on three alternative distribution models that were proposed by the Company. The current distribution model has a delivery window of up to twenty-four hours of an order with a dedicated pre-sales team.

- Model 1: Delivery window is extended to up to forty-eight hours with dedicated pre-sales team
- Model 2: Delivery window is extended to up to forty-eight hours; no dedicated pre-sales team
- Model 3: Delivery window is retained at up to twenty-four hours with dedicated pre-sales team; delivered volume may be more or less than order

Demand Variability

The dataset that was provided by the Bottler covered one full year of transactions from December 2013 to November 2014.

Due to the volume variability, the dedicated fleet may be larger to cover peaks in volume, which appears to be the case for all market areas. While the mean for each market area seems decent, the maximum number of trucks is more than twice the mean. Therefore, an improvement in volume variability will minimize fleet size variability that could bring substantial savings.



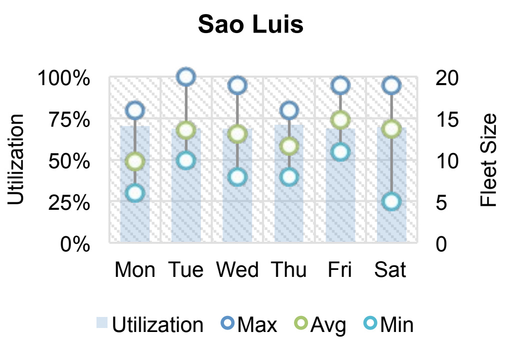


Figure 1. Variability in fleet size by day

Customers like bars, restaurants or supermarkets should not be affected by the new distribution models. For this reason, these "Other" customers will continue to occupy the same amount of space in trucks, which could limit any potential improvements and savings from flexibility. The small-stores were clustered into two sub-groups: "Large" customers with higher average order size and higher standard deviation and "Small" customers that exhibit the opposite characteristics.

Analytical Approach

The authors opted to formulate a mathematical program to determine the optimal number of trucks or fleet size to distribute orders for each market area. The initial formulation was a mixed integer linear programming (MILP) model that represents a distribution network, including order assignment and transportation. The objective of the optimization model is to minimize the cost of selling products to retailers.

As is reflected in the objective function, this has two parts: the cost to operate and maintain a fleet of delivery trucks and the cost to operate a dedicated pre-sales team to collect orders from retailers.

In the Base Model, products are prepared for delivery within twenty-four hours of receiving an order. Delivery trucks are filled and routes are planned with this consideration, as well as these constraints:

- All retailer demand is known and must be met [1]
- The volume of products planned for delivery on each day cannot exceed the combined volumetric capacity of the whole fleet [2]
- As a surrogate for the delivery team's labor hours constraint, the volume of products planned for delivery on each day cannot exceed the number of deliveries that can be done by all delivery teams in a day multiplied by the average order volume per retailer [3]

The following notations were used in the formulation of the Base Model.

Sets

$i \in \{1,\ldots,I\}$	set of truck type
$j \in \{1,2\}$	set of retailer types
$k_j \in \{1,\ldots,K\}$	number of retailers of type *j*
$l \in \{1,\ldots,L\}$	set of zones
$m \in \{1,\ldots,6\}$	set of delivery days

Decision Variables

$x_{i,l}$	number of trucks of type *i* sent to zone *l*
$y_{j,k,l,m}$	volume delivered to retailer *k* of type *j* in zone *l* on day *m*

Parameters

z	combined cost to operate truck fleet and dedicated pre-sales team
C_i	volumetric capacity of truck type *i*
d	driver's salary, per day
a	assistant's salary, per day
t	fixed cost to operate a truck, per day
s	fixed cost to operate dedicated pre-sales team, per day
$D_{j,k,l,m}$	demand of retailer *k* of type *j* in zone *l* on day *m*
h_i	number of deliveries per day using truck type *i*
o	average order volume per retailer

The problem can be formulated as follows:

Objective function:

$$\text{minimize } z = 7 \times \left(\sum_i \sum_l ((d + 2a + t) \times x_{i,l}) + s \right)$$

Subject to:

$$y_{j,k,l,m} = D_{j,k,l,m-1} \qquad \forall j,k,l,m \qquad [1]$$

$$\sum_j \sum_k y_{j,k,l,m} \leq \sum_i (x_{i,l} \times C_i) \qquad \forall l,m \qquad [2]$$

$$\sum_j \sum_k y_{j,k,l,m} \leq \sum_i (x_{i,l} \times h_i \times o) \qquad \forall l,m \qquad [3]$$

$$x_{i,l}, y_{j,k,l,m} \geq 0 \qquad \forall i,j,k,l,m \qquad [4]$$

$$y_{j,k,l,m} \ int \qquad \forall j,k,l,m \qquad [5]$$

Similar mathematical programs were formulated for each alternative distribution model. Additional decision variables, parameters, and modifications to the formulation resulted in non-linear programming models, specifically for Model 1 and Model 2, which can be considered difficult to solve due to the number of decision variables.

Fuel cost, which is directly proportional to the distance traveled by trucks, is absent from the mathematical program since distances between the distribution centers and retailers and between retailers were not available. It would have been ideal to incorporate a vehicle routing problem into the formulation. Furthermore, the Bottler already uses a sophisticated routing system that is able to consider all necessary constraints. Fuel cost savings were expected from the optimization, brought about by volume consolidation and fewer deliveries per day, but were intentionally omitted to be conservative.

Although most parameters are stochastic in nature e.g., demand fluctuates by sales season and market area, the mathematical program was formulated as a deterministic model to manage the complexity. The optimal solution for the number of trucks required can set a baseline for the results of the simulation approach, which incorporated the probabilistic aspects.

Simulation Approach

Using Microsoft Excel and VBA for the underlying code, a simulation model was created with as much of the stochastic elements of relevant parameters to approximate actual operations. The three steps of the simulation are described below. As in the mathematical program, the Base Model served as the foundation for the alternative distribution models.

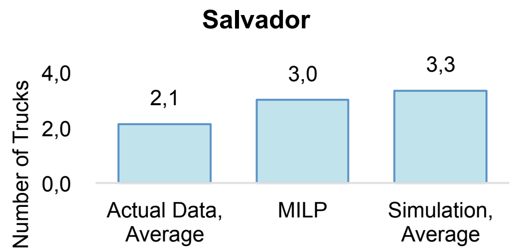
- Generate dummy demand or orders. The order size, unit volume or cube factor (as surrogate for SKU), and quantity are assigned using random numbers and where these fall within cumulative discrete probability distribution, exponential or uniform distribution functions, as applicable. The retailer's type and zone, as well as interarrival time between orders, are assigned following a similar procedure

- Consolidate orders by retailer and to set priority. Sum up order volume by order day and by retailer. To rank orders, the concept of queueing discipline is borrowed from queueing theory. The options are first-come-first-served and by retailer type i.e., "Other" customers that include supermarkets and restaurants, followed by "Large" retailers, and finally "Small" retailers. Within each type, orders are ranked by volume in descending order

- Load orders into virtual trucks. Select trucks from available fleet and fill trucks based on the priority set in the previous step. Repeat the process until all orders that need to be delivered the following day are assigned to a truck for dispatching

Results

The simulation model was validated by comparing certain parameters between the actual data and the Base Model simulation. The number of trucks required to satisfy all deliveries varied across zones. Salvador's results were close but Sao Luis' were quite different. The variance can be explained by the geographic distribution of retailers whereas both the MILP and the simulation used the sale routes as an approximation of relative distances between retailers. Other gaps between the actual data and the Base Model simulation could be attributed to the probability distributions but these assumptions are indispensable to the simulation.



