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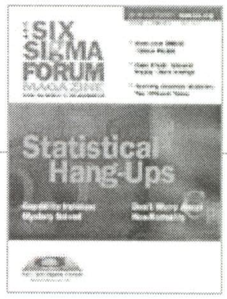

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CASE STUDY

Use What You Have

A NETWORK DESIGN MODEL CAN UNCOVER SUPPLY CHAIN SAVINGS OPPORTUNITIES.

By Erick C. Jones and Josephine A. Hain, University of Nebraska-Lincoln

Technical organizations are often challenged to align their supply chains because engineering managers must coordinate data collection and analysis efforts to evaluate the chains in a cost effective manner. Most organizations use costly software and consultants for such evaluations and never tap into their in-house resources. Internal teams, however, can often be more cost effective because:

1. The data collected will be used again if consultants are deemed necessary.
2. The internal teams will understand the implications of the solutions and can make adjustments for reality.
3. Simplified assumptions can quickly be agreed upon.
4. The project will prepare personnel for change.

An engineering manager's goal when locating facilities and allocating inventory should be to maximize the overall profitability of the resulting supply chain network while providing customers with adequate service. Traditionally, revenues come from the sale of product, and costs arise from facilities, labor, transportation, materials and inventory holding. Ideally, profits after tariffs and taxes should be maximized when designing a supply chain network.

Engineering managers must make some tradeoffs during network design. For example, building several facilities to serve local markets reduces transportation costs and provides fast response time, but it increases the facility and inventory costs incurred by the firm.

No matter the situation, managers should first consider using an internal team and an established network design model. These models provide a rich and robust framework for analyzing data, forming relationships and forecasting. They provide managers with broad and deep insights into effective plans, which are based on the company's decision options, goals, commitments and resource constraints.[1]

Network design models can help teams:

- Decide where to establish facilities and determine the capacity assigned to each facility.
- Assign current demand to the available facilities and identify lanes along which product will be transported.

In both cases the goal is to maximize the profit while satisfying customer needs.

The following information must be available before managers can decide which design model to use:

- Location of supply sources and markets.
- Location of potential sites.
- Demand forecast by market.
- Facility, labor and material cost by site.
- Transportation costs between each pair of sites.
- Inventory costs by site.

- Sales price of product in different regions.
- Taxes and tariffs as product is moved between locations.
- Desired response time and other service factors, such as on time product delivery, order confirmation within 24 hours and backorder notification within two hours.[2]

Once managers have gathered this information, they can choose one of two appropriate models, each of which has different objectives. The two models considered for this case study were the capacitated plant location model and the gravity location model. The capacitated plant location model seeks to minimize the total cost of the current supply chain network by formulating the problem into an integer program. The gravity location model seeks to establish an optimal location based on cost inputs. In this case, we decided to use the capacitated plant location model[3] to determine the minimal number of facilities that could hold inventory and meet customer demand.

Case Description

Our case study took place at the materials management branch (MMB) of a public works facility in Houston. The MMB processes and coordinates all procurement and contract related activities and stores and distributes all general inventory items.

The MMB facilitates purchases ranging from pipes for restoration of sewer lines to computers and traffic signs. To promptly obtain goods and services, the MMB has more than 800 commodity and service contracts.

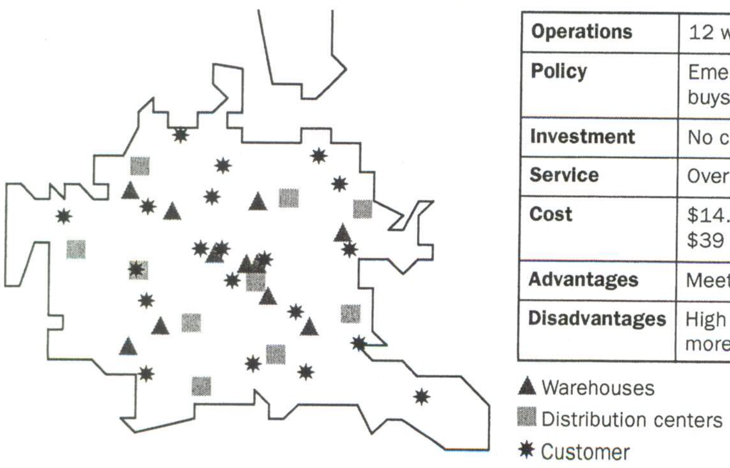
The MMB is divided into three functional sections: procurement, contract management and warehousing and distribution. Our study focused on warehousing and distribution in which two central depots serve as staging locations for inventory that is distributed to a network of 10 general supply warehouses, nine automotive warehouses and many distribution centers throughout the city. The inventory consists of a variety of items, such as pipes, valves, fittings and office and janitorial supplies.

Previous audits of the MMB identified some opportunities for improvement in its warehousing operations, such as reducing excess obsolete inventory, evaluating SOPs and increasing labor productivity. Obsolete inventory is inventory that has not had any requests for disbursement for more than one year.

