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A Modified Lockset Approach To Routing For Backhaul Effectiveness

by

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ABSTRACT

An attempt to simulate and improve upon a distribution system led to the formulation of a lockset algorithm that included a backhaul routing capacity. The problem that motivated the modification is presented. The related methodological characteristics of capacity control, load-size/loading time trade-off and visit-frequency are discussed.

A Modified Lockset Approach To Routing For Backhaul Effectiveness

INTRODUCTION

In a recent attempt to first simulate and then improve upon a farm supply cooperative's distribution system, a lockset algorithm that included a backhaul routing capacity was constructed. This paper presents the problem that motivated that modification, the reasons for selecting the heuristic lockset model utilized, an evaluation of the model's important characteristics, and the discovery of a potential methodological breakthrough with respect to applying routing models. The backhaul adaptability modification is presented, despite its straight-forward nature, as a first attempt to fill the large void in backhaul-related operations research literature. The modified lockset's simulation capability is discussed with respect to capacity control and "load-size/loading-time" trade-off. Finally, the potential for determining visit-frequency within a routing analysis rather than accepting it as a given constant is discussed.

THE PROBLEM

The farm supply cooperative's distribution system centered around two warehouses where supplies were assembled, stored, reassembled, and distributed to retail outlets. Cooperative managers were considering a move to one of seven proposed centralized warehouse locations. A routing model was required that could mimic as well as provide improvements for the existing system in order to generate comparative distribution costs between the current and proposed systems.

Conceptually, the problem is similar to the one presented by Hallberg and Kriebel (p. 2) in that M distribution centers[1] of known locations are distributing to N retail distributors who demand known quantities, q_i $i=1,2,\ldots,N$, of input supplies and are served by one of V vehicles. Retail distributor locations are known precisely as are the costs C_{ij} for driving between them. The capacity of each vehicle is known and identical.

The problem is dissimilar in that the M distribution centers receive a known portion of their supplies, s_i i=1,2,...,P on returning distribution vehicles from P suppliers also of known locations.

The need is to reduce the total of distribution costs to the N retailers plus backhaul assembly costs from the P suppliers. The evaluation requires establishing route numbers, route sequencing, and truck capacity tracing. Capacity tracing is necessary within the model to prevent trips for backhaul supplies until truck space is available to load them.

Even without the backhaul complexities, the remaining classic transportation problem as formulated by Hadley would exhibit prohibitive computational costs. Routing algorithms are classified as combinatorial optimization models. They search a finite alternatives set in order to optimize the object function. Where one warehouse serves N retailers with one truck that returns after finishing its run, ". . . the associated integer programming problem would require N(N-1)/2 activities and (N^2+2) constraints. . . . there are (also) N!/2 possible solutions. . .," (Hallberg and Kriebel, pp. 3-4). Indeed, the computing cost of the branch and bound technique generally used in integer linear program algorithms becomes prohibitive as soon as the matrix acquires any size (Gillett and Miller, p. 341).

With computational costs in mind an attempt was made to formulate a mixed integer form of the farm supply problem. The new formulation was not satisfactory (Robbins, p. 33). Where N=96, P=10, and M=1, the mixed integer linear programming matrix requires approximately 6,000 activities and 9,000 constraints with over half of the activities requiring integer expression. The computer cost of multiple-run analyses with this large number of integer variables remained prohibitive. Indications during the research were that costs per iteration would run many times greater than a similar transhipment model with no integer variables, for example. Hence, the lockset modifications were devised.[2]

Because combinatorial approaches are not efficient, heuristic alternatives have been developed. These heuristic approaches, labeled "lockset" by Schruben and Clifton, introduced by Dantzig and Ramser, modified by Clarke and Wright, and utilized by Hallberg and Kriebel (among others) are alternative approaches for calculating assembly and distribution costs.[3] They route efficiently, but as originally defined, do not force carriers to finish distributing near a backhaul point.

