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Depot Location with Van Salesmen — A Practical Approach

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This paper describes a case study in depot location. The results of the study were required with some urgency and the time to perform any extensive data collection or analysis was not available. It was, therefore, imperative to make a number of assumptions about the model as the data immediately obtainable, though helpful, were limited. For this reason, and because of other limiting constraints, the computer was not used to optimize the model but to cost selected depot configurations. The model has three further points of interest:

(a) It uses a non-linear function of distance rather than straight-line distances to represent the multi-drop nature of the journeys;

(b) It involves a "sales function" in which sales decline with distance from the depot;

(c) It maximizes profits rather than minimizing costs.

INTRODUCTION

THIS PAPER concerns a company operating in the food and drink industry. The company has three products (one main and two subsidiary) which come in small cartons. It manufactures these products at five different factories, and sells them direct to retail outlets. The selling is mainly performed by van salesmen who call at outlets not only in response to telephoned orders, but also in an attempt to stimulate sales, for which they are paid a bonus. They are also responsible for finding new customers as well as servicing known outlets. Large orders such as to supermarket chains are delivered direct.

The area in which the company operates is that part of England and Wales south of a line drawn roughly from Portmadoc to the Wash. This area is shown in Fig. 1, which also shows the locations of the eleven depots operated by the company prior to the study and the areas served by these depots. The area to the north is the territory of an associated but separate company.

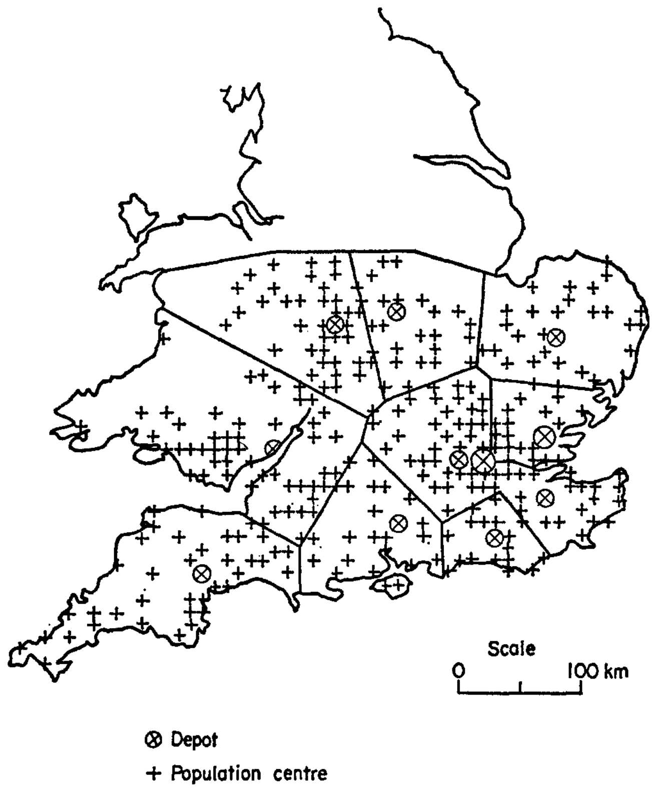

FIG. 1. *Existing system.*

The study was initiated for two main reasons. First, although some of the company's depots are wholly owned, some are leased and the leases of two of the depots were shortly coming up for renewal. Hence a decision had to be made on these two depots in the immediate future. Second, the company is a market leader in its field. This is both a source of pride and a source of worry. The company therefore authorized the study to assist management in making the right decisions on the two depots and also to examine the effect of changing the number and location of its depots on profitability and sales level.

THE MODEL

The elements which make up the model divide conveniently into two parts, namely the revenue derived from the sales and the cost of distribution. The measurement of these two factors will now be described.

Sales revenue

It was not possible to find the precise location or demand of the retail outlets currently being served without embarking on an extensive analysis of sales returns. The time for such an exercise was not available and so this important data had to be estimated. The management of the company were able to help in this task because of the data kept on the company's operating parameters. In particular they were able to supply information on the average number of units sold per call (including no sale calls) and on the frequency of visit to outlets. It remained only to estimate the number and location of calls.

The actual number of retail outlets in any locality to which deliveries can be made is dependent on two factors:

(a) The number of outlets of the appropriate type in each locality;

(b) The distance of the locality from the depot serving it.

In order to determine the number of outlets of the appropriate type in each locality it was decided to make the assumption that the number is proportional to the population. For simplicity a single ratio figure was used. This figure was found from a calibration run of the model. In a later study, when the information became available, it was possible to use separate ratios for different parts of the country in order to represent more realistically difference between regions in either sales penetration or buying habits.