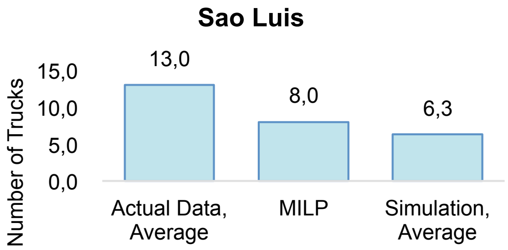


Figure 2. Average number of trucks

For each market area and distribution model combination, a sensitivity analysis was conducted on the utilization threshold to be used ranging from 50% to 90% in increments of 10%. As the threshold increased, the weighted average utilization improved and the fleet size decreased for Salvador. However, this pattern can only be observed up to a certain threshold because the metrics either plateaued or deteriorated at higher thresholds. In certain cases, the weighted average utilization decreased as the threshold increased because some trucks were forced to be shipped out even if their utilization rates were below the threshold as they contained at least one order that was placed two days prior i.e., about to exceed the forty-eight hour service commitment. The recommendation would be to set the threshold at the inflection point, which was typically at 70%, because this threshold would be as equally and sufficiently effective as higher thresholds. There was no change in the results from varying thresholds for Sao Luis.

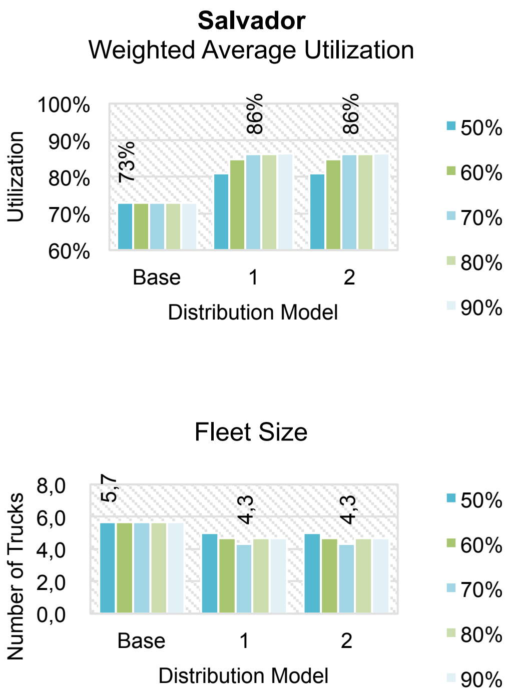


Figure 3. Sensitivity analysis of utilization threshold – Salvador

Based on the results of the simulation, Salvador has an opportunity to save up to 40% of weekly operating costs by employing Model 2 at 70% utilization threshold that would lead to fleet size reduction and elimination of the dedicated pre-sales team. Without any improvements, Sao Luis should retain the current distribution model. Results of the sensitivity analysis that was also conducted for Model 2's productivity loss factor suggest that Salvador is inelastic relative to this parameter since increasing the same did not have any effect on the fleet size and, consequently, the weekly operating cost.

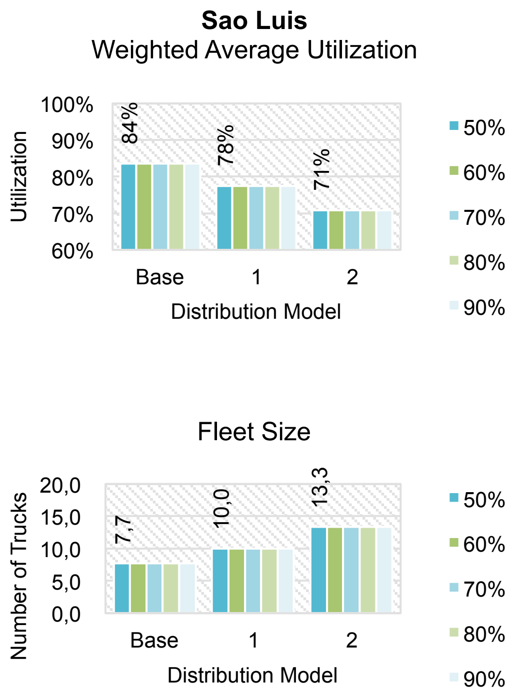


Figure 4. Sensitivity analysis of utilization threshold – Sao Luis

Conclusion

Cost reduction was a main driver of this research. The actual data, the mathematical program's optimal solution for the Base Model, and the simulation results for the same distribution model were three data points that, when compared to each other, confirmed sufficient understanding of actual operations. These data points also served as the baseline of operating costs from which cost savings generated by the alternative distribution models were calculated. The results strongly support the notion that flexibility can also be from the producer's or manufacturer's perspective and to its benefit, as opposed to simply a response to changing customer needs.

Policies were defined for the Bottler to implement the alternative distribution models for appropriate market areas. However, a pilot test with one or two sample market areas would be recommended prior to the full implementation of applying flexibility to current operations.

Key Reference

Zhang, Qingyu, Mark A Vonderembse, and Jeen-Su Lim. "Logistics Flexibility and Its Impact on Customer Satisfaction." *The International Journal of Logistics Management* 16, no. 1 (2006): 71-96.

Network Optimization as a Business Advantage

By Arturo M. García-Calderón Narváez & Edson F. Guimarães Junior
Thesis Advisor: Mustafa Çagri Gürbüz

Summary:
This thesis addresses the design of the supply network for a chemical company that is setting up an operation in an emerging country to explore the nearby markets. We tackled this real-life business necessity with a two-stage approach based on Mixed-Integer Programming and Discrete Event Simulation.

Arturo M. García-Calderón Narváez (Peru): Bachelor in Industrial Engineering and LSS Black Belt. Operations and change management professional with experience in Manufacturing, Financial Services and Consulting in Supply Chain with focus in project management and process improvement.

Edson F. Guimarães Junior (Brazil): Bachelor in Business Administration and Postgraduate in Production Management. Supply Chain professional with experience in the Automotive and Health Care industries with focus in inventory management, sales & operations planning, and foreign trade.

KEY INSIGHTS

1. Scientific methodology and tools cope perfectly with Business Strategic evaluations, mainly due to the possibility of building and analyzing different scenarios to support the decision making process.
2. Mixed-Integer Programming (MIP) is a powerful tool to assess the current Supply Chain Network Design and determine the optimized setup to minimize costs under given operational constraints.
3. Discrete Event Simulation is a complementary tool to evaluate the performance of the Network configuration under uncertainty given a randomly generated demand based on real data statistical distributions.

Introduction

Supply Chain management is a key driver of businesses in the globalized world, and the companies configuration of how they manage their supply chain network and allocate their resources are crucial in whether or not they will still able to prosper healthily towards long term profitability and sustainable growth.

The network design of the logistics and supply chain of a company is of vital importance because as a strategic level plan, it will influence long-term business success. Within the topic of Supply Chain Network Design (SCND), the Aggregate Planning (AP) in the sense of resource allocation is extremely critical and must be done in great detail, carefully considering that optimized material and information flows will have impact on total cost. Melo et al. (2008)

Simchi-Levi et al. (2007) as well as Chopra and Meindl (2012) also highlight the importance of SCND and AP as key drivers to operations cost while satisfying the demand.

SCND and its component AP are the scope of this project, and due to the fact of being a complex process involving strategic decisions, a two-stage approach is required in order to define the optimal network configuration and the corresponding flows among supply and demand nodes.

The sponsoring company of this thesis project is a leading manufacturer of chemical products with Business-to-Business (B2B) worldwide operations.

The focus of this project is on their operation in Europe, Middle East and Africa (EMEA) of one specific business unit (BU). Such BU has among others, a certain product that is mainly a mix of 3 components of different properties. It is important to mention that European Markets for such a product offer very limited growth due to the maturity and stability of the clients' businesses in this region. In that line of thought, the business the sponsor company is setting up an operation in an emerging market to add value locally and expand its current market. This will allow them to produce 2 out of 3 components at a lower cost, being more cost-competitive for the local and nearby markets.

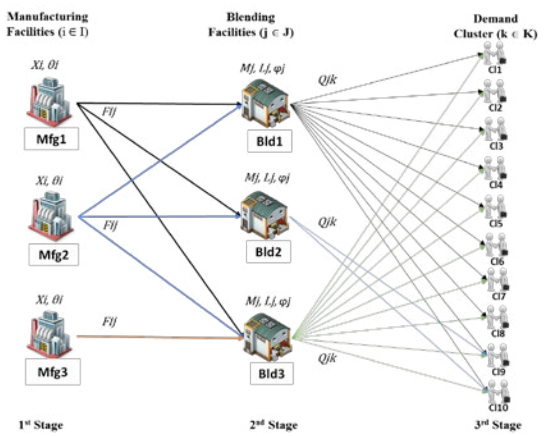
Methodology

Due to the large and complex scope, a two-stage roadmap was developed to tackle this problem, each step containing several tools which are explained in this summary.

