CORPORATE DISTRIBUTION PLANNING

H. Harrison*

INTRODUCTION

A system for planning facilities and resources in distribution networks is presented in the following pages. It was applied at Cahill May Roberts, one of Ireland's largest pharmaceutical companies, having a turnover of £18 million and employing over 300 people.

The planning system, a three stage stochastic programming model, is capable of evaluating alternative management strategies in the face of fluctuating costs and population movements over an extended time horizon. Apart from defining unique territories for the company's distribution centres and optimal customer servicing schedules within those territories, the planning system evaluated alternative locations for distribution centres under the twin uncertainties of cost and demand.

The planning model contained approximately 2,000 variables and 300 equations, whilst the undecomposed route planning model encompassed approximately 300 town/villages and 1,200 customers. Both models, therefore, required substantial data inputs as successive management objectives and assumptions were examined. To facilitate this data preparation and to achieve solutions in a realistic time, a special matrix generator was developed which had the capability of producing data in the required format and inputing directly into both planning models. The generator controls the entire optimizing process and permits a three hundred-fold reduction in data preparation. In effect, the generator permits an optimization procedure to be used in a simulation mode.

The model achieved savings in delivery and transport costs of 23.3% and 20%, respectively, and increased customer service levels by 60%.

HISTORICAL BACKGROUND

Cahill May Roberts, a wholly owned subsidiary of P. J. Carroll & Co., one of Ireland's largest companies, is a wholesale distributor of pharmaceuticals. The company (hereafter CMR) is the largest such organization in the Irish Republic having its head office in Dublin, five country

*The author is Statutory Lecturer in Management Information Systems at University College, Dublin. He wishes to express his thanks to Cahill May Roberts for their co-operation in making the data available for publication and also to Mr. Andrew Deegan of UCD for his assistance in the development of the computer models discussed in this paper. This paper was awarded first prize in 1978 in an annual competition organised by the American Institute of Management Science.

depots at Sligo, Cavan, Carlow, Cork and Limerick (See Figure 1) and prior to this analysis three depots in the greater Dublin area at Harmonstown, Deansgrange and Chapelizod. CMR has three main competitors but accounts for approximately 45% of the Irish pharmaceutical market.

CMR has, over the past few years, experienced a profit erosion from 5% of gross turnover to under 2% of gross turnover, due mainly to the high levels of inflation prevailing in Ireland at that time. Accordingly the senior management of the company commenced, in 1976, a total review of the company's procedures and operations with a view to restoring, and indeed increasing, the profit margin to over 5% of the gross turnover. The author of this paper was asked by the managing director of CMR to examine the distribution system and make it more cost-effective, that is, to give an improved customer service at a cost that is lower than that currently being experienced. This paper describes the measures used to that end and their impact on the company's performance over the period 1976/77.

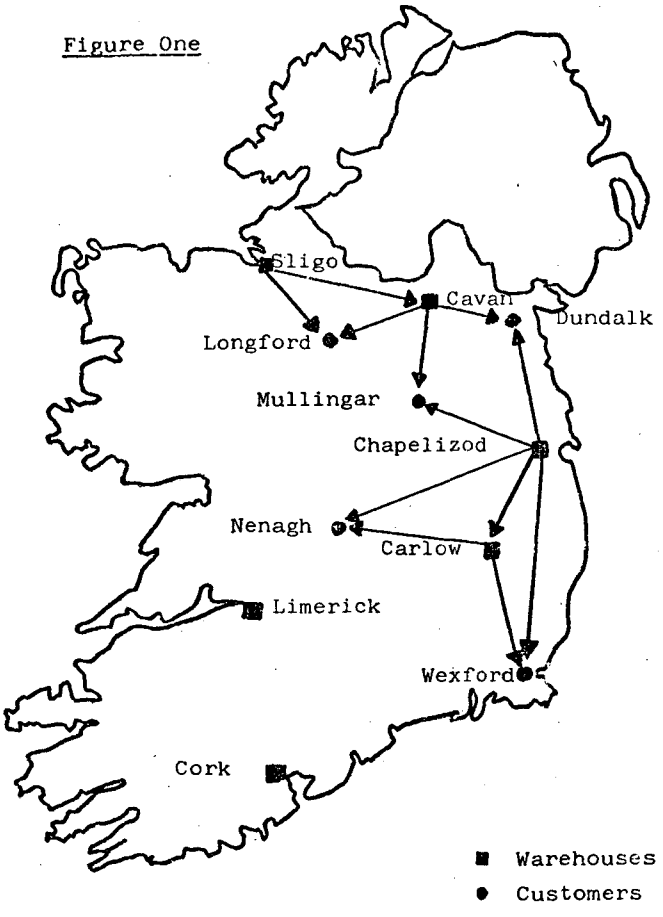
THE DISTRIBUTION SYSTEM

CMR supplies 400 customers (mainly retail pharmacists) in the Dublin region and over 800 customers in other regions with a wide spectrum of pharmaceuticals. This supply is achieved by the company's delivery vans calling on customers with varying frequency. The customer calling frequency can vary from twice per day to once per week. Customers who are visited twice per day are generally located within a ten mile radius of their supplying depot.