The service provided to outlets depends on the methods of operation used by van salesmen. The further a population centre is from the depot the more time the driver is on the road and hence the less time he has to make sales and the less profitable the operation becomes. After some discussion with management a "sales function" was adopted in which 100 per cent of all outlets close to the depot are visited, but this percentage declines in a linear fashion from 100 per cent at 6 miles to 0 per cent at 60 miles from the depot (the broken line in Fig. 2). The figure of 60 miles, which in effect gives the maximum radius of the area to be served by a depot, was developed from a consideration of the average number of calls per trip, the average vehicle speed, the average time per drop, and the length of a driver's working day. It is assumed that depot sales areas are mutually exclusive.

There was no time to investigate the true shape of the sales function. Shenoy and Sifferd [5] suggest some possible hypothetical shapes. Mercer [4] derives an alternative curve but relating market share to distance, the curve being a convex one declining to a near constant value. However, observations in a later study suggest a concave curve where the coverage is more complete, being nearly 100 per cent up to 30 miles from the depot. In fact, a step function representing the linear function as shown by the solid line in Fig. 2 was used because of the ease of making changes in the computer program. We note, as did Shenoy and Sifferd, that it is not easy to develop such a function, which is likely to be different from location to location (this is particularly true in this study where in the case of a nearby town the driver may go quickly to the town and visit all

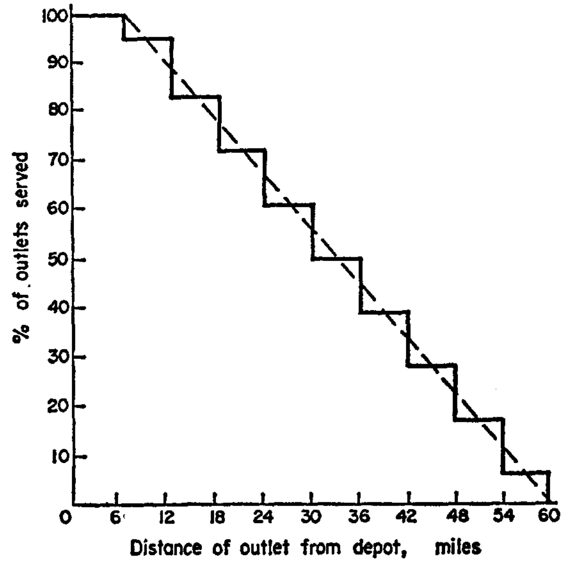

FIG. 2. *Graph of sales function. The computer program uses the step function (the heavy line) as a representation of the linear function (the dotted line) because of the ease of making changes.*

outlets, hence the sales recorded from that town may not behave at all as predicted by the sales function). Furthermore, the sales functions are likely to change with time, particularly with changes in buying habits such as the growth of supermarkets.

In this study the problem was simplified in that the company's depots are cheap to run and are also cheap to set up or close. Indeed the company can and, as a temporary measure in the past, has operated from depots which effectively consisted of a parking lot with a telephone attached (they used a trunk vehicle for storing stock). The company can, therefore, react quickly to changes in the market, and is more interested in a solution determined with current sales functions than with the long term. In addition, supermarkets increasingly tend to pre-order and can to some extent be treated separately. We feel, as do Shenoy and Sifferd, that the functions on average "probably are superior to sales estimates made without the influence of warehouse location".

Distribution costs

Local delivery costs. In order to represent the multi-drop nature of the journeys performed by the drivers we adopted the function developed by Christofides and Eilon [1]. The function (which is concave) relates the actual journey distance travelled to serve a group of customers to the sum of the straight-line distances from depot to customer, the average number of customers visited per vehicle and the area served by the depot. The function was developed under the assumption that the customers were uniformly distributed in the area, and this assumption is not strictly valid here. The area of the region served by each depot also posed a problem as the areas of the population centres were not easy to measure. We overcame this difficulty by using instead of the areas, the number of outlets and their density as given by the average inter-drop distance. The population centres were classified into urban, suburban and rural for this purpose. This method had the effect of relieving the problem of the initial assumption of complete uniformity in that although customers are still assumed to be uniformly distributed, their density varies in different parts of the country.

Two further correction factors were used: the first to correct straight-line distances to road mileages; the second to ensure that the local distribution costs were adjusted to a common time period with the two other cost factors. Figures obtained from a "calibration" run of the model proved comparable with similar figures achieved in practice and gave a satisfactory representation of the real life situation.