After assuming an initial solution of one round trip to each delivery point, "the first step in the lockset method is to compile a list of all possible pairs of points not involving the plant (or origin). . . . The second step is to compute the DSC (distance-saved coefficient) for each pair. . . . The third step is to consider joining the pair with the largest DSC on the same route. . . . The next step is to test the revised route for feasibility. The tentative pairing must meet four tests: (a) each stop must have at least one leg connected to the origin, (b) each stop must have been previously on a different route, (c) a carrier of sufficient size must be available to carry the combined load, (d) a carrier capable of traveling the required distance must be available," (Schruben and Clifton, pp. 862-863). Steps three and four are then repeated with the next largest DSC until all DSC pairings have been considered. An illustrative sample problem is presented in Figure 1 and Table 1. Figure 2 shows the steps in pairing the DSC's from the initial solution in 2.a to the final solution in 2.c.

Despite its efficiency advantages, the lockset process remains deficient. In its current form, it cannot capture potentially significant backhaul cost savings.

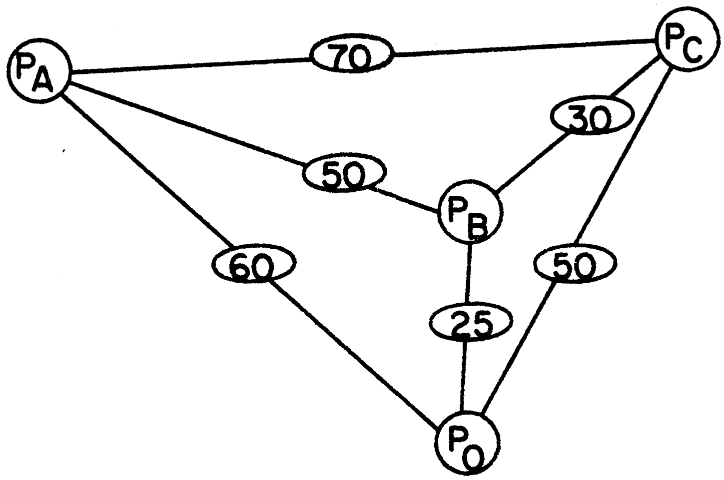
THE MODIFIED LOCKSET TECHNIQUE AND ITS SPECIAL CHARACTERISTICS

When analyzing sizable routes with backhaul problems, mixed integer or traveling salesmen models are likely to be dismissed from consideration. High computational costs eliminate them. The lockset model, however, can be easily modified to force trucks to finish their deliveries near a backhaul point by simply adding a fifth restriction to the feasibility check.

The required fifth restriction is that any backhaul point included have two legs connected to the origin, and that backhauls must come at only one end of the route. With this change and manipulation of capacity restrictions (to be explained later) the modifications force routes to properly include backhaul points as well as trace truck capacities without prohibitive computational time or cost.[4]

More general backhauling would include picking up several backhaul points and possibly having delivered items and backhaul items sharing the trucks simultaneously. The farm supply algorithm does not have this capacity. Multiple pickups were not required because supply points were either widely dispersed or close enough to each other to be considered as one. Item sharing was also not required as the cooperatives fleet had only single-doored trailers. A more elaborate backhaul capacity would have to be written into backhaul routing models before they could be more generally applicable.

Two other problems commonly found in routing research were not faced. The question of how to allocate delivery points between multiple warehouses was assumed away by using the dealer assignments utilized by the cooperative. Also the demand size relative to truck capacity was



(Pi) = Plant i where i = O, A, B, and C

(25) = Distance between points

Figure I. Location of Points for Sample Problem

Table 1. Pairing list and distance-saved coefficients for the sample problem.