In this sense, we started by understanding the thesis problem, collecting data and building a simplified Bill of Material (BOM), which was later confirmed 97%+ accuracy according to the company's ERP. Then, we performed a Pareto analysis in order to narrow down the scope. This was followed by descriptive statistics and distribution identification of the demand, hence looking for trends and seasonality. All of this analysis are described in the following steps.

Mathematical Model

The concept of our model is a supply chain network representation with manufacturing sites, blending facilities and the demand nodes along with all their relevant characteristics, including capacities, possible flows, demand and costs like the following map:



A breakdown of the Mixed-Integer Programming (MIP) will be exposed below and its mathematical notation detailed for further understanding and clarifications. In terms of definition, this mathematical model is a MIP for the multi-source, multi-product, multi-stage supply chain network design problem that it is being thoroughly explained.

Indices

I	set of manufacturing facilities (i ∈ I)
J	set of blending facilities (j ∈ J)
K	set of demand clusters (k ∈ K)

Variables

H_{ij}	Quantity of component *H* produced at *i* and shipped to blending facility *j*
S_{ij}	Quantity of component *S* produced at *i* and shipped to blending facility *j*
N_{ij}	Quantity of component *N* produced at *i* and shipped to blending facility *j*
O_{ij}	Quantity of component *O* produced at *i* and shipped to blending facility *j*
H_{jk}	Quantity of product *H* shipped from blending facility *j* to demand cluster *k*
S_{jk}	Quantity of product *S* shipped from blending facility *j* to demand cluster *k*
N_{jk}	Quantity of product *N* shipped from blending facility *j* to demand cluster *k*
O_{jk}	Quantity of product *O* shipped from blending facility *j* to demand cluster *k*
τ_i	1 if manufacturing facility *i* is opened, 0 otherwise
γ_j	1 if blending facility *j* is opened, 0 otherwise
ω_{jk}	1 if blending facility *j* serves demand cluster *k*, 0 otherwise

Parameters

A_i	Manufacturing cost of component *H* at manufacturing facility *i*
B_i	Manufacturing cost of component *S* at manufacturing facility *i*
C_i	Manufacturing cost of component *N* at manufacturing facility *i*
D_i	Manufacturing cost of component *O* at manufacturing facility *i*
θ_i	Fixed cost of operating manufacturing facility *i*
F_{ij}	Transportation cost per ton from manufacturing *i* to blending facility *j*
Q_{jk}	Transportation cost per ton from blending facility *j* to demand cluster *k*
T_i	Production capacity of component *H* at manufacturing facility *i*
U_i	Production capacity of component *S* at manufacturing facility *i*
V_i	Production capacity of component *N* at manufacturing facility *i*
W_i	Production capacity of component *O* at manufacturing facility *i*
X_i	Total production capacity of manufacturing *i*
M_j	Capacity of blending facility *j*
L_j	Blending cost per ton at blending facility *j*
φ_j	Fixed cost of operating blending facility *j*
E_k	Demand of product *H* at demand cluster *k*
G_k	Demand of product S at demand cluster *k*
R_k	Demand of product N at demand cluster *k*
Y_k	Demand of product O at demand cluster *k*

Since this is a cost-minimization problem, the following objective function accounts for manufacturing and blending costs, either variable and fixed, as well as transportation costs among all nodes.

Minimize (z) =

$$\sum_{i\in I}\sum_{j\in J}\{[H_{ij}*A_i + S_{ij}*B_i + N_{ij}*C_i + O_{ij}*D_i] + \quad \leftarrow \text{Manufacturing Cost}$$

$$\sum_{i\in I}\sum_{j\in J}[F_{ij}(H_{ij} + S_{ij} + N_{ij} + O_{ij})] + \quad \leftarrow \text{Transportation Cost from manufacturing to blending}$$

$$\sum_{j\in J}\sum_{k\in K}[Q_{jk}(H_{jk} + S_{jk} + N_{jk} + O_{jk})] + \quad \leftarrow \text{Transportation Cost from blending to clusters}$$

$$\sum_{j\in J}\sum_{k\in K}[L_j(H_{jk} + S_{jk} + N_{jk} + O_{jk})] + \quad \leftarrow \text{Blending Cost}$$

$$\sum_{i\in I}[\tau_i*\theta_i] + \sum_{j\in J}[\gamma_j*\varphi_j]\} \quad \leftarrow \text{Manufacturing and Blending Fixed Cost}$$

Subject to:

$$\sum_{j\in J}(H_{ij} + S_{ij} + N_{ij} + O_{ij}) \le X_i*\tau_i \quad \forall\, i \in I \quad \leftarrow \text{(1) Total production capacity of manufacturing } i$$

$$\sum_{j\in J}H_{ij} \le T_i \quad \forall\, i \in I \quad \leftarrow \text{(2) Production capacity of } H_{ij}$$

$$\sum_{j\in J}S_{ij} \le U_i \quad \forall\, i \in I \quad \leftarrow \text{(3) Production capacity of } S_{ij}$$

$$\sum_{j\in J}N_{ij} \le V_i \quad \forall\, i \in I \quad \leftarrow \text{(4) Production capacity of } N_{ij}$$

$$\sum_{j\in J}O_{ij} \le W_i \quad \forall\, i \in I \quad \leftarrow \text{(5) Production capacity of } O_{ij}$$

$$H_{2j} = H_{3j} = 0 \quad \forall\, j \in J \quad \leftarrow \text{(6) Manufacturing Capability}$$

$$\sum_{k\in K}(H_{jk} + S_{jk} + N_{jk} + O_{jk}) \le M_j*\gamma_j \quad \forall\, j \in J \quad \leftarrow \text{(7) Blending facility capacity}$$

$$\sum_{i \in I}(H_{ij} + S_{ij} + N_{ij} + O_{ij}) = \sum_{k \in K}(H_{jk} + S_{jk} + N_{jk} + O_{jk}) \quad \forall j \in J \qquad \leftarrow \text{(8) Conservation of flows}$$

$$\sum_{j \in J} \omega_{jk} \leq 1 \quad \forall k \in K \qquad \leftarrow \text{(9) Each cluster is served by one blending facility only}$$

$$\omega_{29} = 1 \qquad \leftarrow \text{(10) Cluster } k\text{=9 (New Market) is served by blending facility } j\text{=2}$$

$$\sum_{j \in J} H_{jk} \geq E_k \quad \forall k \in K \qquad \leftarrow \text{(11) Demand Fulfillment}$$

$$\sum_{j \in J} S_{jk} \geq G_k \quad \forall k \in K \qquad \leftarrow \text{(12) Demand Fulfillment}$$

$$\sum_{j \in J} N_{jk} \geq R_k \quad \forall k \in K \qquad \leftarrow \text{(13) Demand Fulfillment}$$

$$\sum_{j \in J} O_{jk} \geq Y_k \quad \forall k \in K \qquad \leftarrow \text{(14) Demand Fulfillment}$$

$$H_{ij}, S_{ij}, N_{ij}, O_{ij}, H_{jk}, S_{jk}, N_{jk}, O_{jk} \geq 0 \quad \forall i \in I, j \in J, k \in K \qquad \leftarrow \text{(15) Non-negativity constraint}$$

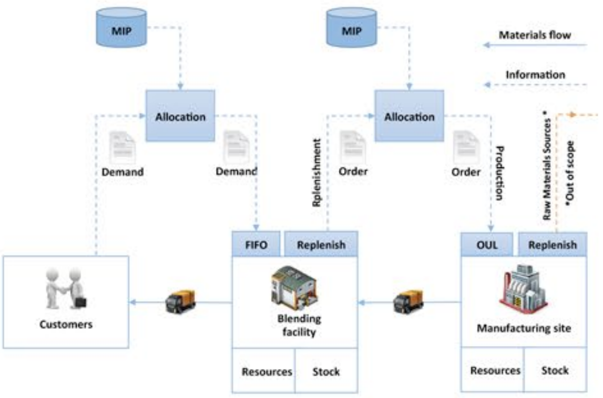
$$\tau_j, \gamma_j, \omega_{jk} = binary \quad \forall j \in J, k \in K \qquad \leftarrow \text{(16) Binary Constraint}$$

This MIP model is subject to several constraints that not only assure its functionality, but also incorporate the real world limitations that the sponsoring company has. For instance, among others there is a bounding constraint like number (6), which is intrinsically related to each manufacturing facility where one or more components cannot be produced.