The current system contains 12 warehouses and 28 distribution centers, with an ongoing cost of \$14.94 million (see Figure 1). Upon inspection, the warehouses were estimated to be using only 30% of their space. The public works department owned \$10.1 million of the inventory housed in the MMB warehouses. (The remainder was owned by other city entities.) The inventory that was deemed obsolete was valued at \$3.6 million or 35% of total inventory.

The city decided to try to consolidate warehouse facilities and asked management whether all 12 facilities were necessary. The managers assigned a supply chain team of University of Nebraska-Lincoln and city

Figure 1. **Current Supply Chain Description**



Operations	12 warehouses and 28 distribution centers.
Policy	Emergency credit card buys, contract buys and noncontract buys.
Investment	No change.
Service	Over the counter and some delivery.
Cost	\$14.9 million with transportation. \$39 million with facility acquisition.
Advantages	Meet some customer demand.
Disadvantages	High amount of inventory that hasn't been ordered for more than one year. Amounts to \$0 in orders that year.

personnel to study the network for the public works operations and identify the warehouses that could be closed.

Our goal was to formulate the model to minimize total costs, taking into account costs, taxes and duties by location. Given that taxes and duties do not vary between locations and the city does not pay taxes, the team decided to use the existing facility locations and allocate demand to the open warehouses to minimize the total cost of facilities, transportation and inventory.

The Capacitated Plant Location Model

The capacitated plant location network optimization model requires the following inputs:

- N = number of potential locations.
- M = number of demand points.
- D_i = annual demand from market i.
- K_i = potential capacity of plant i.
- F_i = annualized fixed cost of keeping factory i open.
- C_{ij} = cost of producing and shipping one unit from factory i to marker j. The cost includes production inventory, transportation and duties.

This model also requires the following decision variables:

- Y_i = 1 if plant is open; otherwise Yi = 0.
- X_{ij} = quantity shipped from factory i to market j.

The problem is formulated as the following integer program

$Min\left(\sum_{i=1}^{n} F_i Y_i + \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} X_{ij}\right)$, and is subject to the following:

- Equation one: $\sum_{i=1}^{m} X_{ij} D_{ij}$ for j = 1 ...... m.
- Equation two: $\sum_{j=1}^{n} X_{ij} \leq K_i Y_i$ for i = 1 ...... n.
- Equation three: $Y_i \in (0, 1)$ for i = 1 ...... n.

The objective function minimizes the total cost (fixed + variable) of setting up and operating the network. The constraint in equation one requires the demand at each facility market be satisfied. The constraint in equation two states no plant can supply more than its capacity. The capacity = 0 if closed and K_i if open. The product of the terms $K_i Y_i$ captures this effect. The constraint in equation three ensures each plant is either open (Y_i = 1) or closed (Y_i = 0).

The model is solved using the solver tool in Excel.[4] This linear programming tool can be added to any Excel program by clicking on Add-ins in the Tools menu. Check the box next to Solver Add-in, and then click OK. Once added, click on the Tools menu and then on Solver. To use the tool, place the constraints in the correct format and click Solve. The solution will identify the plants that are to be kept open, their capacity and the allocation of regional demand to these plants.

DMAIC and the Network Model

We used the define, measure, analyze, improve, control (DMAIC) approach and integrated the capacitated plant location model into the analyze phase.

Define. In the define phase, team members determine what the project should accomplish and confirm their understanding with their sponsor. They should agree on the problem, understand the project's link to corporate strategy and its expected contribution to return on investment capital (ROIC), agree on the project's boundaries and know which indicators or metrics will be used to evaluate success. The last two issues are particularly important in service environments.[5]

The MMB team decided the goal for this project was to reduce obsolete inventory.

Measure. One of the major advances of Six Sigma is its demand for data driven management. Other improvement methodologies tend to jump from the define stage into the improve stage without allowing time to gather sufficient data to understand the underlying causes of the problem. The measure phase is generally broken into three steps: establish baselines, observe the process and collect data.[6]

The MMB team decided its measure of success was to reduce the percentage of obsolete inventory in the supply chain.

Analyze. The analyze phase attempts to make sense of all the information and data collected in the measure phase. Teams must stick to the data and not use their own experience and opinions to make conclusions about the root causes.[7]

There are many tools available in the analyze phase, including network modeling. After using regression analysis and design of experiments, the MMB team chose to use supply chain optimization—the capacitated plant location model—to garner a more robust solution.

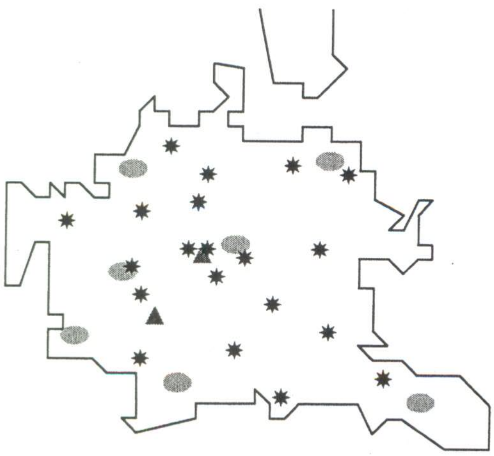
In implementing the capacitated plant location model, the team:

1. **Collected input data and established a baseline:** The current supply chain information was collected to form the input data for the network model. The inputs included costs for electricity, gas, data lines and labor. Holding and transportation costs were also estimated for each facility. The warehouses don't pay taxes or water costs because they are in city owned buildings, so information regarding lost water sales and lost taxes was also captured and used in the cost equations.
2. **Set optimization constraints:** The optimization constraints included the size limitations and the future demand of each facility. The facility size was collected from operations, and the future demand on inventory was estimated to be the same as last year's value.
3. **Ran alternatives with the capacitated plant location model:** The team input the costs and data collected in steps one and two into Excel and used the solver tool to run alternatives of the least expensive model.
4. **Showed alternatives in revenue, savings and customer service:** The team evaluated the different alternatives for revenue and savings with an ROI calculation assuming the project had a five-year life. The customer service provided in each alternative was evaluated by a team from operations. Savings were associated with space reduction, and taxes and depreciation were associated with closing some facilities. The savings accumulated in closing some facilities was limited because the team accounted for the savings from eliminating long-term leases, not the profit made by selling the property. Also, the city does not pay property taxes, so the savings were minimal compared to those in other industries.
5. **Selected an alternative:** The optimal solution contains two centrally located warehouses (see Figure 2), eliminates 96,000 square feet and translates into a \$3.5 million savings over five years. This solution will increase space utilization to 65% and reduce obsolete inventory to 10% of the total value held within the warehouses.

By following these steps, the MMB team discovered an alternative that minimized the cost of the supply chain and directed the tasks in the next phase.

Improve. In the improve phase, teams change a process to eliminate the defects, waste and costs linked to the customer needs identified in the define stage.[8] Though the improve stage differs for every Six Sigma project, all improvements should focus on the

Figure 2. **Optimized Supply Chain**



Operations	Two warehouses, no distribution centers.
Policy	Vendor credit card, emergency credit card, contract, noncontract and internet.
Investment	Warehouse management system, consolidation and delivery operation cost.
Service	Over the counter and delivery service to site.
Cost	Additional fleet maintenance, new racking and project manager.
Advantages	Vendor managed inventory on noncritical, fast moving items; critical items better managed, reduced labor and reduced facility cost.

▲ Warehouses
Vendor sites
✱ Customer

Table 1. **Key Performance Indicators**

Category	Metric	Definition
Service	Turns	Annual money issued/average
Service	Percentage of obsolete inventory	Number of commodity codes (CC) that have not been issued for more than one year/total number of CCs
Cost	Cost/pick	Total labor cost/total number of picks
Cost	Cost/order	Total labor cost/total number of orders
Asset management	Facility utilization	Number of pallet positions used vs. number available
Future		
Transportation	Shipments/division	Track number of deliveries to site for each division
Inventory	Velocity	Annual revenue/daily overhead
Labor	Percentage of productivity by area/task	Actual labor hours/efficiency standard for task; track by employee
Labor	Picks/hour	Number of pick issues/pick labor hours
Purchasing	Purchase card spending by category	Purchase card spending by contract, noncontract and emergency usage vs. total purchase card spending

largest issues found in the analyze phase.

After finishing the analyze phase, the MMB team knew to concentrate on consolidating facilities and using a more robust criterion for eliminating outdated inventory.

Control. The control phase ensures any gains made will be preserved until new knowledge and data show a better way to operate the process. Teams must document improved processes, turn the results into dollars, continually verify maintenance of gains, install automatic monitoring systems, pilot the implementation and develop control plans. They must address how to hand off what they learned to the process owners and ensure everyone working on the process can use any new, documented procedures.

In this phase, the MMB team identified several key performance indicators (KPIs) to track with statistical process control (SPC) charts the following year (see Table 1). As the city moved toward the optimized model, the control phase kept the improvements in place and running smoothly.

Lessons Learned

Before configuring your own network design model, consider some of the lessons learned by the MMB team. The capacitated plant location model was originally chosen because the team wanted a first look at the supply chain and a simple implementation. A more complex model could have been used if better data had been available. Unfortunately, the available data could not be validated because it came from the department's antiquated enterprise resource planning system. Remember, the model is only as good as the data it is provided. If you put garbage into a model, you'll get garbage out of it. Besides, if the team had decided to use a more complex model, it would have had to hire consultants and use software other than Excel.

It was also difficult for the different divisions to agree on which part of the cost data could be considered reduced costs. For example, the MMB team should have been able to figure the overall utility costs at a facility by calculating the percentage of space used for inventory storage. But what if that facility was recommended for closing? Then the other nonstorage operations would have to move before the cost savings could be realized. Further, the cost savings had to be deeply discounted because the city did not have to pay taxes on utilities and did not invest, but instead spent, money that was saved. These types of constraints did not fit smoothly into the linear model, but they had to be addressed before the recommended changes were accepted.

Integrating the capacitated plant location model into the analyze phase of the DMAIC process is a quick and inexpensive way for a team to uncover supply chain savings opportunities. It makes use of internal personnel who may have a better understanding of operations than outside consultants and uses existing spreadsheets instead of costly software and consultants.

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