Pairing	Distance-Saved Coefficient						
P_iP_j	P_oP_i	+	P_oP_j	-	P_iP_j	=	DSC
P_AP_B	60		25		50		35
P_AP_C	60		50		70		40
P_BP_C	25		50		30		45

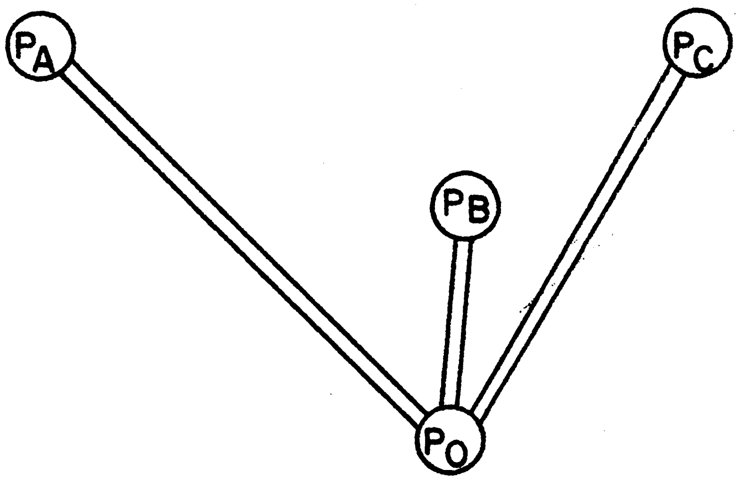


Figure 2a. Initial Solution for the Sample Problem

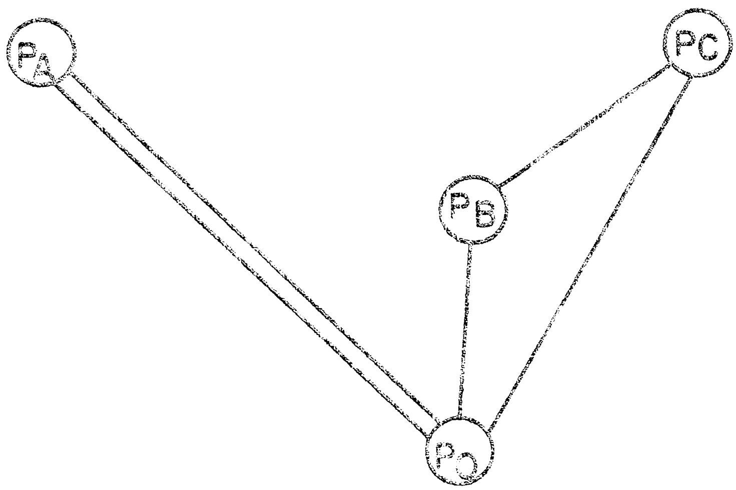


Figure 2b. Intermediate Solution for the Sample Problem

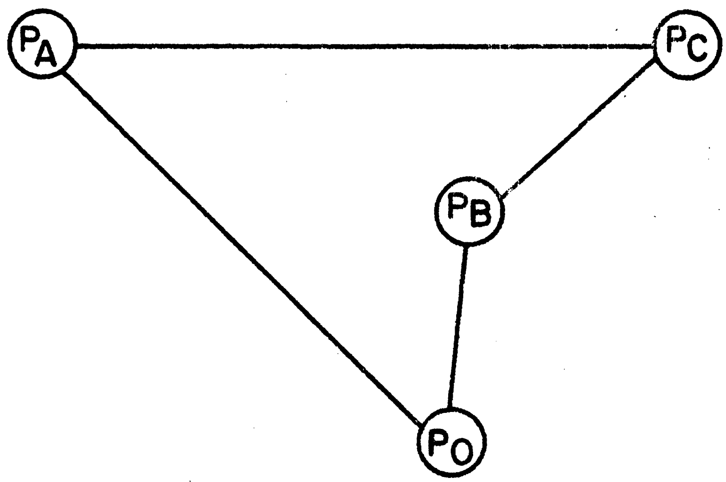


Figure 2c. Final Solution for the Sample Problem

not addressed. The farm cooperative limited alternative evaluations to only those that would include the current fleet.

