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Locating Spare Part Warehouses Using the Concept of Gradual Coverage - A Case Study

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Abstract. In covering problems demand is usually covered by a facility, if it is less than a certain distance away., but if the distance is greater, none of the demand is covered. With gradual coverage, a fraction of the demand can be covered between an upper and lower distance. In this paper a case study for MAN Diesel SE is presented, where gradual coverage has been used for locating warehouses for spare parts. In particular it is described, how coverage decay functions are found, which identifies customers' reaction to the offered 'speed of delivery' and 'total order cost'. With these functions, demand at each demand node, given which candidate site supplies that node, can be found. A MILP model is developed, that also considers modality selection.

Keywords: Facility Location, Gradual Coverage, MILP, Coverage Decay Functions, Modality Selection,

1 Introduction

Many companies today are using mathematical models to help them plan operations in their supply chain. Traditional models related to facility location have focused on balancing internal cost such as facility cost with transportation cost. But often profit is more dependent on customers' willingness to choose that company's services, than the company's internal cost structure.
MAN Diesel SE [MD], a large manufacturer of marine diesel engines, is faced with this problem in its after sales division. For them, not only the price of spare parts, but also the delivery date offered to the customer affects whether the customer orders from MD or not. As MD cannot offer a better service, than the transportation options from the facility permit, the location problem has a direct and very crucial effect on the bottom line. Solving this problem is therefore paramount.

2 Theoretical Background

For a long time inadequate techniques were available for companies such as MD to plan where to locate facilities. That has changed in later years.
Traditionally, demand is covered, if a customer is situated within a certain distance. If the

customer is further away demand cannot be covered. In Drezner et al. (2004) there is skepticism about this form of binary coverage, as it is argued, that it does not portray reality accurately for most businesses. The authors find it unrealistic, that if the maximum service radius is 5 miles, customers 4.9 miles from the facility will be completely covered, whereas customers 5.1 mile away will not be covered at all. Instead they propose having two radii, where all demand is covered below the lower radii and nothing is covered above the larger. In between the two radii only a fraction of the demand is covered.
Berman and Krass (2002) mentions, that the gradual coverage has been known in the retail business for some years, but the concept is only used indirectly in making the location decisions. Sources are quoted to give a rule of thumb as to how many potential customers should be within certain distances. The authors define several different radii each with a coverage level and then present a mixed integer linear programing model for this group of problems they call *generalized maximal covering location problems*.
Continuous *coverage decay functions* are first introduced in Berman et al. (2003) to describe the decrease in demand as the distance between facility and demand point grows. The work from the previous article is complemented with the use of continuous functions instead of stepwise changes, and several model formulations are discussed.
In both Berman et al. (2006) and Berman et al. (2007) gradual coverage is combined with queuing theory to model service facilities, where the customers have to travel to the service facility. Demand is thereby be lost either if the queue or the distance to the facility are too long for the customer. These model formulations are more relevant for retail businesses, whereas other industries such as e-businesses and service providers are not covered.
In our contribution focus is given to those other industries. Here, it is more relevant to combine gradual coverage with other supply chain related issues such as complex distribution planning. The article also serves to illustrate, how coverage decay functions can actually be determined and used in companies such as the relevant case study.
In the next section the case company is described in greater detail, and the problem of the company is clearly identified. In section 4 the model formulation is presented. In section 5 it is explained, how coverage decay functions are actually found and used. The results of the project is then stated, before a conclusion is reached and further research outlined.

3 Case Study

MD is a major manufacturer of large diesel engines for marine and power generation purposes. A key part of the company's activities is the activities related to selling spare parts. Increased competition is forcing the after sales division to pay more attention to customers demand. As a part hereof the division wants to expand its spare part warehouse network, which currently only consists of a warehouse in Copenhagen, Denmark[1].
Spare part sales follow a request-quote-order scheme, where the party responsible for the engine (the customer) requests an offer or quote from MD and whomever could possibly also sell that spare part. Given which quote the customer prefers, he/she then responds to that quote with an order, and the spare part is sent. This makes it important to offer the best quote possible to the customer. Careful analysis shows, what influences customers when

[1] Only the 2 stroke department under the after sales division has been included in this case study.

deciding which quote to choose. The major influences or sales drivers which relates to the supply network are *'speed of delivery'*, which describes how fast MD can deliver the spare part, and *'total order cost'*, which is the total cost of the order incl. shipping costs.
Due to the large variation in the size of the different spare parts, several modalities have to considered. DHL is the main logistics provider, and the modalities chosen are mainly the ocean freight here called 'ship' and air courier service here called 'plane'.