Simulation Model

The purpose of this simulation model is to evaluate the performance of the optimized flows and network setup derived from the MIP under randomly generated demand according to statistical distribution based on historical data.

The overall logic of our simulation model is shown in the figure below (adapted from Pirard et al. 2010), which represents the high-level exchange of information (dotted line) and materials (solid line). This model shows the interactions among the three layers of the supply chain: customers, blending facilities and manufacturing sites. Raw materials sourcing is out of the scope.



Since this is a high level modeling exercise for which we have weekly data, we opted to work with days as the simulation base time unit. Having said this, every seven days our customers express their demands of specific combinations of the four components and these demands are allocated according to the MIP findings. As soon as the order is prepared, it is shipped to the corresponding cluster.

Inventories in blending facilities are a mix of the component, whose levels decrease whenever the demands are allocated and the outputs are shipped. At this point the model opens in two parts as blending facilities one and two (Bld1 and Bld2) produce their own components, whilst Bld3 source its components from other. The former two blending locations run continuous production-plus-blending operations, whereas the latter runs a periodic review every seven days to comply with an Order Up-To Level stock policy.

Manufacturing sites have stocks of components that are fed right after finishing production and consumed after shipping the materials to the blending facilities. It is important to keep in mind that Mfg1 is placed in the same location as Bld1 and Mfg2 is placed in the same location as Bld2. As this is the case, we assumed transportation time zero and transportation cost zero. On the other hand, Mfg3 sources a self-sustainable market but has some spare capacity, which could be used to source only Bld3.

The simulation records flows generated in order to meet the clusters demand and calculates revenues for each component-cluster combination. In brief, though the MIP was conceived as a cost minimization exercise, the results of the DES are expressed in revenue since we are pursuing new markets and further business growth.

Setting Data for the MIP

Once the data was first analyzed, we realized that the complexity and level of granularity was not manageable under the scope and timeline of the project. In the table below it is presented the breakdown of the Pareto Analysis that left us with a scope accounting for 90.4% of the total demand.

Round	Kg	Percentage
Baseline	24,561,039	100.0%
Pareto destinations	-345,580	-1.4%
Sub total	24,215,459	98.6%
Pareto FGs	-378,740	-1.5%
Sub total	23,836,719	97.1%
Product type XTZ	-1,319,437	-5.4%
Sub total	22,517,282	91.7%
Imports other regions	-310,650	-1.3%
New Baseline	**22,206,632**	**90.4%**

Apart from the resulting 22,207 tons, an additional 3,600 tons were included regarding the company expectations on the demand increase due to the prospected markets.

According to the same line of reasoning, it was decided to perform a cluster analysis using Minitab, where eight demand clusters were built. An additional two clusters were built aggregating the demand of the current market that surrounds our sponsor's new plant, as well as the expected new market to be served from this location. The ten clusters centroids are presented in the map below.

Nevertheless, this clustering efforts popped up the need of calculating new transportation cost from all four potential blending facilities to all 10 centroids. In order to perform this task, we used weighted averages with demand as the weighting factor.

After this, since the composition of all finished goods is a mix of the 3 same components and considering the fact that there is no major difference in transporting components or FGs, a simple yet creative approach was deployed. In order to capture the flows of finished goods, we aggregated the demand of every component for each cluster.

Then, we used Minitab's Distribution ID with Anderson Darling Normality test to define whether we had evidence to demonstrate that the sample could be approximated by a Normal distribution. Our sponsor company advised us to assume deterministic demand for those nodes that did not follow any other distribution.

MIP Results

The software chosen to develop the computerized model of the presented formulation was Excel Solver full pack, being the reason for this that it can be easily replicated or used whenever needed by the sponsoring company.

The AS-IS Scenario consisted of 12 months of historical data and was used to find out the current network total costs. As seen in the following table, only manufacturing site 1 (Mfg1) and blending facility 1 (Bld1) are active in the current setup. It is also important to mention that Bld2 is considered active only when there is a receiving flow of component H from Mfg1.

Manufacturing Plants			Blending Facilities		
Mfg1	Mfg2	Mfg3	Bld1	Bld2	Bld3
ON	OFF	OFF	ON	OFF	OFF

The TO-BE scenarios were made up from the combination of three factors suggested by the sponsoring company: new market demand (1000 Tons or 3600 Tons); capacity at Mfg2 (3600 Tons or 14400 Tons); and backhaul optimization (fully optimized or partially optimized). Regarding the latter, we called partially optimized whenever we had empty backhauls, and fully optimized whenever we were able to avoid them.

	Manufacturing Plants			Blending Facilities		
	Mfg1	Mfg2	Mfg3	Bld1	Bld2	Bld3
TO-BE 1	ON	ON	OFF	ON	ON	OFF
TO-BE 2	ON	ON	OFF	ON	OFF	OFF
TO-BE 3	ON	ON	OFF	ON	ON	OFF
TO-BE 4	ON	ON	OFF	ON	ON	ON

It is important to see how the network is configured under different parameters. It is relevant to mention that Bld3 operates only in TO-BE 4 and that Mfg 3 clearly should not operate.

Setting Data for the Simulation

As the TO-BE 4 scenario is aligned with the sponsor's long-term strategy, this was the one chosen to be evaluated by the Simulation model.

Apart from the optimal network configuration given by the MIP, we had to define stock policies to be used in the simulation for which we defined along with our sponsor an Order-up-to-Level (OUL) policy with periodic review with the corresponding base-stock (S) levels.

Simulation Results

The results of the simulation are presented in the following tables respectively: Flows among facilities, which clearly shows the interactions among manufacturing sites and blending facilities; and revenues by blending site, which is an important kpi for the company in order to control their operations.

Tool	Mfg site	Component	Bld1	Bld2	Bld3
MIP	Mfg1	H	6,890.11	759.44	1,454.15
		S	-	-	-
		N	3,458.57	-	647.64
	Mfg2	H	-	-	-
		S	4,554.00	2,201.79	3,591.48
		N	-	2,200.36	-
DES	Mfg1	H	6,456.70	795.86	1,454.18
		S	-	-	-
		N	3,396.49	-	682.05
	Mfg2	H	-	-	-
		S	4,538.70	2,154.97	3,754.92
		N	-	2,139.42	-

Bld site	Revenue
Bld1	6,852,032
Bld2	3,038,865
Bld3	2,054,702

Based on the results showed above, as well as, other executions of the simulation, we conclude that the footprint calculated for this scenario is enough to source the market while absorbing demand variation.

Investment Analysis

The implementation of the recommended Supply Chain Network configuration for the short and long term will require the usage of special containers to transport components and store them. The estimated number was calculated by dividing the sum of S levels for all components by the unit capacity.

Additionally, the sponsor company required an investment analysis in order to define whether they should buy or lease the containers. After contacting the potential supplier of the solution, we performed an NPV analysis bringing the monthly leasing cash flows for the next ten years to the present value.

Finally, we found that purchasing ended up being 29% cheaper than leasing, so we recommend buying them which will pay back in less than 2 years.

Conclusions

The MIP scenarios that were built are part of our lessons learnt, because as we started to run them, we realized the real meaning of performing sensitivity analysis and understanding the dynamic in the background of the results. Another important action was the sensitivity analysis and adjustments of the intermediate transportation flows cost that was performed along with the sponsor company, when we had to analyze the penalties of empty backhauls and execute new runs of the model to assure the network configuration would not change.