Initially, the modified model assumes one route for each dealer as in the unmodified model. With this as a starting point, dollar saved coefficients, as suggested by Hallberg and Kriebel (p. 6), are calculated to indicate the number of dollars that could be saved by combining dealers to reduce route numbers. Any dealer whose demand is greater than the maximum allowed on one carrier is listed as a round-trip, one-dealer route. The residual demand is then recorded so that this dealer can later be included in a multiple-dealer route. Restrictions are required to keep the total cubic volume carried on one route under some maximum volume and, of course, force backhaul components to the end of a route.[5]

One objective of route configuration research is to build a model that will approximate an existing system's cost structure by simulating reasonably realistic routes. Once either the lockset or modified lockset model is validated by simulating history it can be used to give a common basis for comparing alternative warehouse location-number designs.[6] Because lockset does not guarantee the one minimum cost routing structure routes may be rearranged to gain some savings. In actual application, however, either model usually does at least as well as, if not better than, dispatchers' routing schemes, (Schruben and Clifton, p. 855; Hallberg and Kriebel, p. 5).

Carrier capacity assignment is crucial to the modified model's simulation nature. Managing capacity as if it were controllable is essential despite the fact that it is actually a non-controllable parameter once a particular sized carrier is assumed. Assigning various maximum capacities provides researcher control in simulating average capacity. Two firms utilizing equal capacity tractor trailers could easily exhibit different sized average loads because of different product densities, bulk, shape, or combinations. Therefore, lockset validation also requires an iterative search for that maximum capacity that will simulate actual average capacity. Once an acceptable maximum capacity is identified the modeled transportation cost should approach reality. Failure to achieve reality may indicate that restrictive management policies exist that are not included in the model. Restrictions beyond the five in the feasibility check may be required. Simulated costs greater than actual costs are unlikely, but if present, probably indicate input errors (Schruben and Clifton, p. 855).

The need to manipulate maximum capacity presented itself in the farm supply research. Apparently, cooperative dispatchers regularly underutilized their cubic truck capacities. Therefore, parameter manipulation was required to simulate average truck capacity. Curiosity as to the motivation behind such capacity utilization revealed the importance of the load-size/loading time trade-off.

Consequently, maximum capacity was varied in a sensitivity analysis to evaluate the trade-off between loading time and average load-size. Loading times and therefore costs increase more than proportionately as load-size (LS) increases for a given carrier capacity (CC). More and more time and expense is incurred in the loading effort as larger and larger proportions of the total capacity are utilized (Figure 3).[7] In other words, as the LS/CC ratio increases the loading time and therefore the loading cost (LC) increases more than proportionately. The cost in time spent loading carriers must be offset by the number of visits that can be made with each carrier per trip. The more available capacity utilized the more visits each carrier can make per trip, and the lower the total system's delivery (DC) (Figure 3). Total system's distribution costs (TC) where TC = LC + DC, might be reduced by increasing the number of trucks (routes) if the subsequent decrease in LC was greater than the increase in DC.