Prior to the analysis to be described, no coherent distribution plan for the company as a whole had been formulated. It was not unusual, indeed it was the rule, for customers to receive their supplies from more than one depot. This situation led to some very odd arrangements, in that Chapelizod, for instance, delivered to Wexford, Nenagh and Carlow. The depot in Carlow also delivered to these locations. A glance at Figure 1 will show the illogicality of this, and other delivery patterns, and were clearly a very inefficient method of satisfying customers' demands.

A quick tabulation of customers and their locations showed that over 70% of CMR's customers featured in the "joint-delivery" situation. This does *not* mean that over 70% of CMR customers received deliveries from two or more different warehouses. The correct interpretation is that the *location* in which they reside received visits from vans from different CMR warehouses. Similarly a study of the "shared-location" pattern showed that out of a total of 294 locations (towns, villages, etc.) visited, 135 or 46% received visits from CMR vans from two different warehouses.

Figure One



WAREHOUSE HANDLING COSTS

The unit handling costs (labour and administrative costs divided by the number of orders processed) of some CMR warehouses are shown in Table 1 for the period May 1975 to April 1976. As this table indicates wide variations in unit handling costs existed over this time period. These variations were typical of all depots of CMR.

From the point of view of the subsequent analysis, the within-warehouse variation in unit handling costs is a little troublesome since it does not follow any definite pattern. Figure 2 depicts this variation for Chapelizod for the period 1975-76 as well as an idealized unit cost curve – the type of cost curve one would normally expect to find, that is, low volume high unit costs, high volume low unit costs. The idealized cost curve is a very poor approximation for the real data.

Had cost curves of the idealized type, illustrated in Figure 2, been the rule at each of the warehouses, then piecewise linear approximations

TABLE ONE : Maximum, Minimum and Mean Handling Costs for Depots, 1975–76.

Depot	Unit Handling Costs* (£)			Max., Min. VARIATION
	Maximum	Mean	Minimum	
Chapelizod	2.232	1,516	1,112	100.72%
Sligo	1.670	1,214	0.810	106.17%
Cavan	2.180	1.981	1.503	67.70%
Carlow	1.723	1.306	1.062	62.24%
Limerick	2.752	2.725	1.980	38.99%
Cork	1.008	0.805	0.677	48.89%
	*Unit Handling Costs = $\frac{\text{Lab. Costs + Admin. Costs}}{\text{Orders Processed}}$			

could have been used in the analysis. Since this approach was not feasible, an idea due to Balinski-Mills[1] was used, where one approximates the warehousing cost function for each warehouse by the average unit cost of operating that warehouse at some high level, such as the warehouse capacity, or the total flow of goods passing through the system during the year. The use of this approximation ensures that all non-linearities are eliminated from the warehousing cost function. In addition one also takes the maximum unit cost over the same period in order to test the sensitivity of the system to changes in the warehousing cost functions.

If the value of the solution under the Balinski-Mills approximation is designated λ^* and the value under the maximum unit cost criteria λ_* then the actual optimal solution (denoted by λ_o) to the problem must be in the region

$$\lambda^* < \lambda_o < \lambda_*$$

TRANSPORT COSTS

With the strange transportation patterns associated with each warehouse and the fact that the frequency of service was different at each (Carlow, for instance, delivered to its customers every day of the week while Sligo had a less frequent delivery schedule) one would expect unit transportation costs to vary significantly from warehouse to warehouse. This was indeed so. Table 2 shows the unit transportation costs, along with the budgeted costs, for 1976/77.

TABLE TWO : CURRENT AND BUDGETED COSTS OF TRANSPORTATION.

Warehouse	Transportation Costs (per mile)*	
	Current (1975/76)	Budgeted (1976/77)
Sligo	0.116	0.108
Cavan	0.156	0.158
Chapelizod	0.171	0.155
Carlow	0.126	0.144
Limerick	0.180	0.159
Cork	0.162	0.129

*Costs estimated according to the equation.
Transportation Cost per Mile = Yearly Transportation Cost/Annual Mileage Travelled.

CUSTOMER REQUIREMENTS

As has already been mentioned, each warehouse has its own particular policy with regard to supplying its customers. Whereas records are kept of the value of orders a customer requests, no records are kept of the number of orders a customer receives. Since customers' requirements can (and no doubt will) change, any analysis must be able to cater for these changes in demand. It is, therefore, necessary to estimate the number of orders to customers in any location per week, per month and per year. These estimations were accomplished through a procedure which yielded expected group orders (excluding Chapelizod) of only 1.78% in excess of those actually received for the period 1975/76.