Moreover, the MIP allowed us to reach conclusions and recommendations for the company of how they should structure their network in the short-term, as well as in the long-term, empowering their competitiveness within the markets that they operate and prospected ones. The outcome of this thesis will allow the sponsor company to optimize their network and reduce operation costs when compared to their current supply chain network cost structure as well as increase revenues due to higher market reach.

The simulation model was very time-consuming and required a very detailed and careful approach, being its major importance the fact of evaluating the performance of the network configuration suggested by the MIP under uncertain demand randomly generated following the historical demand distributions. In this case we were able to attest that the new network setup, along with the stock policy developed, are able to run the business with no major headwinds.

As the recommended new supply chain network setup involves the usage of a special type of container, an investment analysis was made comparing the possibility of buying or leasing such equipment. This necessary investment led us to also compare whether the benefits of the new network would payoff the investment in containers within a reasonable time frame

The most important takeaway is the alignment between Business and Academia as value partners in order to solve complex business problems and support the strategic decision making process.

Cited Sources

Chopra, S., & Meindl, P. (2012). Supply Chain Management: Strategy, Planning and Operations. Prentice Hall.

Melo, M., Nickel, S., & Saldanha-da-Gama, F. (2008). Facility location and supply chain management. European Journal of Operational Research.

Pirard, F., Iassinovski, S., & Riane, F. (2011). A simulation based approach for supply network control. International Journal of Production Research, 49, 7705-7226.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2007). Designing and Managing the Supply Chain: Concepts, Strategies and Case Studies. New York: Mc Graw-Hill.

Strategic Sourcing in Complex Environments

By Hugo Hotte and Sharad Vaish
Thesis Advisor: Prof. David Gonsalvez, Ph.D.

Summary: Our thesis proposes a mathematical model to solve the supplier selection problem over a multiyear planning horizon in changing regulatory environments. We also confirm that Brines, a subcategory of chemicals, is a good candidate for increasing local content in certain target countries.

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KEY INSIGHTS

1. The supplier selection process must take into consideration changing local content requirements.
2. In order to increase their local content, companies need to focus on expanding their supplier base in low complexity and high spend categories.

Introduction

Sub-Saharan Africa has been described as a rapidly developing market for the oil and gas industry. New discoveries in East Africa (Uganda in 2006 and Kenya in 2012) generated intense interest amongst investors and created opportunities for oil and gas service companies. In parallel, procurement decisions for these companies have become more complex. Governments in new as well as in mature markets in the region have adopted or are considering adopting policies aimed at maximizing the impact of the oil and gas industry on their economies. While quality and costs continue to be important factors in sourcing decisions for the oil and gas industry, the introduction of local content requirements is rapidly reshaping the industry's regulatory environment.

The problem is that this complex business environment requires an in-depth analysis to ensure that procurement units deploy a supplier portfolio that takes advantage of sourcing opportunities in sub-Saharan countries.

This research was undertaken at the request of an upstream oil and gas service company active in sub-Saharan Africa. In order to meet the needs of the sponsor company this research focused on three countries: Angola, Kenya, and the Republic of Congo.

Suppliers in countries with limited industrial capacity are often unable to serve the oil and gas industry. Therefore, in order to reduce costs, maintain quality standards, and ensure the reliability of deliveries the upstream oil and gas industry relies largely on global supply chains. In this context, increasing local content presents a challenge.

The concept of “local content requirements” (LCR) captures a broad set of government policies aimed at generating benefits to the local economy by increasing linkages between the oil and gas industry and other sectors. According to a World Bank report, LCR generally refer to the share of employment or of sales to the oil and gas sector locally supplied at each stage of the production process [Tordo et al., 2013]. For instance, local authorities might set minimum levels of employment of local workforce and determine training requirements. LCR policies might also promote local supplier development by requiring a minimum percentage of local purchases. For the purpose of this research, we primarily focus our attention on local content policies promoting supplier development, as these are most likely to impact the supplier selection process.

LCR policies can be difficult to interpret and implement for companies. The level of details and the scope of local content policies vary greatly between countries. As a result, companies are faced with a unique set of requirements in each country of activity.

Methodology

The methodology used for this research can be defined as a three-step process. First, we reviewed the local content policies in place in Angola, Kenya, and the Republic of Congo. We also examined the local content policies of Brazil, Ghana and Nigeria as they might serve as models for future regulations in the countries considered in this research. This process helped determine how local content requirements could be integrated into a mathematical model aimed at solving the supplier selection problem at hand.

Second, we analyzed the sponsor company’s average expenditures in Angola, Kenya, and the Republic of Congo. At the request of the sponsor company the analysis centered on the distribution of the expenditures in the chemicals category. In our analysis, we identified opportunities for increasing local content through the existing supplier base. We also performed a Pareto analysis to determine which subcategory of chemicals should be considered in priority to increase local content.

Finally, we presented an approach to include supply and demand risks into the total landed costs of a commodity sourced from a given supplier. We then used this formulation to develop a mathematical model that could solve the supplier selection problem over a multiyear planning horizon and take into consideration changing local content requirements. Because the sponsor company sources chemicals worldwide, we formulated the supplier selection problem as an uncapacitated facility selection problem.

Local Content Requirements (LCR)

Local content requirements can be implemented through a wide variety of tools and mechanisms. In addition, local content requirements can vary in scope. Companies might be subject to minimum local expenditures imposed on the total value of a project or on specific categories of products. We have established that there is a high likelihood that the target countries will adopt new local content regulations over the next few years. In addition, our research has also shown that local content requirements can change unexpectedly. Finally, we have established that non-compliance with local content requirements can lead to escalating penalties.

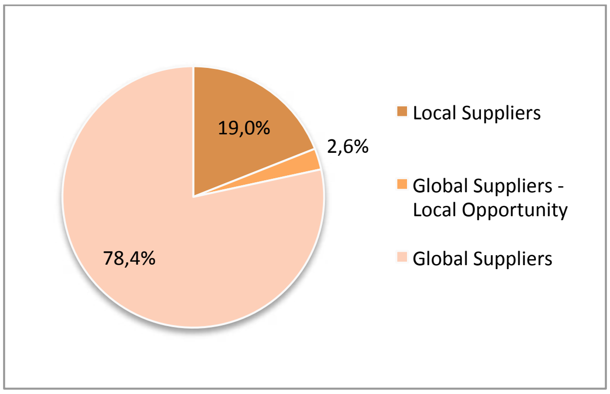
As a result, the mathematical model we will propose must be able to handle the following elements:

- Different LCR targets per category of product
- Multiyear planning with changing LCR targets
- Increasing financial penalties for non-compliance

Spend Analysis

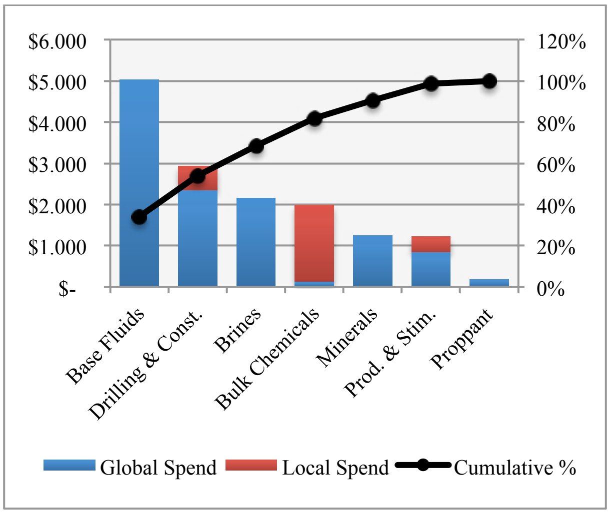
We analyzed the sponsor company’s average spend profile on chemicals in the target countries. For each country we first established the distribution of the supplier base and identified opportunities for increasing local content by maximizing purchases from existing local suppliers. We then analyzed the distribution of expenditures per subcategory using a Pareto analysis. For each country we attempted to determine which subcategory is the best candidate for increasing local content.

