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A DISTRIBUTION SYSTEM DESIGN MODEL

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ABSTRACT: *Large varieties of mathematical programming models have been developed to provide decision support to the design engineer. The paper deals with some of the problems and offers practical solutions.*

KEY WORDS: *Warehouses, Distribution system design.*

I. Introduction

Distribution system design is the strategic design of the logistics infrastructure and logistics strategies, which delivers products from one or more sources to the customers. Because of the long-term impact of the distribution system, the interrelated design decisions, and the different objectives of the various stakeholders, designing a distribution system is a highly complex and data intensive engineering design effort [2, 8]. The results of the models and tools have to be very carefully validated. The uncertainty of the forecasted data has to be explicitly incorporated through sensitivity and risk analysis. The final configuration is often based on the balance between many different factors and many alternative configurations may exist. However, modeling-based design is the only available method to generate high-quality distribution system configurations with quantifiable performance measures [5].

II. Exposition

In today's rapidly changing world, corporations face the continuing challenge to constantly evaluate and configure their production and distribution systems and strategies to provide the desired customer service at the lowest possible cost. Distribution system design focuses on the strategic design of the logistics infrastructure and logistics strategies to deliver the products from one or more sources to its customers at the required customer service level. Typically, it is assumed that the products, the sources of the products (manufacturing plants, vendors, and import ports), the destinations of the products (customers), and the required service levels are not part of the design decisions but constitute constraints or parameters for the system. Distribution system design focuses on the following interrelated decisions [7]:

1. Determining the appropriate number of distribution centers
2. Determining the location of each distribution center
3. Determine the customer allocation to each distribution center
4. Determine the product allocation to each distribution center
5. Determine the throughput and storage capacity of each distribution center

The data analysis and synthesis phase of the design project will be highly dependent on the individual project. The overall goal of this phase is to create a data set that contains valid and agreed-upon data for all the major components in the design project. For many objects in the data set, there may be only a single data value, for example, the longitude and latitude coordinates of city. For other objects, the data can only be described by statistical distributions and their characteristics in function of possible scenarios.

For example, the demand of a particular customer area for a particular product may be stored as its statistical distribution type, mean, and standard deviation for the worst-case, best-guess, and best case scenarios.

All the data for a distribution system design project [9] is typically stored in a single database. Using a database allows the use of database validation tools and consistency checks. The data is organized in function of objects and their characteristics. Similar objects are collected in classes. The most important objects in a distribution system design project [4] and some of their characteristics are described in the following.

The Location-Allocation model considers manufacturing facilities (plants), customers, and distribution centers (depots). It determines the location of the distribution centers and the allocation of customers to distribution centers based on transportation costs only. The distribution centers can be capacitated and flows between the distribution centers are allowed.

The algorithm starts with an initial solution in which the initial location of the distribution centers is specified. This initial location can be random, specified by the user, or the result of another algorithm [3].

Based on this initial location, the network flow algorithm computes the transportation distances d and then assigns each customer to a distribution center with sufficient capacity by solving the following network flow:.

$$\min \sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij} d_{ij} w_{ij} + \sum_{j=1}^{n}\sum_{k=1}^{l} c_{jk} d_{jk} v_{jk} \tag{1}$$

$$\sum_{j=1}^{n} v_{jk} = dem_k, \qquad k = 1...l \tag{2}$$

$$\sum_{j=1}^{n} w_{ij} \le cap_i, \qquad i = 1...m \tag{3}$$

$$\sum_{k=1}^{l} v_{jk} \le cap_j, \qquad j = 1...n \tag{4}$$

$$\sum_{j=1}^{n} w_{ij} - \sum_{k=1}^{n} v_{jk} = 0 \qquad j = 1...n \tag{5}$$

Where;

w_{ij}, v_{jk} - the product flows from plant *i* to distribution center *j* and from distribution center *j* to customer *k*, respectively.

c_{ij}, c_{jk} - the transportation costs per unit flow and per unit distance from plant *i* to distribution center *j* and from distribution center *j* to customer *k*, respectively.

d_{ij}, d_{jk} - the inter-facility transportation distances from plant *i* to distribution center *j* and from distribution center *j* to customer *k*, respectively.

cap_i, cap_j - the rough put capacity of plant *i* and distribution center *j*, respectively.

dem_u - demand of customer *k*.