THE CONSTRUCTION OF THE MATHEMATICAL MODEL

We now address the problem of the construction of an analytical model which permits the identification and evaluation of:

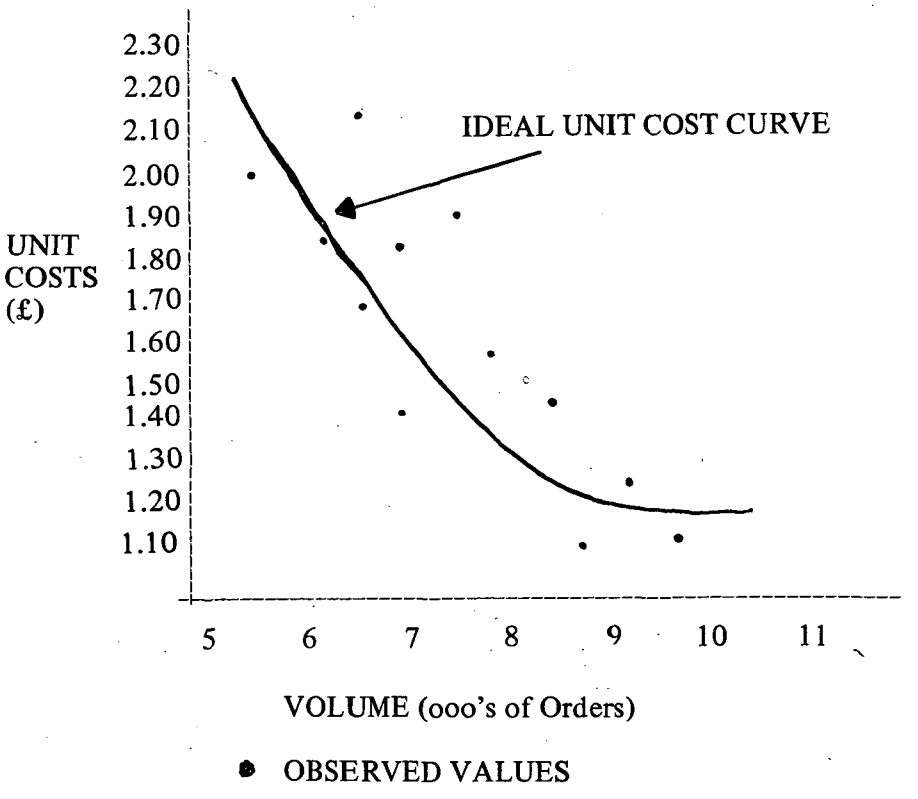
(a) the optimal distribution pattern from existing warehouses;

(b) alternative warehouse locations with regard to customer location and demand;

(c) the effect of varying unit delivery costs, warehouse capacity restrictions, and customer demand patterns, on overall distribution policy.

FIGURE 2

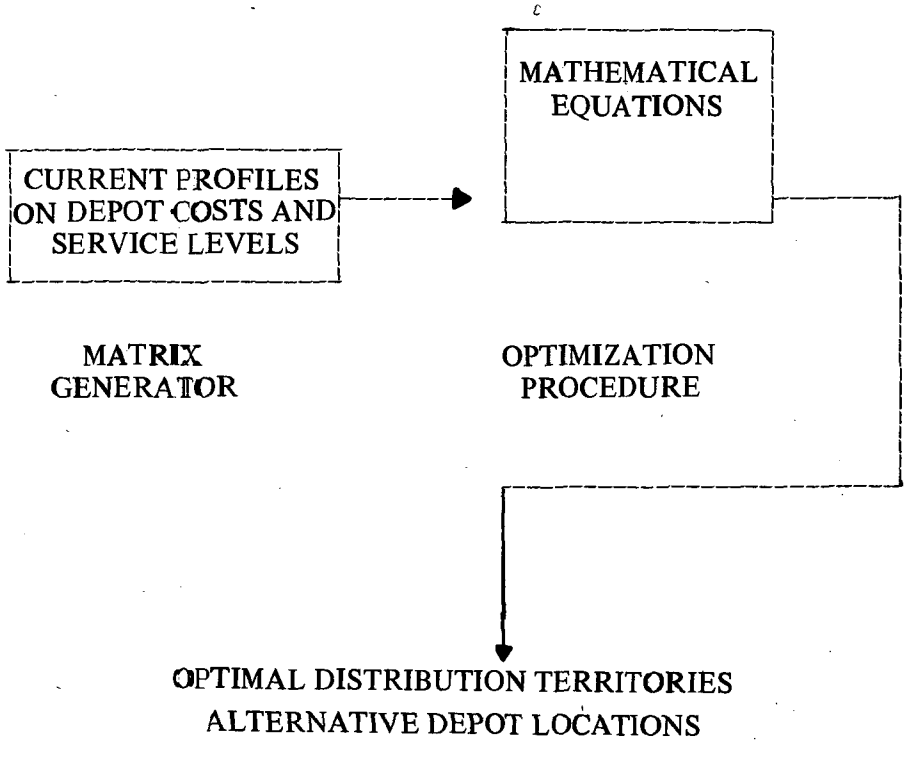
UNIT HANDLING COSTS IN DISTRIBUTION CENTRES



Computer planning models can take many forms, but generally they fall into two distinct types, namely optimization models or simulation models. The model that was constructed was of the hybrid variety. It is an optimization procedure which can be used to simulate a variety of alternatives being considered by the management of CMR. That the model is of the dual variety is entirely due to the development of a special matrix generator which permits rapid evaluation of alternative management strategies. Figure 3 portrays the first two stages (which includes the matrix generator) of the planning model. The objective of these stages is to derive that pattern of locations which should be supplied from each depot consistent with minimum delivery cost. The matrix generator controls the entire optimization procedure and permits a three hundred-fold reduction in data preparation.