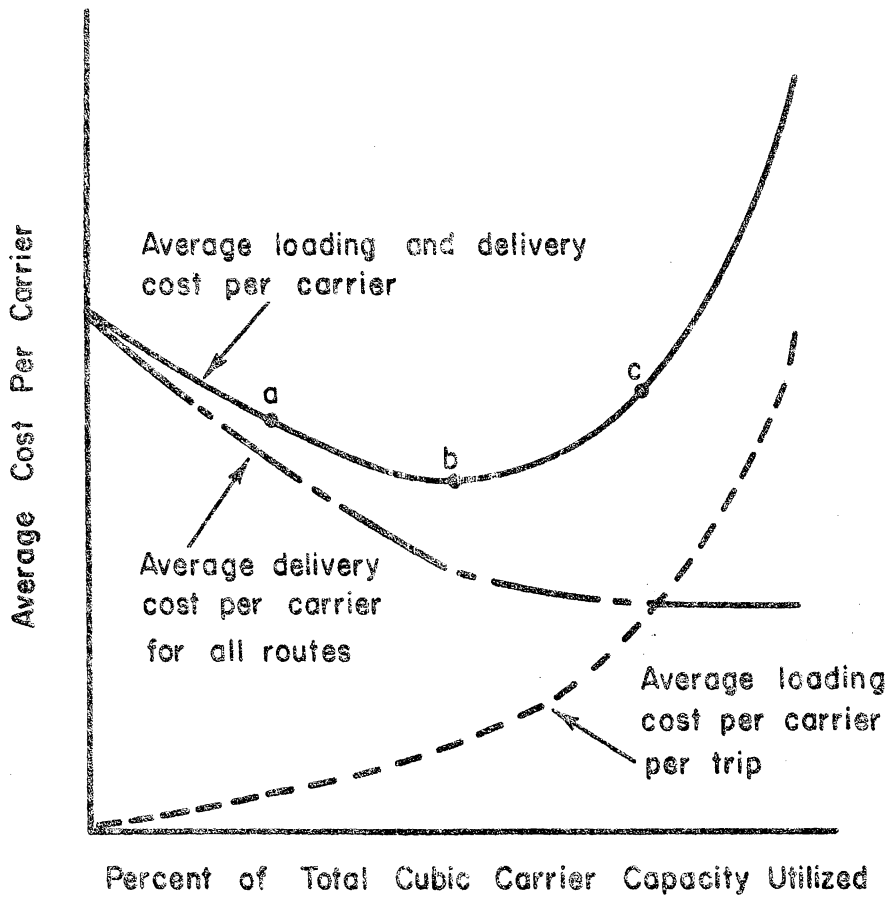


Figure 3. Hypothetical relationships between loading and delivery cost per carrier trip as they relate to degree of total cubic carrier capacity utilization.

The farm supply firm's management was adding a route to a weekly distribution system despite an average carrier utilization of less than 50% in cubic measure. The transportation manager justified the added route in terms of loading times. Given that managers may tend to turn first attention to what currently seems to be their most troublesome areas it is likely that the cooperative's distribution situation had proceeded to the right of point b in Figure 2 before the need for change was realized. Further firm-level research on this aspect of the problem would likely pay high premiums to decision makers.

The modified lockset procedure utilized a form of Hallberg and Kriebel's (p. 6) dollar saved coefficients (MSC's) rather than the original lockset's distance saved coefficients (DSC's). MSC's were added to allow the modified procedure to reflect road variability. Normally, $r * DSC = MSC$ where r is the cost per mile, but where roads are poorly constructed, hilly, or curvy the model should include the extra cost required. When this occurs, $r * DSC \neq MSC$ instead $MSC = r * DSC + C$, where C is a constant added to account for poor road conditions.

The question of what should be done with dealer demands that are greater than carrier capacities was solved in this form of the lockset algorithm by forcing round trips to the applicable dealers. However, forcing round trips to dealers with demands greater than the carriers capacity may not be ideal as only the residual demand is treated by the actual route structuring portion of the algorithm. Total costs may be minimized if the large dealer's demand is parceled out to two or more nearby routes.

Implicitly, the lockset and modified lockset models, as with other routing models, assume a given visit frequency. Demand expressed as daily, weekly, or monthly dealer requirements forces daily, weekly, or monthly delivery. Manipulating visit frequency is likely to reduce cost over a solution that requires uniform regular delivery. Frequency manipulation appears to be an area of potential improvement in routing theory. A sample lockset problem was presented and solved in Figures 1 and 2 in combination with Table 1. When all the initial restrictions are met, the route formed (OACBO) saves 120 miles over the initial solution for each time period, one week for example. If, however, point C could accept less frequent visits, say once every four or eight weeks, adding C to the weekly route would be sub-optimal. In this particular example, up to two round trip deliveries to C per month would be less expensive than including C in the total route every week (Figure 4 and Table 2). In an actual situation, less frequent visits to C might allow less frequent visits to the remaining points in the main route and therefore reduce cost.[8] Replacing less frequent round trips to C with occasional full route trips whenever possible, e.g. OABO three times per month and OACBO once per month saves even more travel (Figure 4 and Table 2).

An immediate solution to the visit frequency opportunity area is not apparent. For small problems or even large problems where only a small portion of the dealers exhibit irregular demands, frequencies might be established by inspection. The difficulty is in computerizing large problems. One untried possibility would require a three-stage approach. The first stage would aggregate dealers with similarly sized demands, geographically. The second would assign visit frequencies and the third would establish routes for each frequency. For example, if twenty dealers were to be visited once, thirty dealers twice, and fifty dealers four times per month, three routings would be required. One sequencing would be established for the two weeks that only fifty dealers were to be visited. Another sequencing would be required for the one or two weeks that eighty or more dealers were to be visited.