The pie chart below divides the average annual expenditures on chemicals in Angola into three categories according to the type of supplier base: local suppliers, global suppliers, and global suppliers - local opportunity. The *Local Suppliers* category captures all local expenditures. The *Global Suppliers* category captures all expenditures for which no local supplier is available in the sponsor company’s dataset. Finally, the *Global Suppliers – Local Opportunity* category captures the amount of money directed to global suppliers for commodities where at least one local supplier is available in company's dataset.



The *Global Suppliers – Local Opportunity* category represents an opportunity for local sourcing amounting to 2.6% of the total amount spent on chemicals. The possibility of increasing local content through the sponsor company's current supplier base is therefore limited.

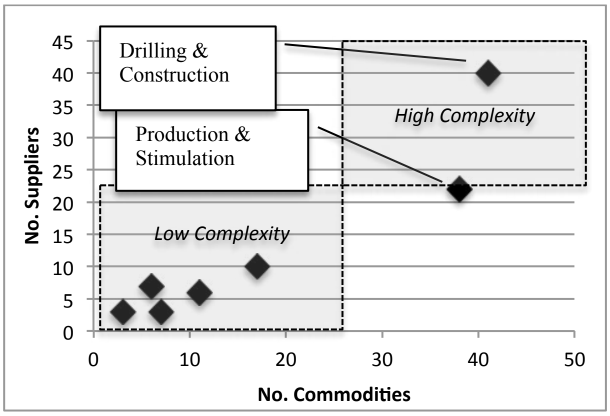
As a result, in order to significantly increase local content in chemicals, new suppliers must be identified or developed. To identify potential candidates for local sourcing, we performed a Pareto analysis of the expenditures on chemicals for Angola at the subcategory level. We ranked the subcategories of chemicals per amount spent and distinguished between local and global expenditures. The results of this analysis are shown in the figure below.



In terms of expenditures, Base Fluids are the most important subcategory. However, the sponsor company did not wish to consider local suppliers for Base Fluids because of their strategic importance. This decision removed 34% of the current spend from the pool of expenditures that could be considered for local sourcing. It also placed an important limit on the maximum level of local content that can be achieved in the category of chemicals.

We can observe from the Pareto analysis above that local suppliers are available in three subcategories: Drilling & Constructions, Bulk Chemicals, and Production & Stimulation. Unfortunately, none of these categories is a good candidate for increasing local content.

Drilling & Construction and Production & Stimulation are very complex subcategories with large numbers of suppliers and commodities. In the case of Bulk Chemicals, local content appears to have already been maximized: local suppliers account for 93% of total expenditures in this subcategory.



As a result, Brines, with 14.6% of all expenditures on chemicals, appear to be the best subcategory for the company to start increasing local content. This subcategory has a low level of complexity with only six commodities and seven suppliers.

A similar analysis was performed for the expenditures on chemicals in the Republic of Congo and Kenya. The main findings are:

- Base Fluids capture an important proportion of expenditures on chemicals (between 34% and 41%), thus limiting the maximal local content that can be achieved in the category of chemicals.
- The current supplier base cannot support an increase in local content of more than a few percentage points. The sponsor company must expand its local supplier base to meet large increases in LCR.
- In Angola and Congo, the subcategory of Brines is a good candidate to increase local content because it presents low levels of complexity and high levels of spend.
- To increase its local content in Kenya, the sponsor company should expand its local supplier base in other subcategories.

Mathematical Model

Using the findings of our research on Local Content Requirements, we developed a model that can account for evolving LCR and escalating penalties for non-compliance in the framework of a multiyear planning horizon. In addition, the model used to solve the supplier selection problem accounts for two costs: (1) the costs of starting business with a supplier and (2) penalty for changing the supplier base.

In order to support the implementation of this model, we developed an approach to calculate the total landed cost (TC) of a commodity. We proposed to define the total landed cost as the sum of four elements:

(1) Additional logistics cost of expedited shipment,
(2) Purchase cost including normal logistics cost,
(3) Pipeline inventory cost, and
(4) Customs and tariffs.

We believe that the proportion of expedited shipments is an adequate proxy for the supply and demand side risks faced by the company when using a given product-supplier combination.

In order to verify the validity of our mathematical model we used the expenditures on Brines in Angola as a test case. The test revealed that the model could successfully make tradeoffs between realizing local content and incurring penalties. However, the results showed that the modeling of penalties and of other parameters, such as inflation, have a significant impact on the behavior of the model in a multiyear scenario. Therefore, careful modeling of these costs is essential to ensure that the supplier portfolio proposed by the model is optimal.

Conclusion

It is clear from the spend analysis of chemicals that the sponsor company's current supplier base does not allow it to significantly increase its local content. To increase local content in chemicals beyond a few percentage points, the company must expand its existing supplier base. For its operations in Angola and Congo, the subcategory of brines appears to be a good candidate. The relatively low level of complexity of this subcategory combined with high level of expenditures will ensure a sizable impact on local content while minimizing the number of changes in suppliers. However, in the case of Kenya other subcategories, such as Drilling & Construction, should be considered.

An important contribution of this research is the development a methodology to integrate the supply and demand risks into the total landed cost of a commodity. We achieved this by suggesting that these risks can be factored in as a percentage of expedited orders. This approach can be used as a standalone procedure to evaluate the cost of sourcing a commodity from a given supplier or in combination with the mathematical model suggested.

This research also provides the sponsor company with the capability to evaluate the impact of changing local content requirements on its supplier base. By changing the levels of local content requirements considered by the model, managers can explore the financial consequences of different scenarios. The model developed can help procurement units determine the optimal portfolio of suppliers over a multiyear planning horizon. This model can suggest a portfolio of suppliers that takes into consideration evolving local content requirements. In addition, the model proposed is generic enough to be applicable to the company's operations in multiple countries. Even though the results are based on the analysis of a single subcategory of product, our model can be applied to multiple categories of products simultaneously. However, beyond a certain number of commodities, the computational burden of the calculations will become problematic.

An important limitation of this research is that important variables, such as the cost of changing supplier and the penalty for non-compliance, were set arbitrarily. As we have shown, these costs can have a significant impact on the behavior of the model. Therefore, careful modeling of these costs is essential to ensure the accuracy of the model's results. Additional research is needed to determine the cost to the company of setting up and changing suppliers. In addition, our model currently does not take into account the inventory holding cost of commodities. Future efforts could therefore explore how to integrate this cost into the mathematical model suggested.

References

Tordo, S., Warner, M., Manzano, O. E., & Anouti, Y. (2013). *Local Content Policies in the Oil and Gas Sector* (World Bank). Washington, DC: The World Bank. http://doi.org/10.1596/978-0-8213-9931-6

Managing Supply Chain Risk by Predicting Service Disruptions

By Matthias Kottmann & Dhawal Khabya

Thesis Advisor: Dr. Alejandro Serrano

Summary: This thesis analyzes the relationship among various factors that cause service disruptions in a leading medical devices company and assesses the feasibility of developing a model that could predict those disruptions. A service disruption occurs when a customer places an order, and the firm is unable to fulfill it completely and is measured by a metric called Customer Service Level (CSL) or Line Item Fill Rate (LIFR). To identify the leading indicators that affect the CSL, a holistic analysis of the entire supply chain including inventory policies, demand-forecasting methods, production scheduling, supplier performance, and so on, was performed. We came up with a prediction model that combines forecasting techniques using historical data and a regression model to predict CSL.

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KEY INSIGHTS

1. Deviation between planned and actual supply chain parameters such as lead-time impacts Customer Service Level.
2. Integration of disparate data sources, aligning service metrics with forecasting and considering end-to-end supply chain as a part of a network rather than as silos, will provide better visibility and predictability to improve service level.
3. Several production parameters such as batch sizes, capacity utilization, scheduling prioritization affects service level.

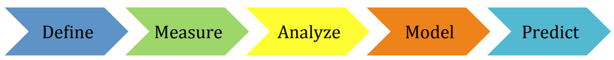
Introduction

Risks or uncertainties are the two words that are very much relevant in today's global business environment. In the supply chain world, there always lies a risk of an interruption to the flow of goods, information, or finances. These disturbances may appear in the form of transportation delays, poor communication, or even natural disasters. In the context of this thesis, whenever a customer order is not completely fulfilled, the firm calls it a service disruption. The firm currently measures these service disruptions by a metric called Line Item Fill Rate (LIFR), which is simply a measurement of their Customer Service Level (CSL). This thesis deals with a situation where a leading medical devices company is trying to reduce its service disruptions caused by inadequate availability of one of its extremely critical surgical products. In the life sciences industry, a service disruption or poor service level may directly affect human lives.