Trunking costs. The depots were supplied on average daily from five factories, each making one product. Because there were no particular capacity problems at the factories, there was a choice in the case of two products of which factory should make delivery. This choice was resolved by allocating the depots to the nearest factory making the relevant product. The cost of trunking was determined by summing the distances between depots and the appropriate factories and multiplying by the cost per mile and the two correction factors similar to those described above. The "calibration" run of the model gave results which were comparable with actual costs.

Depot costs. In this study where the stocks are replenished on a daily basis, the amount in inventory held at the depot is small. This item was, therefore disregarded. Even so, it is important to take account of the costs of owning and operating the depots in the system. At the outset the final size and therefore costs of the depots are not known. A suitable method for solving this problem is to use historical data to develop a relationship between cost and size or rather throughput, which is usually proportional to size and easier to measure. A function determined in this manner can then be used to calculate the cost of any depot once its size is known, bearing in mind, of course, the effects of inflation on prices.

The company kept cost figures for their current depots, including notional rents for owned premises to make them comparable with rented premises. The costs consisted of such items as rent, rates, light, heat, telephone and wages and salaries of those people connected with the depots. Such items as drivers' wages and bonuses, and vehicle costs, were removed as they were already included under the heading of local delivery costs. Using regression analysis, a relationship was found which seemed both sensible and fitted the data reasonably well.

Other Factors

Because of the shape of the sales function in which sales decline with distance from the depot, it would be possible to get certain anomalies if the objective were to minimize costs. For example, a depot at the North Pole would have no customers, and hence only the fixed depot costs would be chargeable; this might prove to be the global minimum. To avoid any such problems a policy of maximizing profits was adopted. The number of units sold was obtained by multiplying the number of calls by the average amount sold per call. The profits were calculated by multiplying the units sold by the "profit" per unit, a figure from which all charges other than distribution costs (raw materials, promotion, administration, etc.) were deducted, and finally subtracting the distribution costs as detailed above. The complete function is shown below.

$$\text{Profit} = PU - (H+G+F) \tag{1}$$

where P = "profit" net of distribution costs per unit sold

U = total units sold

$$= ufV \tag{2}$$

where u = average number of units sold per call

f = frequency of visit

V = number of calls

$$= S\,g(d) \tag{3}$$

where S = number of outlets and is assumed a function of the population.

$g(d)$ = the percentage of outlets visited in relation to the distance (d) between the depot and the population centre as illustrated in Fig. 2

H = local delivery costs

G = trunking costs

F = depot costs.

Two constraints on the system were noted. First, a capacity constraint of ten vehicles on the London depot. This was incorporated by limiting the size of the area served from that depot. Second, that Exeter delivered to Cornwall by means of two-day journeys. Due to modelling complexity this constraint was ignored.

METHOD OF SOLUTION

The model of the system is complex in that it incorporates a sales function in which sales decline with increasing distance from the depot. For this reason a "trial and error" approach was adopted with a selected set of possible depot locations. The method is called "trial and error" in the sense that the model used would not optimize the locations of the depots, but merely determine the profitability of any configuration of depots which were fed in as input.

The procedure, therefore, was to select a particular configuration of depots. The appropriate cards were punched and read by the computer, which allocated customers to the nearest depots, calculated the number of outlets served and summed the total number of units sold for each depot, found the cost of each depot and determined the profitability of that configuration. The results were then examined and noted; some changes were made to the selection of sites and the process was repeated. Although there was a relatively small number of possible sites to choose from, there were an extremely large number of possible combinations that could be selected and costed by the computer. The number of selections was kept as small as possible by picking the combinations "intelligently". One factor in particular simplified this task, namely the shape of the sales function, which enabled a small part of the country to be optimized at a time. Various other constraints were also useful in this respect: e.g. the depot in London was small and inconvenient to operate; the location was, however, very central and the rent so reasonable that it would have been extremely foolish to close it. The approach in the method of solution was helpful in incorporating constraints of this nature, which would have been difficult to incorporate in an optimizing model. Some 40 possible sites were selected for the study. These sites were selected for one or more of three reasons:

(a) *Size of town.* Because of the sales function, increased sales can be obtained by locating in areas of large population. Kuehn and Hamburger [3] also suggested this approach—possibly for similar reasons.

(b) *Increased coverage.* Possible sites were selected in areas where the coverage was sparse, i.e. no depot site selected in the vicinity.

(c) *Managerial suggestion.* Some sites suggested as likely locations by management were added.

It should be noted that these depot sites were not investigated in any detail at all. At this stage of the study there was insufficient time to find out whether there were sites available in the chosen localities or what they might cost in terms of rent, etc. However, because of the company's ability to adapt quickly to changes and the relative cheapness of their depots, this was not thought to be too severe an assumption.