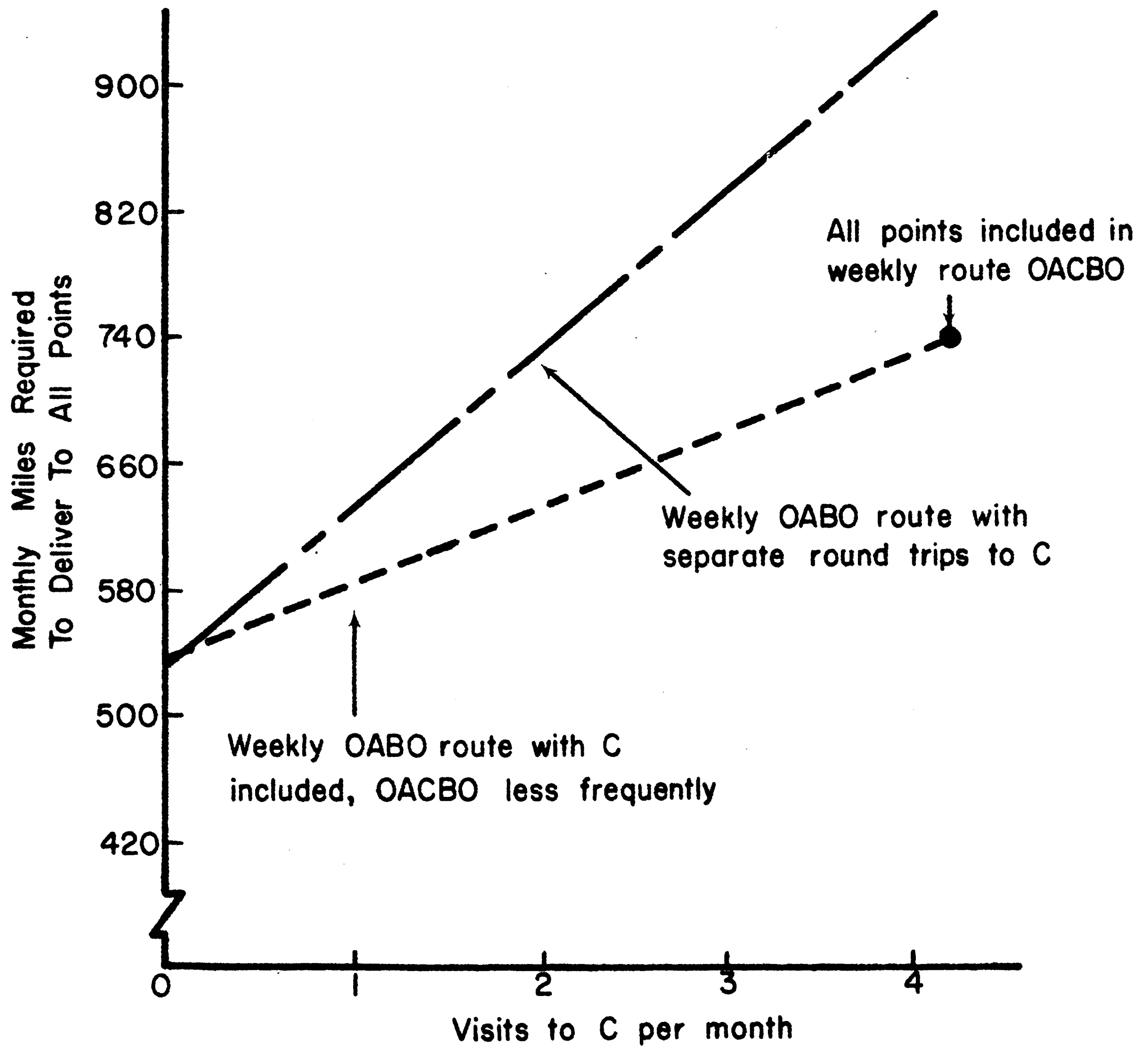


Figure 4. Sample problem's trade-off between separate round trips, less frequent visits, and equal visit frequency to C in miles traveled per month.