4 Model Formulation

Below is the model formulation, which is an extension of the proposed formulations in Berman and Krass (2002) and Berman et al. (2003). Centralized assignment and modality selection is assumed.

Sets:

$ports$	Set of demand nodes, alias P, indexed by p.
$warehouses$	Set of candidate warehouses, alias W, indexed by w.
$modality$	Set of modalities, alias M, indexed by m.

Parameters:

$demand_{w,p,m}$	Demand in port $p \in P$ when supplied by warehouse $w \in W$ via modality $m \in M$.
$OpenCost$	Fixed cost of locating a facility at a candidate site.
$OpenLimit$	The maximum number of warehouses to open.
$Profit$	Profit margin on spare parts.

Variables:

$Open_w$	1 if warehouse w is opened and 0 otherwise.
$ShipOpen_{w,p}$	1 if port p is assigned to warehouse w and 0 otherwise.
$ShipFlow_{w,p,m}$	Fraction of demand in port $p \in P$, covered by warehouse $w \in W$ via modality $m \in M$.

Objective Function:

$$\text{Max.} \sum_{w \in W} \sum_{p \in P} \sum_{m \in M} Profit \cdot demand_{w,p,m} \cdot ShipFlow_{w,p,m} - OpenCost \cdot \sum_{w \in W} Open_w \quad (1)$$

Subject To:

$$\sum_{w \in W} ShipOpen_{w,p} = 1 \qquad \forall p \in P \quad (2)$$

$$ShipOpen_{w,p} - Open_w \leq 0 \qquad \forall w \in W,\ p \in P \quad (3)$$

$$\sum_{m \in M} ShipFlow_{w,p,m} - ShipOpen_{w,p} \leq 0 \qquad \forall w \in W,\ p \in P \quad (4)$$

$$\sum_{w \in W} Open_w \leq OpenLimit \quad (5)$$

Bounds:

$$Open_w \in \{0,1\} \quad \forall w \in W \tag{6}$$

$$ShipOpen_{w,p} \in \{0,1\} \quad \forall w \in W,\ p \in P \tag{7}$$

$$0 \leq ShipFlow_{w,p,m} \leq 1 \quad \forall w \in W,\ p \in P,\ m \in M \tag{8}$$

In the model formulation gradual coverage only effects the demand parameter, which is now dependent on the which warehouse is used to supply it. This parameter is found in the objective function in equation (1), which aims at maximizing the profit of the supply network and is otherwise very typical for facility location models.
Compared to the standard model formulation there are here 2 types of assignment variables. The first $ShipOpen_{w,p}$ indicates which demand nodes are assigned to which warehouse. The other $ShipFlow_{w,p,m}$ indicates how much of demand is send via modality m. The reason $ShipOpen_{w,p}$ variables are needed, is that the model has to clearly assign demand nodes to warehouses. Otherwise good properties of the individual modality can be exploited, but the orders will then potentially be split, which is not permitted in our case study application. Since order can be sent with different modalities a new set of variables, $ShipFlow_{w,p,m}$, are needed.
Constraints (2), (3) and (5) are all known from the standard formulation. Constraint (4) is new, which just as (3) only allows demand to be covered between mutually assigned warehouses and demand nodes. By taking the sum of the modalities the demand can only be covered once.
This formulation is a very simplified version of the one made for MD. That model formulation also included time and product indices, several different types of costs and a series of capacity and economic constraints.