Circumstance (2) ensures that each customer receives its full demand. Circumstance (3) and (4) ensure that the capacity of the plants and distribution centers is observed. Circumstance (5) ensures that the total inflow into a distribution center is equal to the total outflow, that is, that conservation of flow is maintained. This network flow formulation can be very efficiently solved by a linear programming solver for all realistic problem sizes. The result of the allocation phase is the assignment of customers to distribution centers as given by the flow variables.

$$x_j = \frac{\sum_{i=1}^{m} c_{ij} w_{ij} a_i + \sum_{k=1}^{l} c_{jk} v_{jk} a_k}{\sum_{i=1}^{m} c_{ij} w_{ij} + \sum_{k=1}^{l} c_{jk} v_{jk}} \tag{6}$$

$$y_j = \frac{\sum_{i=1}^{m} c_{ij} w_{ij} b_i + \sum_{k=1}^{l} c_{jk} v_{jk} b_k}{\sum_{i=1}^{m} c_{ij} w_{ij} + \sum_{k=1}^{l} c_{jk} v_{jk}} \quad (7)$$

Where:

$(a_j, a_k), (b_j, b_k)$ - cartesian location coordinates of customers i and plants k.

x_j, y_j - the location coordinate variables of distribution center j.

The solution provided by (6) and (7) is optimal with respect to the squared Euclidean distance norm, and it provides sufficient accuracy at this level of a strategic design project for the Euclidean distance norm. It should be noted that the iterative solution algorithm based on the partial differential equations is usually started with this center of gravity solution as starting point. The location phase provides new locations for the distribution centers. Based on these new locations the distances between the various facilities can be updated.

The models ignore the capacity restrictions of distribution centers. All of the previous models considered only a single product and this ignore the single-sourcing customer service constraints.

Through developing a model that incorporated both capacity and single-sourcing constraints, one of its fundamental characteristics was that the flow was modeled along a complete path from supplier, through the distribution center, and to the customer by a single flow variable. Formulations of that type are called path-based [6]. If a flow variable exists for each transportation move, then the formulations are said to be arc-based [4]. The difference between path-based and arc-based formulations is illustrated in Figure 1. Path-based formulations have many more variables than arc-based formulation for the equivalent system. On the other hand, arc-based formulations have to include the conservation of flow equations for each commodity and each intermediate node of the logistics network.

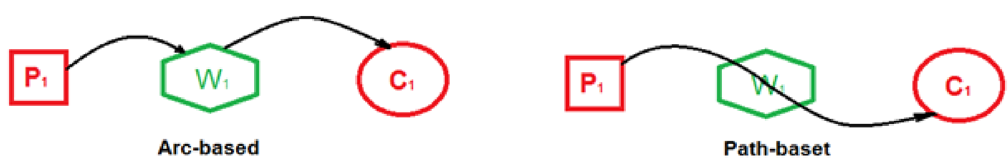

Fig. 1. Illustration of arc and path-based transportation flows.

In the dynamically changing market sphere, the distribution centers function as warehouses and warehouse areas, where one or a few producers accumulate huge amounts of products before distributing and shipping them to end consumers. The distribution centers are usually owned by the same producers of by a wholesaler, who functions as a distributer. In turn the distributers trade the products by selling them with a discount or a markup to the retailers or directly to the companies. In this case they use the services of brokers, dealers and agents who directly contact the actual or potential customers and thus they contribute to the increase of the sales volume [10, p. 27]

Several major factors such as cycle and safety inventory and taxation have not been discussed so far. More comprehensive models that incorporate these factors have been developed, but such models must be used with extreme care and typically have a steep learning curve.

III. Conclusion

This design project illustrated again the following observations about strategic distribution system design. First, without modeling-based decision support, the configuration of a distribution system is essentially reduced to intuition or guesswork. Second through careful modeling-based sensitivity analysis a limited number of high-quality candidate configurations can be identified and submitted for final selection.

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