Figure 3

THE GENERAL STRUCTURE OF THE FIRST TWO STAGES OF THE COMPUTER PLANNING MODEL



THE OPTIMIZATION PROCEDURE

The well-known classical transportation problem is formulated as:

$$\text{Minimize: } \sum_{i=I}^{m} \sum_{j=I}^{n} c_{ij} \ldots x_{ij} \quad \ldots . \text{ (i)}$$

$$\text{Subject to: } \sum_{j=I}^{n} x_{ij} = S_i \quad \text{(supply) } \ldots . \text{ (ii)}$$

$$\sum_{i=I}^{m} x_{ij} = D_j \quad \text{(demand) } \ldots \text{ (iii)}$$

$$x_{ij} \geqslant O \quad \ldots . \text{ (iv)}$$

Equation (iii) implies that equations (i) through (iv) have been augmented by n second-stage variables:

$$\phi_j = D_j - \sum_{i=I}^{m} x_{ij} \qquad \text{for } j=I, 2, \ldots, n$$

where the ϕ_j are unconstrained in sign.

Let $\hat{j}(\phi_j)$ denote the cost or penalty associated with the resultant level ϕ_j, that is, the difference between demand and supply. This function, of course, need not be linear.

If we now assume that the objective function is the sum of the delivery costs and the expected value of the penalty costs we can now re-express the classical model as:

$$\text{Min:} \quad \sum_{i=I}^{m} \sum_{j=I}^{n} c_{ij} x_{ij} + \sum_{i=I}^{n} E\left[C_j \left(D_j - \sum_{i=I}^{m} x_{ij}\right)\right]$$

$$\text{Subject to:} \quad \sum_{j=I}^{n} x_{ij} = S_i \qquad i = I, 2, \ldots, n$$

$$x_{ij} \geqslant O \qquad \text{for each i and j}$$

and

$$\phi_j = D_j - \sum_{i=I}^{m} x_{ij} \qquad j = I, 2, \ldots, n$$

By making two further postulates namely,

$$x_j \equiv \sum_{i=I}^{m} x_{ij}$$

and

$$C_j(x_j) \equiv E\left[C_j \left(D_j - x_j\right)\right]$$

this formulation becomes mathematically equivalent to an ordinary transportation problem and is a stochastic programming model, which through the expectation function, can cope with uncertainties in demand.

In the case of CMR, uncertainties in demand are likely to arise both through competition, and through population movements induced by the government's strategy of attracting foreign investment to geographically diverse parts of Ireland.

SEQUENTIAL SOLUTIONS TO THE MODEL

The stochastic programming model that has been described can be examined in three modes:

(a) Assuming that both $\phi_j = O$, and

$$\sum_{j=I}^{n} E \left[C_j \left(D_j - \sum_{i=I}^{m} x_{ij} \right) \right] = O$$

the model reduces to the classical transportation problem with linear costs. We will describe this as a Mode I solution

(b) Assuming that both $\phi_j = O$, and

$$\sum_{j=I}^{n} E \left[C_j \left(D_j - \sum_{i=I}^{m} x_{ij} \right) \right] = O$$

, but that the costs C_{ij} are non-linear. We will describe this as a Mode II solution.

(c) The Mode III solution – analysis of the full stochastic programming model.

These sequential solutions will now be examined.

SEQUENTIAL SOLUTIONS AND MANAGEMENT STRATEGIES – MODE I SOLUTIONS

Depot delivery areas (city deliveries excluded)

Mode I solutions, that is the classical linear cost model, are the most straightforward to achieve and the quickest to expedite. This latter consideration, the rapidity with which various management strategies can be evaluated, was the most important determinant in the decision to examine the consequences of Mode I solutions initially. Accordingly, a linear cost model was formulated containing in excess of 2,000 variables and 300 equations.

The objective of the two-stage model is to minimize the cost (defined as either delivery or transportation) of the CMR Group of warehouses consistent with the capacity of those warehouses and the demands of their customers. The model expresses its output in terms of the locations to which the vans of any one warehouse should deliver and indicates the lowest cost (optimal) associated with this (optimal) delivery pattern. An outstanding feature of the model's solutions is the complete lack of "joint-deliveries", a feature which has important consequences for some of the existing warehouses.

An additional important feature of the two-stage model is its ability to evaluate the benefits of:

(i) changing the cost structures of existing warehouses,
(ii) closing down one or more of the existing warehouses,
(iii) establishing new warehouses at any desired location(s) in the country.

Tables 1 and 2 clearly show that the handling and transportation costs of the six warehouses are different. This, in turn, implies that the delivery costs are also different. The model was initially programmed to derive the minimum delivery cost patterns for the group of warehouses. These delivery patterns are shown in Figure 4, where one of the most noteable features is the overall country delivery area for Chapelizod. This is in marked contrast to the present geographical area covered by Chapelizod's delivery vans (See Figure 1). The model indicates that, should this delivery pattern be adhered to, then the yearly delivery cost (excluding city deliveries in Dublin, Cork, Carlow, Limerick and Sligo) could be reduced by 27% through a reorganization of current delivery patterns.

The solution presented above has been computed on the basis of delivery costs, that is, a warehouse's combined handling and transport costs. It can be argued that a warehouse's handling costs can be more of a target for management action than can the transport cost. Therefore (under this philosophy) it is only necessary to compute the transport cost patterns for the warehouses – management action being directed to achieving handling costs of the same magnitude in each warehouse. Accordingly, the optimal solution was obtained and its most noticeable features were the small country delivery area for Chapelizod and the relative similarity with the optimal solution for delivery costs.

