MGV- 206V – Decision Analytics
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White Paper

Supply Chain Optimization Model

About Product

Companies use a distribution network to bring their products from manufacturing facilities to end consumers. This entire movement of products incur a huge cost and can save a lot of money for them if managed properly. A company designs its distribution network such that it creates a balance between fulfilling the retailers' demand of products in time and the cost of distribution.

Supply Chain Optimization model is one such model that helps the companies to identify the right number and location of warehouses for them. Further, it helps to determine the network of each warehouse that further distributes the products to other warehouses/retailers. In addition, the model determines the units of product that a company should ship from one warehouse to another while maintaining the minimum service level at minimum cost.

The model allows the user to generate optimal results by entering the parameters such as the transportation cost per mile per unit of product, current location of warehouses, distances between warehouses, radius of distance within which a warehouse could distribute products, fixed cost to operate each warehouse, variable cost per unit of product associated with each warehouse, maximum capital available for fixed cost, demand of products by each warehouse, maximum distribution capacity of each warehouse, and minimum service level to be maintained by the operational warehouses.

Application with Example

New England Root Beer Distributors (NERD) was founded in the late 1800's in East Kingston New Hemisphere. Always family owned, NERD has grown tremendously from its humble origins selling root beer from a horse-drawn carriage to now serving the better part of the North Eastern United States root beer market.

Over the last few years, the distribution system within New England itself has come under scrutiny. The current central distribution centers (CDCs) and region distribution centers (RDCs) have been haphazardly selected over time through mergers and acquisitions of other smaller root beer breweries. CDCs receive the barrels of root beer directly from the factory, sell them in the local market, and supply them to RDCs. The current managers think that there are too many CDCs.

Each CDC has its own fixed operational costs, variable costs per barrel of beer, and transportation costs per mile per barrel to deliver beer to the respective RDC. In addition to fulfilling the demands of the RDCs, CDCs also have limited supplying capacities and minimum service levels that they need to honor as per Service Level Agreement.

Now, NERD wishes to re-design its distribution network using an automated model. The model will be used to determine which CDCs should be open and what number of barrels should be distributed from which CDCs to RDCs such that it optimizes the total costs associated with distributing the root beer from factory to CDCs to RDCs.

Following principles are used to automate the distribution network and number of barrels on each arc to optimize the total distribution costs for NERD:

1. Any CDC would distribute barrels to RDCs within fixed distance of its radius
2. Every CDC, if operational, need to maintain minimum service level
3. Total fixed costs of operational CDCs should not exceed certain amount at any point of time

The Model

Index sets

$$N = Central\ distribution\ centers$$

$$M = Regional\ distribution\ centers$$

Variables

$$x_{ij} = Flow\ quantity\ from\ CDC\ i\ to\ RDC\ j, \forall\ i\ \in N\ and\ \forall\ j\ \in M$$

$$y_i \in \{0, 1\} :\ 1\ if\ the\ CDC\ is\ open,\ 0\ otherwise\ \ , \forall\ i\ \in N$$

Parameters

$$D_j\ = Demand\ for\ the\ RDC\ j, \forall\ j\ \in M$$

$$S_i = Supply\ from\ the\ CDC\ i, \forall\ i\ \in N$$

$$c\ = Transportation\ Cost\ per\ product\ per\ mile$$

$$d_{ij} = Distance\ from\ CDC\ i\ to\ RDC\ j, , \forall\ i\ \in N\ and\ \forall\ j\ \in M$$

$$f_i\ = Fixed\ cost\ for\ the\ CDC\ facility, \forall\ i\ \in N$$

$$V_i = Variable\ cost\ per\ CDC\ facility, \forall\ i\ \in N$$

$$SL =\ The\ probability\ of\ being\ able\ to\ fulfill\ the\ RDC's\ demand\ without\ losing\ sale\ or\ violating\ service\ level\ agreement.$$

$$C = Maximum\ planned\ capital\ investment\ the\ firm\ is\ willing\ to\ make.$$

$$SD = Maximum\ distance\ a\ CDC\ would\ be\ able\ to\ fulfill\ the\ demand\ of\ the\ RDC.$$

Calculated Parameters:

$$A_{ij} = \{0,1\} : 1 \; if \; d_{ij} \le SD, 0 \; otherwise, \forall \; i \in N \; and \; \forall \; j \in M$$

$$D = \sum_{j \in M} D_j \;, where \; D_j \; is \; the \; demand \; for \; the \; RDC \; j.$$

Objective function

Minimize

$$Cost = \sum_{j \in M} \sum_{i \in N} x_{ij} * c * d_{ij} + \sum_{i \in N} f_i * y_i + \sum_{i \in N} \sum_{j \in M} x_{ij} * V_i$$

Constraints

Supply constraint:

$$\sum_{j \in M} x_{ij} \le S_i \qquad \forall \; i \in N$$

Demand Constraint:

$$\sum_{i \in N} x_{ij} \ge D_j \qquad \forall \; j \in M$$

Linking constraint:

$$\sum_{j \in M} x_{ij} \le B * y_i \qquad \forall \; i \in N,$$

$$Where \; B \; is \; a \; big \; number, ideally \; the \; capacities \; of \; CDC$$

Service level constraint:

$$\sum_{j \in M} \sum_{i \in N} \frac{A_{ij} * x_{ij}}{D} \ge SL$$

Capital Investment constraint:

$$\sum_{i \in N} f_i * y_i \le C$$

Output:

The model will give the number of CDCs that should be operational, their location, and the number of barrels that should be shipped from each operational CDC to RDC such that the cost is minimized, and each CDC operates at minimum specified service level.

This way NERD could use this model to find the right number and location of CDCs, optimal number of barrels to be shipped from each CDC such that it optimizes its cost while operating within its resource constraints.

Further, we performed the sensitivity analysis on transportation cost per mile per barrel, and minimum service level to find out the effect of each of these parameters on the total cost.

For NERD, we found that the cost varies linearly with each of these parameters within a specific range, i.e. the cost increases by a fixed amount per unit increase of one of these parameters, others held constant. The total cost increases by $118 per 1% increase in minimum service level, in the range from 91% to 99%. The total cost also increases by $517.3 per $0.01 increase in the transportation cost per product per mile, in the range from $0.50 to $0.60.