Table 2. Sample Problem's trade-off between separate round trips, less frequent visits, and equal visit frequency to C in miles traveled per month.

Routing Plan	Visit Frequency Per Month				Total travel per month (miles)
		Route stop sequence*			
	to C	OACBO** (185 miles)	OABO (135 miles)	OCO (100 miles)	
1	4	4	0	0	740
2	3	3	1	0	690
3	2	2	2	0	640
4	1	1	3	0	590
5	0	0	4	0	540
6	4	0	4	4	940
7	3	0	4	3	840
8	2	0	4	2	740
9	1	0	4	1	640

*Route mileage given in parentheses.

**OACBO is the route made up of P_A, P_C, P_B, in that order, originating and ending at P_O. Similarly OCO just includes P_C and OABO includes P_AP_B.

The final routing would be for the one week that carriers visit ninety or 100 dealers. The specifics required to implement this algorithm form have yet to be developed.

SUMMARY, CONCLUSIONS, AND IMPLICATIONS

The lockset model, as modified, does solve for backhaul savings while approximating an existing system's cost structure by simulating reasonably realistic routes. Backhaul points, traditionally not included by lockset formulations can be included in the modified approach by requiring that they be added to the end of the closest route. Although lockset does not guarantee the minimum cost routing structure it does provide a common basis for evaluating management policy and physical design changes.

Research into modification possibilities is necessary if the model is to parcel out a dealer's demand to two or more multiple-dealer routes when that demand is greater than the carrier's capacity. The farm supply lockset algorithm may have been too restrictive in that round trips to reduce the demand to less than one carrier's capacity are forced into the solution.

Similarly, the entire notion of visit frequency has been essentially ignored by operations research literature. The assumption that all dealers will be visited on a regular interval basis is often injected into transportation analyses without inspecting the implications. The sample problem demonstrated what could be great potential savings if regular time interval visits are not required.

Until a transportation model becomes available that will determine visit-frequency internally, visit-frequency allocation decisions must be made externally. Because current lockset algorithms do as well or better than manual routing schemes, it must be assumed that either apparent conceptual advantages of frequency allocation do not exist, or else managers have overlooked a large potential source of transportation cost saving. More investigation is needed.

Meanwhile, problems which include large individual firm demands and problems which require visit frequency calculations must be solved outside existing transporation models. However, certain backhaul, load-size/time trade-offs, and management control evaluations can be made by utilizing modifications to the lockset method.

FOOTNOTES

1. Where M > 1 the N retailers were externally assigned specific distribution centers.

2. Current studies at Michigan State University by R. Black and G. Schwab with a less intricate version of the branch and bound technique (for a 70 x 150 mixed integer L.P. with only 5-10 integer activities) are five times larger than without the mixed integer mode. The programming is Fortran on a CDC 6500 computer.

3. The discussion of lockset transportation cost functions is equally valid for assembly and distribution. Here the concern is with simultaneous minimization of distribution and backhaul-assembly costs, or assembly and backhaul-distribution costs.

4. Total computational and print costs ranged from nearly $12.00 per iteration for one warehouse system to $15.00 for two warehouse systems. The program was written in Fortran for a CDC 6500 computer. (Robbins)

5. Until a backhaul is included, the route is not directional. Once one is included, however, the route is obviously directional and must move in the direction that would put backhauls last on the route.

6. Validation can also be accomplished i) if the model can predict the future and ii) by insisting that the modeled relationships conform to theory. The farm supply logistics model was validated by forcing it to simulate history and by requiring that it conform to theory.

7. The cost relationships shown in Figure 3 are general and are presented for ease of conceptualization. The functions continuity and inflection point locations are not intended to reflect one specific situation, only general relationships.

8. The weekly frequency is simply assumed as a starting point for this discussion. Any other interval and its multiples would yield the same relative results.

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