The model indicates that purely on the basis of transport costs, a reorganization of current delivery patterns could save CMR up to 27% of current transport charges.

Alternative (country) depot locations

Various writers (see [3–6], for example) have written extensively on the depot location problem, one of their themes being the necessity for models to be able to *compute* optimal depot locations. However, in this instance, management considerations selected six different locations as potential sites for depots, namely Dundalk (as a substitute for Cavan), Galway, Tralee, Waterford, New Ross and Drogheda. These potential locations, together with their relevant cost profiles, were input into the matrix generator whose output was accepted by the optimization procedure. The results of this analysis were that the substitution of Dundalk for Cavan would reduce transport costs by a further 3%. Further-

more, the introduction of new depots at Galway, Tralee, Waterford and Drogheda would result in a 30% reduction in current transport costs, whereas the introduction of new depots at Galway, Tralee, New Ross and Dundalk, would result in a 28% reduction in current transport costs.

These results clearly indicate that the potential reductions in transport costs achieveable by additional new depot locations would be insufficient to recoup, in a reasonable time, the capital costs of establishing these new warehouses.

Efficient route planning within the optimal warehouse territories

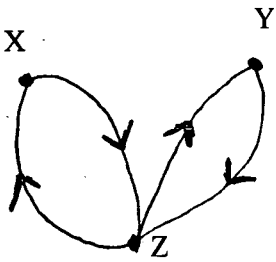
The optimized warehouse territories have considerable operational implications for the local management of the depots. Table 3 summarizes the situation.

TABLE THREE : Towns, Villages Visited

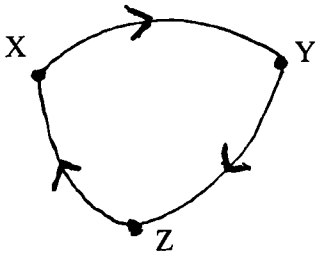
Warehouse	Pre Analysis (Including Joint Deliveries)	Post Analysis
Sligo	68	61
Cavan	47	32
Chapelizod	79	25
Carlow	61	67
Cork	66	53
Limerick	99	51

Thus it is quite evident that substantial changes in the traditional routes operated by the warehouses will be necessary. In addition, the acceptance of the new and the ceding of old customers by warehouses will result in very different patterns of call if the existing levels of service to customers are to be maintained. Leaving the design of new routes and patterns of call to warehouse managers would lead to confusion, initial loss of service to customers, inefficiency and an increase in transport costs due to more miles than necessary being travelled by individual warehouse vehicles.

The procedure used to develop optimal customer calling sequences is based on the following simple principle, originally introduced by Clarke and Wright[2]. Two destinations, X and Y, can be supplied either separately or by a round trip from depot Z.



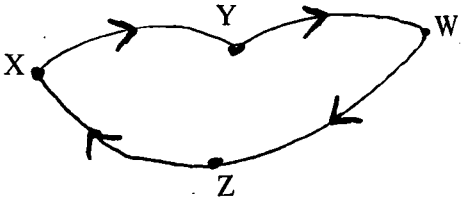
Separately



Round Trip

Total Distance = 2XZ + 2YZ Total Distance = XZ + XY + YZ
Route saving by round trip: XZ + YZ – XY
If we now add a third destination W we have:

Route saving by round trip: 2XZ + 2YZ + 2WZ
–(XZ + XY + YW + WZ)
= (XZ + YZ – XY) + (YZ + WZ – YW)
= route saved by linking X and Y
+ route saved by linking Y and W



The addition of the route planning model to both the optimization procedure and the matrix generator completes the third stage of the planning system for facilities and resources in the CMR distribution network. Figure 5 portrays the general structure of the complete planning model.

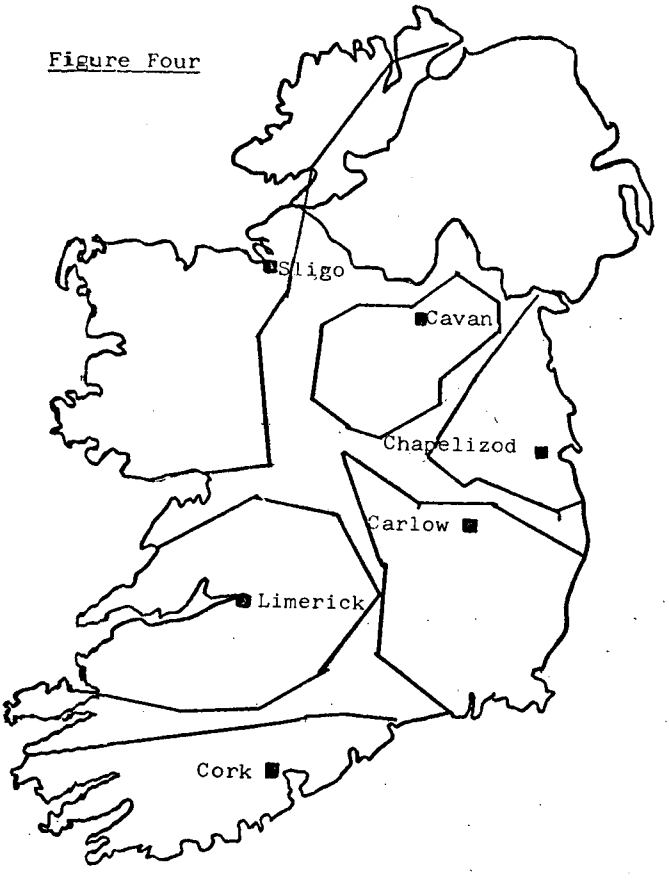
The Carlow depot, having a customer calling frequency of once per day, was selected as the first area of application of the route planning model. Apart from customer calling frequency, other data inputs to this third stage included length of working day, manpower and vehicle resource levels, vehicle road speed, and such customer idiosyncracies as opening time, closing time, half-day closure, etc. The model then computed trips indicating optimum customer visiting sequences, together with the expected trip distances and trip durations. Table 4 compares the route