The computer used was an IBM 1130 and the time per run (i.e. per configuration tested) was approximately two minutes, once all the customer data had been stored in the computer.

RESULTS

There were two criteria for measuring the desirability or otherwise of any particular depot configuration namely profitability and sales. Although many configurations were examined, we could find no one solution which maximized both criteria. However, using the method described above we obtained finally three "best" solutions. The first gave the largest profits with twelve depots and a very small increase in sales.[1] The second gave the largest increase in sales with 17 depots and quite a reasonable improvement in profits. The third solution which we recommended had 16 depots and attempted to balance the two criteria; it gave a 10 per cent increase in sales which was only just short of maximum sales, and an increase of an estimated £60,000 per annum in profits, which was about £2500 per annum less than the maximum profits. This solution involved closing three existing depots and opening eight new depots. The final depots and the areas they should serve are shown in Fig. 3.

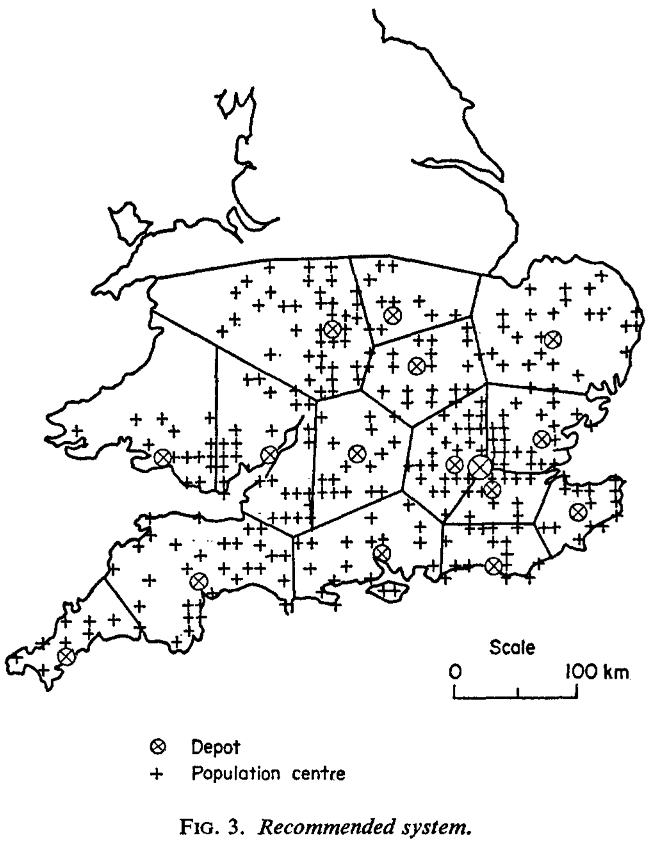

FIG. 3. *Recommended system.*

A sensitivity analysis of the model forms a very significant part of any study and this was particularly so in this case. There was no time to examine completely what should be done under every possible circumstance, but the

[1] Later tests using the "drop" heuristic of Feldman, Lehrer and Ray [2] also gave this solution for maximum profit.

behaviour of the three "best" solutions was analysed under a variety of different conditions which might occur in practice:

(a) Changes in sales levels;

(b) Changes in the radius of the areas served by the depots, i.e. the sales function;

(c) Changes in local delivery charges;

(d) Changes in trunking charges.

Both sales and profits were relatively sensitive to changes in the parameters, but the recommended solution seemed slightly more stable than the other solutions. Some reactions to these changes of individual depots were also noted. Changing the penetration figure to represent an increase in sales had a much more noticeable effect on the profitability of the town depots, e.g. West London; reducing the radius of the areas from 60 miles to 50 miles to represent a reduction in the length of a driver's working day reduced both the total profitability and sales of the recommended solution by about 4·5 per cent, but the effect was far more severe on the rural depots, reducing, for example, the sales at the Norfolk depot by 17 per cent.

Some factors were not so easy to examine, for example, changes in depot costs which would mean a probable change in the shape of the depot cost function, and it is difficult to justify any particular change in this function. Similarly, the unit cost of the products were assumed constant, whereas economies of scale resulting from increased sales could give a reduction in the product unit cost and hence an increase in profits. Furthermore, a study of the operation of the vans might well have proved worth-while as another area for the improvement of profits, but this was not undertaken.

The whole project was completed in about four weeks. The company accepted the recommendations and with one change the solution is being implemented as we suggested. Recent discussions with the company have indicated that the implementation is being highly successful.

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