5 Finding the Coverage Decay Functions

The approach is described for 'speed of delivery', but holds for both sales drivers.
Finding customers' reaction to the service provided by MD is done by considering customers' historical inclination to accept a quote and turn it into an order as found in the data records from MD. In this type of environment the term *'Hit Rate'* refers to the ratio of orders over quotes: $HitRate = \sum Orders / \sum Quotes$, and it is a good measure as different hit rates easily can be compared. It is also possible to find the delivery times. Based on this information the graph in figure 1 is derived. Due to confidentiality reasons the hit rate has been indexed.
Figure 1 relates the total ordering time to the hit rate, and it gives a good indication of how customers inclination to order from MD drops, when delivery times are increasing. Assuming that only the speed of the logistics provider influences how fast shipments can be sent out, the hit rate can be found from each candidate warehouse site to each demand node, since the transit time of the logistics provider is known for all modalities. When this is compared with the hit rate from the existing Copenhagen warehouse, the expected percentage of additional demand can be found, and demand from each candidate site to each demand node is given by equation 9.

$$demand_{w,p,m} = Forecast_{'CPH',p} \cdot \frac{HitRate_{w,p,m}}{HitRate_{'CPH',p,m}} \quad \forall w \in W,\ p \in P,\ m \in M \tag{9}$$

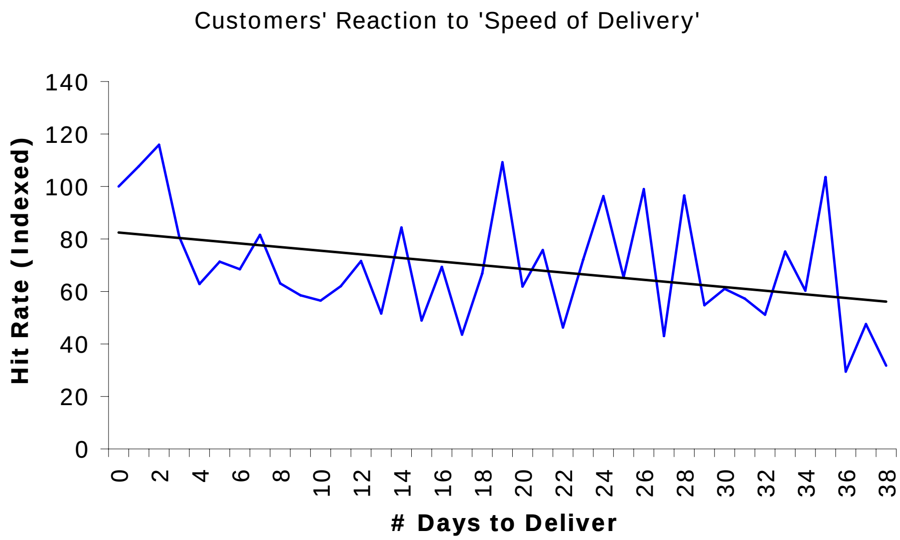

Fig. 1. Customers' Reaction to the offered 'speed of delivery', and the linear trend curve. 0 days to deliver is set to index 100.

6 Results

Several different possible scenarios for changing the network are set up, different sales forecasts are used and the effect of gradual coverage is weighed differently in a series of calculations to give sufficiently good indication of the solution robustness. The CPLEX solver is used for solving the model through OPL Studio 5.5. Solutions are normally reached within a couple of minutes.

The result of the entire series of tests points toward the same location as the best site for operating a single warehouse. The reason for this clear result is found in the presence of a major hub for DHL in this location.

The use of the different modalities is interesting to follow, since it is in part governed by several minor business rules that must be enforced due to the different sizes of the different spare parts. The split between plane and ship modalities is very consistent and resembles the current split well. Clear improvement in the average offered delivery time and transportation cost is also observed. The results generally appear stable and very few drastic changes are observed in the proposed supply network; even with the use of different forecasts. The biggest variations in the supply network relates to which year it is best to open the new warehouse.

7 Conclusion and Further Research

In this paper gradual coverage was identified as a important tool for modeling facility location decisions. A company was described and a mathematical formulation, which focused on gradual coverage, was developed for this application. A method for determining and using gradual coverage was described, and some results presented. The model performs as expected, reflects the current modality split and results in a notable improvement in the service offered to customers by use of the new supply network.

It has hereby been shown that the concept of gradual coverage can be used in a wider range of applications than only retail stores. It is proposed, that future research should be focused on integrating gradual coverage into other typical supply chain problems such as distribution planning and supplier selection.

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