TABLE FOUR : Computed and Actual Trip Characteristics

Depot	No. of Routes	Computed			Actual			Errors	
		Distance (Miles)	Duration Hrs.	Mins.	Distance (Miles)	Duration Hrs.	Mins.	Distance	Time
Carlow	4	891	34	42	901	35	30	1.11%	2.25%
Cork	4	843	30	56	860	31	51	1.98%	2.88%
Limerick*	6	1285	43	20	1317	45	06	2.43%	3.92%

*Alterations made to two of the proposed routes in order to provide an improved service to selected high-volume customers.

Figure Four

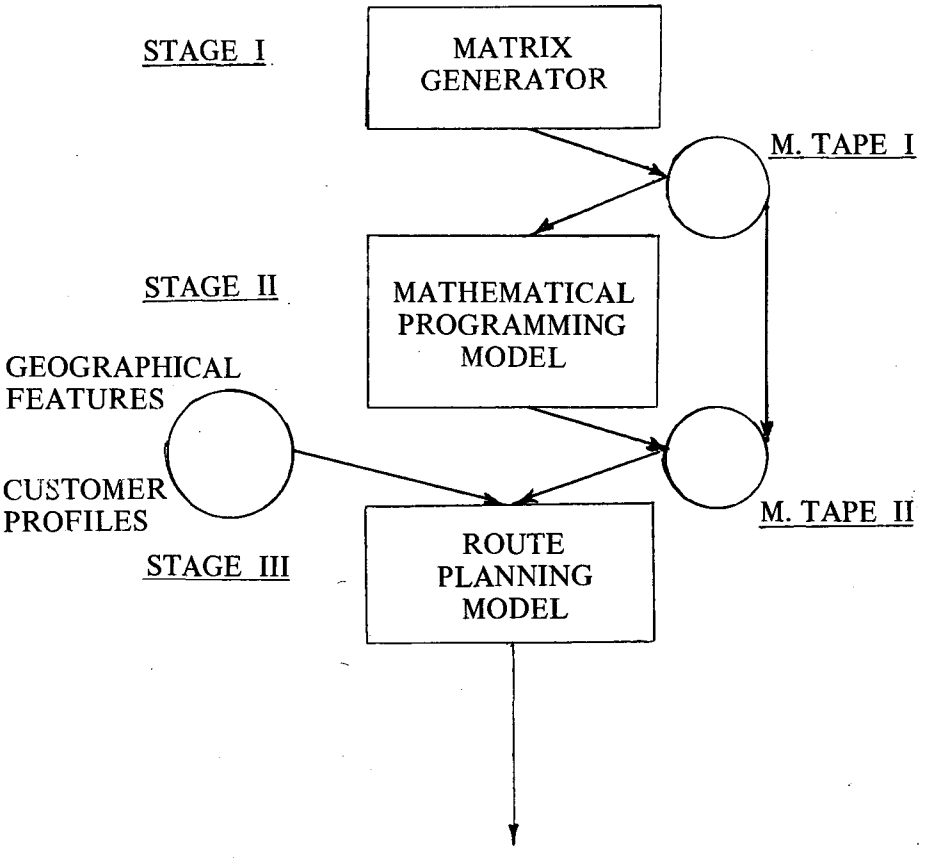


planning model's predictions with the results obtained by CMR personnel when the computed trips were made operational. This table shows that the model's trip distances and durations correlate very closely with the actual distances and durations observed in practice.

Following the successful implementation of the procedures for the Carlow depot, CMR senior management instructed similar analyses to be carried out for the remaining depots. Currently, the model's computed trips from the Cork, Limerick and Chapelizod depots have been implemented. Table 4 also displays the comparisons between the computed and actual trips for the Cork and Limerick depots. The Dublin city routes from the Chapelizod depot have been changed somewhat by CMR management in order to give an even better service to various high-volume customers. In so far as comparisons can be made on the common elements of the computed and actual routes, little difference in time and distance has been observed.

FIGURE FIVE

A PLANNING SYSTEM FOR FACILITIES AND RESOURCES IN DISTRIBUTION NETWORKS



The Cavan Depot

As shown in Table 3 the Cavan depot should deliver to only 32 towns/villages instead of its current complement of 47. In terms of customers, this means a reduction from 187 to 102; the difference, 85, being allocated between Sligo and Chapelizod. In view of this significantly reduced market for Cavan, it is pertinent to examine the effect on CMR Group operations if the Cavan depot ceased to exist. The full model was run under this assumption.