The purpose of this project is to understand the relationship among various factors that affect service level and assess the feasibility of developing a model that could predict a service disruption. A CSL or LIFR is defined as the number of lines shipped over the number of lines ordered by a customer.

$$\text{CSL or LIFR} = \frac{\text{Number of lines shipped}}{\text{Number of lines ordered}} \text{x} 100$$

The company defines a LIFR higher than 95.8% to be acceptable. As the issue is highly data-intensive, we approached the problem following a six-sigma DMAIC method albeit with some modifications.



- **Define** – Firstly, we identified and defined the problem. We clearly outlined what is in scope and what is out of scope.
- **Measure** – Secondly, we understood the problem by studying the AS-IS state and

measuring the Key Performance Indicators (KPI): CSL or LIFR

- **Analyze** –Thirdly, we mapped the end-to-end flow of the supply chain, from the procuring raw material to final delivery to the customer.
- **Prediction Model –** Lastly, we developed a model that explains the behavior of the KPI in order to predict service disruptions.

Qualitative Analyses

- **Root Cause-Fishbone**

We interviewed and performed a Fishbone analysis with the key stakeholders. We identified and segmented various potential causes into categories such as Information, Inventory, Planning, Production, Materials and Forecasting to better understand cause and effect relationship.

- **Supply Side Analysis**

We found that nearly 53% of the suppliers had lower than acceptable LIFR. Lack of data related to suppliers limited our ability to find out whether the unavailability of a specific raw material from the supplier led to a low LIFR.

- **Raw Material Availability**

The company's Advanced Planning System (APS) does not have information about raw material availability. Therefore, in some situations, the production unit cannot schedule an SKU in spite of an APS signal to produce, because of unavailability of raw material. If the SKU is not produced, there will be a delay in fulfilling the order at the demand locations, thereby affecting service level.

- **Production Capacity Utilization and LIFR**

Preliminary analysis showed that only when the capacity of a line is greater than 100% utilized, we see an impact on LIFR.

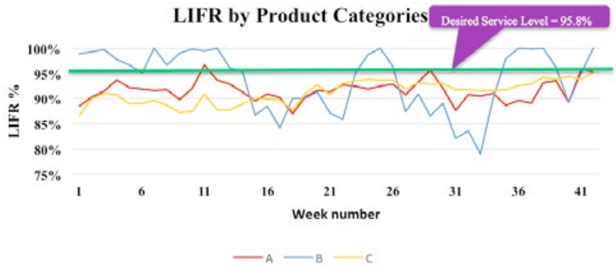
- **Production Batch Size and LIFR**

Certain SKUs are only produced a few times a year. Due to higher than required quantities produced and stocked, these SKUs have higher LIFR, as compared to SKUs that are produced several times in a year.

Quantitative Analyses

- **Data Analysis**

The first task was to validate the current service levels by measuring the CSL. As the figure above shows, the LIFR is clearly below the desired level.



Then we looked into several clusters such as product type, manufacturing location, manufacturing lines, and so on, and their corresponding LIFR behavior. One classification was the product category and the question was whether one category performed differently from another with respect to their LIFR. The above figure shows that only the B-category was able to reach a satisfying level. Furthermore, we performed a Mann-Whitney test that let us draw statistical conclusions.

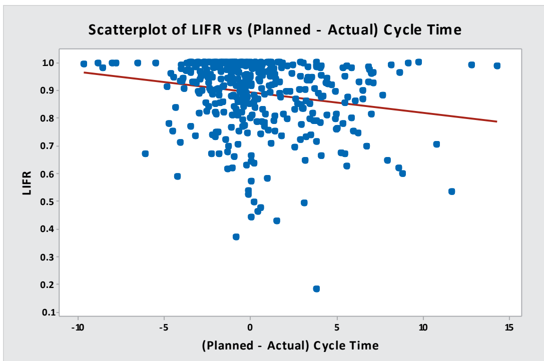
We also looked into the possible regression analysis to investigate the behavior of the entities and their impact on LIFR performance. However, none of them gave any significantly higher R^2 value. Therefore, we could not use the regression equation using average values of independent variables to develop a prediction model.

Deep Dive Analysis

We further dive deep to understand the reasons behind the preliminary results.

- **Deviation in Total Planned Lead-Time vs. Actual Lead-Time**

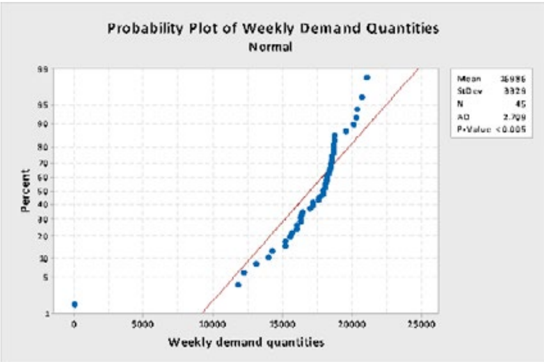
We took the average lead-time deviation between planned and actual lead-time and averaged it for all the applicable SKUs. The correlation between the LIFR and average deviation between planned and actual lead-time was negative although not strong, as the figure below shows. The reason for a weak correlation was that the company actually considers the effect of lead-time variability in its safety stock calculation, which cushions the variability's impact on LIFR.



- **Coefficient of Variation of Demand and LIFR**

We got very low correlation between LIFR and coefficient of demand variation because the company's safety stock calculation takes into consideration the demand variability factor for each SKU. Hence, demand variability's effect on LIFR is shielded.

- **Safety Stock Calculation and Normality Assumption of Demand**



The company assumed demand to be normally distributed, which was not a correct assumption as the figure below depicts. All the safety stocks were calculated based on demand normality assumption, and hence safety stock calculations were not accurate, potentially impacting LIFR.

- **Demand Forecast Error and LIFR**

MAPE (Mean Absolute Percentage Error) and LIFR were very poorly correlated because forecasting is done based on demand quantities, whereas LIFR is measured in terms of lines ordered.

Regression analysis

We then ran a multiple-regression model among several variables such as deviation in actual and planned lead-time, manufacturing frequency and Unable to Schedule (UTS) percentage data. The results of the regression analysis show that the above factors do not sufficiently explain the dependent variable.

Possible Models

Firstly, we developed a multiple-regression model: however, the model did not sufficiently explain the variation in the CSL. Secondly, we used a logistic regression model, which can be used for binary data. In our case, we converted the LIFR into a binary response variable by segmenting values of 95.8% and above as 1 and any value below as 0. This yielded us a much stronger regression equation with R^2 of 52% and all the goodness of fit tests had a high p-value. The output of a logistic regression model is a probability of an event (0 implies a disruption and 1 implies no disruption) but this output is not very useful for the company.

Finally, we come up with a hybrid model that predicts LIFR combining a regression model and forecasting techniques. A user can adjust weights between the regression and the forecasting model based on the R^2 value of the regression model. If the R^2 is low, higher percentage weight can be given to the forecasting model and if R^2 value is high, higher percentage weight can be given to the regression model. The final predicted value is a weighted average of regression and forecasting model as the figure on above illustrates.

- **CSL Simulation Using Arena**

We also created a simulation model to see the impact of certain variables on the number of customers lost. By modifying these variables such as target stock levels, batch size, reorder point, and so on, the impact on the service level was analyzed.

Findings

- **Lead-time variability's impact on LIFR**

Seemingly, obvious factors such as long lead-time or long manufacturing cycle-time does not necessarily lead to poor service level.

- **Deviation in actual versus planned lead-time adversely affects LIFR**

The correlation analysis between "actual lead-time - standard lead-time" and LIFR supported our hypothesis that the variability of planned and actual parameters of an SKU affects LIFR.