It was found that if the Cavan depot did not exist, the customers in its present territory would be serviced from Sligo and Chapelizod in the approximate ratio of 2:3. These customers, together with the existing customers of Sligo and Chapelizod, could be serviced from Sligo and Chapelizod with no diminution of present service levels, Cavan's existing vans being relocated at Sligo and Chapelizod. Some of the van routes, however, (particularly from Sligo) would be rather long (in excess of 200 miles), but the analysis indicates that they should be capable of completion within an 8½ hour working day. Due to these longer routes the annual van mileages of Sligo and Chapelizod would increase, the level of increase being dependent on the level of service (i.e., number of calls per week) extended to customers. On the assumption that the aforementioned customers have a maximum service frequency of five calls per week, the increased cost of servicing Cavan customers from Sligo and Chapelizod should not exceed approximately 6% of their current distribution expenses. A lower service frequency would naturally result in a reduced percentage increase.

o

The Carlow depot

The results of the examination of eliminating the Cavan depot prompted the CMR senior management to consider the position of the position of the Carlow depot. A glance at Figure 4 shows that Carlow's territory could probably be efficiently divided between the Chapelizod, Cork and Limerick depots. This assumption (together with the closure of Cavan) was tested in the full model. The following are the more important results of this analysis.

The allocation of towns, villages/locations to the four remaining depots showed that Sligo got 84, Chapelizod 75, Cork 54 and Limerick 76. Comparison of this allocation with that of the original scenario, shows that Chapelizod will have an additional 50 locations to service; Limerick an additional 25; Sligo an additional 23 and Cork one location *less* to service. Longer van routes will be experienced from Chapelizod, Sligo and Limerick, resulting in an increase in their variable costs of distribution. Some of the routes may well exceed the stipulated 8½ hr. working day – this result is, to an extent, dependent on the level of service offered to customers.

Deliveries in the Dublin Region

The analytical procedure that has been described for "country" deliveries was systematically applied to customer deliveries within the Dublin region, that is, from the company's Chapelizod, Harmonstown and Deansgrange warehouses. Prior to this analysis, however, the customers within this region were classified as:

A Class : 105 : 2 calls per day
B Class : 196 : 2 calls per day
D Class: 80 : 1 call per day
Total Customers : 381

These classifications were based on the current levels of business that each customer has with CMR.

The initial run of the optimization model indicated a customer dispersal pattern of 38% for Chapelizod, 32% for Harmonstown and 30% for Deansgrange. The second analysis of the optimization model was conducted on the basis of only two supplying warehouses, that is, Chapelizod and Harmonstown. The results of this analysis indicated a customer dispersal pattern of 48% for Chapelizod and 52% for Harmonstown.

The third stage of this analysis concentrated on only Chapelizod remaining as the supplying warehouse. As the optimization model is technically incapable of analyzing this situation, the route planning model was used to evaluate this alternative. The main conclusions emanating from this analysis were that delivery vans, using Chapelizod as a base, could supply A, B and C class customers twice, twice and once per day, respectively, within the overall constraint of an 8½ hour working day. It also showed that a maximum of 11 vans would be needed to provide this service. Further, the service could be supported by 10 delivery vans if certain centre-city A and B class customers were to be serviced with one van. Only two routes might prove a little difficult to achieve within the overall constraint of an 8½ hour working day. A cost increase would be incurred if Chapelizod were to be the only supplying warehouse for the Dublin region. That increase, however, would be confined to the variable cost factor (i.e., fuel costs) of distribution costs.

From the purely distribution point-of-view, therefore, Chapelizod could supply all the needs of CMR's customers in the Dublin region.

OPERATIONAL AND FINANCIAL CONSIDERATIONS OF THE MODE I SOLUTIONS

Operational considerations

The three-stage planning model under Mode I solutions has defined optimal distribution territories for the CMR Group of depots and com-

puted optimal trips within each depot's distribution territory. In addition the model has evaluated alternative locations for potential new depots together with potential rationalizations within the existing CMR Group of depots.

Due to social and environmental circumstances the full implementation of recommended solutions must be phased over a period of time. However, as of now, CMR senior management have implemented the optimal country distribution territories for the Chapelizod, Carlow, Cork and Limerick depots. Sligo and Cavan have been delayed pending a decision as to whether a depot will be established at Dundalk. Optimal (country) trips within the aforementioned distribution territories and optimal *city* distribution territories for the Chapelizod and Harmonstown depots, together with their trips, have also been implemented. The Deansgrange depot has been closed in accordance with the model's evaluations.

Management is still studying the possibility of introducing a new depot at Dundalk and at the same time retaining the Cavan depot but at a reduced economic level. Decisions on the closing of Cavan, Carlow and Harmonstown are also pending.

Financial considerations

The full financial benefits that could accrue to the CMR Group have, at this time, not been realised due to the impending decisions mentioned above. Thus the financial savings described have been tabulated under "those actually achieved" and "those already identified as being achievable."

As mentioned, the planning model indicated a 27% reduction in both delivery and transport costs as being achievable. It has been certified by the Group's director of finances that delivery costs have been reduced by 23.3% and transport costs by 20%. (Note that the model's strategies for Sligo and Cavan have not, as yet, been implemented.)

The third stage of the planning model computed optimal trips from each depot. These trips were computed on the basis of a customer service frequency of 5 calls per week for country depots and up to 10 calls per week for the two city depots of Chapelizod and Harmonstown. Many country customers previously only received one, two or three calls per week. Although some customers in Dublin city area received up to 10 calls per week, the number now receiving that level of service has increased through the implementation of the trips computed by the third stage of the planning model. In both instances these increased levels of service were achieved with the existing level of resources, that is, the company's delivery fleet was not increased. Thus the overall level of service to customers has been substantially improved and has been calculated to be a minimum improvement of 60%.

MODE II SOLUTIONS – CITY DELIVERIES EXCLUDED

As Figure 2 indicates, the unit handling costs in CMR warehouses do not follow the idealized cost curve. Indeed the unit costs are so erratic that they cannot efficiently be described by a nonlinear function. Faced with this situation the advice offered by William of Occam, the 14th century scholastic philosopher, and known as Occam's Razor, namely, "Vain to do with more what can be done with fewer," was accepted. Analyses were carried out using the maximum, minimum and mean handling costs for each depot over the period May 1975 to April 1976. Table 1 portrays this data where it can be seen that large variations occur in unit handling costs both between and within the CMR depots. Linear transport costs were used in these analyses since no information existed on which a nonlinear hypothesis could be tested.

The output of the model, under the maximum, minimum and mean cost hypotheses showed that, whereas group delivery costs varied in accordance with each hypothesis, the geographical delivery areas of each depot did not vary significantly from one to the other. It was concluded, therefore, that Mode I solutions would be reliable indicators of the likely outcomes of various management strategies.

MODE III SOLUTIONS

Mode III solutions include the effect of the expected value of the penalty costs on future management strategies. It deals with future strategies because the stochastic model measures the impact of the company's inability to meet orders generated in the future. These (future) orders can be generated in three ways, namely; an increase in company service levels leading to an increase in sales; an increase in the company's market share; and population increase due to an increasing birth rate and/or population shifts due to current government strategies. These alternatives are not necessarily mutually exclusive.

A previous section of this paper indicates that the service levels to CMR customers have been increased with a measurable increase in the volume of sales. Any further increase in sales that can be expected through increased service levels is a subjective judgement based on a knowledge of the market place.

The company's market share has increased by 3 percentage points over the past two years, the magnitude of the gain being dependent on CMR's cost effectiveness and the economic viability of some of its competitors. Again the future impact of these factors are subjective judgements based on a knowledge of the market place.

Ireland's population has been increasing steadily in the last decade – from 2.88 million in 1966 to 3.19 million in 1977. By 1986 the population is expected to be approximately 3.51 million. Against this increase in population there has been a steady decline in the number of phar-

macies from 1,500 to 1,100 in the last 10 years. The net result of these two trends is anticipated to be a decreasing number of orders from pharmacists to CMR but a significantly increasing order value. Indeed CMR has anticipated this changing situation by designing a computer-based inventory planning package, which enables the pharmacist to know, at any time, his current stock position and how much, and when, he should order to meet anticipated demand. Pulling these three strands together, the senior management has estimated that if there is no decrease in the intensity of competition, CMR will experience a 3% volume growth per annum. However, if there is a decrease in the intensity of competition, then CMR will experience an immediate 12% volume growth, followed by a 3% volume growth, per annum, thereafter.

COMPUTATIONAL CONSIDERATIONS

Only one uncertain demand mode is of primary interest to the company, namely when the demand exceeds supply. In this situation, the company is incapable of supplying its customers' requirements and it therefore faces the possibility of one of its competitors gaining an increasing share of the pharmaceutical market.

The company anticipates that the increasing demand for its services will primarily come from its A class customers and to a lesser extent its B class customers. The increase in individual demand is not known with certainty, but probabilities, based on subjective judgement, can be put to A class customer demand. The remaining demand, up to the limits already indicated, will be assumed to come from B and C class customers in the proportions 2:1. The large once-and-for-all increase of 12% indicated in an earlier section will be assumed to be an across-the-board-increase regardless of customer status.

The uncertain demand solutions are currently being investigated with the primary aim of establishing their likely effect on group strategic management over the period 1978/80.

REFERENCES

1. Balinski, M. L. and Mills, H., "A warehouse problem" prepared for Veterans Administration; *Mathematica*, Princeton, New Jersey, April 1960.

2. Clarke, G. and Wright, J. W., "Scheduling for Vehicles from a Control Depot to a Number of Delivery Points." *Operations Research* 11, 568, 1973.

3. Higgins, J. C., "On the Merits of Simple Models in Distribution Planning." *International Journal of Physical Distribution*, Vol. 2, No. 3, 1972.

4. Kuehn, A. A., and Hamburger, K. J., "A Heuristic Program for Locating Warehouses." *Management Science*, 643, 1963.

5. Shycon, H. N. and Maffei, B. B., "Simulation – Tool for Better Distribution." *Harvard Business Review*, 65, 1960.

6. Baumol, W. J. and Wolfe, P., "A Warehouse Location Problem," *Operations Research* 6, 252, 1958.