- **Demand forecast and LIFR**

Demand forecast for the SKUs is done in quantities whereas LIFR is measured in lines shipped over lines order. Therefore, even if the demand forecast is very accurate, it does not necessarily lead to a high CSL.

- **Demand variability and LIFR**

The firm has an inventory model that takes into account the demand variability of an SKU while allocating the appropriate safety stock to it. Therefore, we did not see a strong correlation, as the effect of variability was already accounted for in the inventory model.

- **Production batch size and LIFR**

SKUs that have batch sizes higher than or comparable to their annual demand have better LIFR performance. This implies that these higher performing SKUs shield other low-performing SKUs and secondly, the batch size of the higher performing SKUs are too large, thereby incurring relatively high inventory holding cost.

- **Safety stock calculation and normality assumption**

The safety stock calculation of the company for SKUs assumes normal demand distribution, which is not the case. Hence, an inaccurate safety stock calculation may lead to a poor CSL.

Conclusion

We started with a problem statement to develop a model that can predict a customer service disruption; a problem that the firm wanted to resolve to have a better LIFR. In order to do so, we analyzed the end-to-end supply chain right from supplier performance and availability of raw materials, to production schedules and inventory policies. We dived deep into data to understand the relationship among various supply chain parameters, variables, and LIFR.

One key insight is that a longer lead-time does not necessarily result in a poor LIFR, instead a deviation between planned and actual lead-time affects LIFR adversely. We also found that inaccurate assumptions in calculating safety stock leads to poor CSL. Another finding is that LIFR is measured in lines shipped over lines ordered whereas SKU demand forecast is done in quantities, which means improving demand forecast may not improve LIFR. In addition, a delay in supply of raw materials or capacity constraint on a production line can lead to a delay in production of an SKU, thereby affecting LIFR.

We also understood that the batch size of an SKU could also potentially affect LIFR; if batch size is comparable to a SKU's annual demand quantity, we see near 100% LIFR performance.

We also found that the inventory model of the firm considers the demand volatility to allocate safety stock, thereby shielding the effect of demand volatility on LIFR. Finally, certain human decisions that are not captured in any system affect LIFR. For example, the difference in prioritization methods for order fulfillment at different warehouse locations implies inconsistency in measuring LIFR. Eventually, we incorporated all these findings to create a framework for a model, which uses a combination of a regression model and forecasting techniques to predict LIFR performance.

The framework used in this model can be used as a building block to a more sophisticated, robust, and inclusive prediction model. The company can integrate disparate data sources, align LIFR metrics with forecasting and consider end-to-end supply chain rather than silos for better visibility and predictability. Furthermore, capturing human decisions in a system and plugging those into the model may improve the accuracy of the model. Once all the above mentioned findings are incorporated, we believe that this inclusive prediction model can help the firm take more informed data-based decisions and act proactively to mitigate the risk of a service disruption.

ZLOG CLASS OF 2015

THESIS PROJECTS

Product Portfolio Analysis & Evaluation of Technical Criteria for Product Phase Out
By Aram Aharonian & Diana García

This thesis provides a structured approach with the goal of reducing product complexity. This includes a thorough product portfolio analysis and subsequent optimization recommendations. Based on these findings, the analysis of soft and technical factors is conducted, evaluating the feasibility of the aforementioned proposals. Lastly, the supply chain impact is determined if the recommendations were to be put in place.

Collaboration Across Boundaries
By Christian Bautista

This thesis examines the relationship between counterintuitive elements and benefits by market research and empirical evidence. These elements shall help Supply Chain Collaboration (SCHC) propagation and adaptation to almost any industry worldwide. In addition, it proposes SCHC practice guidelines based horizontal collaboration survey to professionals' analysis; and proven collaboration practices that are highly successful in pockets of the supply chain.

Innovating Flexible Distribution - Alternative Route-to-Market Models for the Beverage Industry
By Vincent Chong & Ricardo Salvatierra

The objective of this study is to quantify cost savings from introducing flexibility to product distribution. A simplified linear program was formulated to identify the optimal solution assuming a deterministic scenario, while simulations were developed to incorporate stochastic variables. Recommendations include an evaluation of alternative route-to-market models and insights on market characteristics where these models may be successfully implemented.

European Trucking Optimization
By David Fernando & Yongbae Lee

This thesis aims at proposing a new optimization of the European road transportation model which reflects current and future geographical changes in demand. In order to do so, a methodology of action has been developed, it contains the following activities: the development and analysis of the current road transportation model, the creation of a cost analysis tool, the sensitivity analysis of future trends and some scenario analyses that provide the solutions.

Network Optimization as a Business Advantage
By Arturo García & Edson Guimaraes

This thesis addresses the design of the supply network for a chemical company that is setting up an operation in an emerging country to explore the nearby markets. We tackled this real-life business necessity with a two-stage approach based on Mixed-Integer Programming and Discrete Event Simulation.

Transforming Procurement from Minimizing Cost to Maximizing Value
By Kanupriya Godara & Francisco Márquez

This thesis identifies the leading enablers to transform procurement from a purely-cost driven to a value-driven process. We model the problem of value creation in procurement as an Analytical Hierarchy Process (AHP) to understand the correlation between the value drivers and values that are important for companies today. To assess the capability of the sponsor company in terms of the top five value drivers, we developed a maturity assessment tool with best practices and levels of accomplishment.

Supplying Small Stores in Megacities
By Dhriti Goswami & Yongcheng He

This thesis aims at providing best practices in city logistics to deliver goods to small stores or nano-stores in megacities, faced with the constraints of congestion, pollution, and city regulations. After analyzing several existing practices, we propose a consolidation center model with electric vehicles for the city of Madrid.

Managing Supply Chain Risk by Predicting Service Disruptions
By Dhawal Khabya & Matthias Kottmann

This thesis analyzes the relationship among various factors that cause service disruptions in a pharmaceutical company and assesses the feasibility of developing a model that could predict those disruptions. A service disruption occurs when a customer places an order, and the firm is unable to fulfill it completely and is measured by a metric called Customer Service Level (CSL) or Line Item Fill Rate (LIFR). To identify the leading indicators that affect the CSL, a holistic analysis of the entire supply chain including inventory policies, demand-forecasting methods, production scheduling, supplier performance, and so on, was performed. We came up with a prediction model that combines forecasting techniques using historical data and a regression model to predict CSL.

Strategic Sourcing in Complex Environments
By Hugo Hotte & Sharad Vaish

This thesis proposes a mathematical model to solve the supplier selection problem over a multiyear planning horizon in changing regulatory environments. We also confirm that Brines, a subcategory of chemicals, is a good candidate for increasing local content in certain target countries.

Measure & Monitor: Improving Identification to Increase Keg Rotations
By Bian Li & Eduardo Perea

The purpose of this thesis is to gain an in-depth understanding of the feasibility and capacity of existing tracking technology to improve visibility of keg flows, as well as potential impacts of technology implementation, including any opportunities for increased keg rotations and improved financial and operational impacts.

Improving Downstream Retail Operations
By Kevin Lin & Carlos Soto

This thesis tackles the question of alleviating stress on the supply chain and retail stores of a fashion retailer that accommodate a "push model" of inventory. One way is through the design of a user interface model for allocators based on the Analytical Hierarchy Process, and the second way explores a more qualitative format such as cartonization rules of the distribution center to employee management.

The Request-for-Proposal: Creation, Sharing and Management of Information in the Tender Process
By Vinod Parmar

This thesis tackles the question of what the best practices are to create an efficient Request for Proposal during a tender process. It highlights the main issues faced by our sponsor company when it tries to communicate the necessary information from a service provider and vice-versa.

Customs, Transportation and Warehousing Capabilities required in Piraeus Port to Increase Competition as a Mediterranean Logistics Hub
By Ioannis Solomakakis

This thesis aims to identify the actions to be taken in order to minimize the transshipment turnaround time for the company's containers at the hub port of Piraeus in Greece. To achieve that purpose, container operations at the port of Piraeus are analyzed and bottleneck processes are determined. The root causes for the delays are identified and recommendations for improvements are proposed.

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