A MODIFIED LOCKSET APPROACH FOR ENHANCING ROUTING EFFECTIVENESS

Lynn W. Robbins

In a recent attempt to emulate by simulation and then to improve upon a farm supply cooperative's distribution system, a lockset algorithm that included a backhaul routing capacity was constructed. The author describes the problem that motivated that modification, the modification itself, and a possible methodological improvement for applying routing models to firm-level distribution problems. 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 distribution routing analysis rather than accepting it as a given is discussed.

THE PROBLEM

The farm supply cooperative's distribution system centered around two warehouses where a variety of nonhomogeneous supplies were assembled, stored, reassembled, and distributed to approximately 100 retail outlets via 17 routes. Cooperative managers were considering a move to one centralized warehouse location. Seven proposed sites were to be evaluated. A routing model was required that could mimic as well as provide improvements for the existing system in order to generate comparative distribution costs for the current and proposed systems.

Conceptually, the problem is similar to the one presented by Hallberg and Kriebel [6, 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,...,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 capacities of the vehicles are 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 reproduce current and predict future total distribution costs to the N retailers plus backhaul assembly costs from the P suppliers. The evaluation requires establishing routes, route sequencing, and truck capacity tracing. Capacity tracing is necessary within the model to prevent trips for backhaul supplies until an empty truck is available.

Even without the backhaul complexities, the remaining classic traveling salesman problem as formulated by Hadley [5] would exhibit prohibitive computational costs. Routing algorithms are classified as combinatorial optimization models. They search a finite set of alternatives to optimize the objective 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...," [6, pp. 3-4]. 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 [4, p. 341].

Because of the computational costs, an attempt was made to formulate a mixed integer form of the farm supply problem. The new formulation was not satisfactory [7, 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 more than one-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 be many times greater than for a similar transhipment model with no integer variables, for example. Hence, the lockset modifications were devised.[2]

Lynn W. Robbins is Assistant Professor, University of Kentucky.

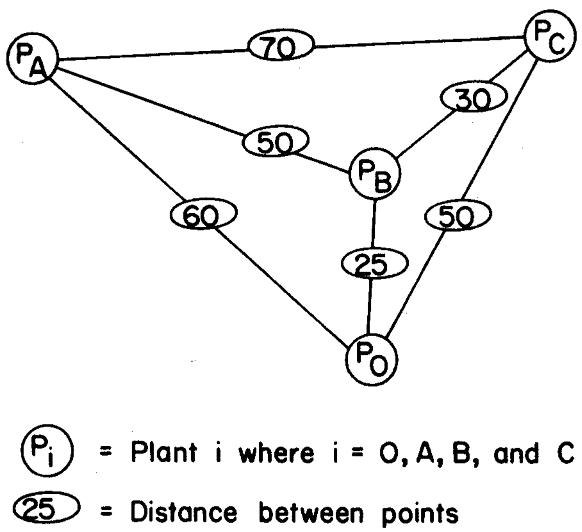
[1]Where M > 1 the N retailers were assigned externally to specific distribution centers.

[2]Professional computer programmers' cost estimates for the 6000 × 9000 mixed integer program exceeded $100 per run. 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 × 150 mixed integer LP 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.

Because combinatorial approaches are not efficient, heuristic alternatives have been developed. These heuristic approaches, labeled "lockset" by Schruben and Clifton [8], introduced by Dantzig and Ramser [3], modified by Clarke and Wright [2], and used by Hallberg and Kriebel [6] (among others) are alternative approaches for calculating assembly and distribution costs.[3] They route efficiently but, as originally defined, do not include a backhaul option.

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: (1) each stop must have at least one leg connected to the origin, (2) each stop must have been previously on a different route, (3) a carrier of sufficient size must be available to carry the combined load, (4) a carrier capable of traveling the required distance must be available" [8, 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. The final lockset solution is OACBO, a total route distance of 185 miles, assuming a carrier of sufficient capacity is available to supply the three points.

FIGURE 1. LOCATION OF POINTS FOR SAMPLE PROBLEM



Despite its efficiency advantages, the lockset process is deficient. In its current form, it cannot capture potentially significant backhaul cost savings. Modifications are required for the lockset technique to include only one backhaul at one end of each route. A backhaul point included in the unmodified lockset solver would be treated like any other delivery point.

THE MODIFIED LOCKSET TECHNIQUE

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

Modifications

The required fifth restriction is that any backhaul point be included only after all non-backhaul points have been considered, the backhaul points must have two legs connected to the origin, and backhauls must come at only one end of the route. With this change and manipulation of capacity restrictions (to be explained hereafter), the modifications force routes to include backhaul points properly as well as trace truck capacities without prohibitive computational time or cost [7, pp. 50-55].[4]

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

[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]For the 32 computer runs required to analyze the firm's present system plus the seven proposed systems (for current and future semiannual demands) the modified lockset technique saved a minimum of $2,720 (2 half years × 2 states of nature × 8 alternatives × $85, $100 or more per mixed integer program run less $15 per modified lockset run). This value would probably be enlarged many times if it were to reflect additional costs incurred in the debugging, calibration, and validation procedures.

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 also was not required as the cooperative's fleet had only single-doored trailers. A more elaborate backhaul capacity would have to be written into lockset routing models before they could be more generally applicable.

Two other problems commonly found in routing research were not addressed. The question of how to allocate delivery points among multiple warehouses was eliminated in the two warehouse alternative by applying the dealer assignments used by the cooperative. Also the demand size in relation to truck capacity was not addressed. The farm cooperative limited alternative evaluations to those that would include the current fleet.

Initially, the modified model assumes one route for each dealer as in the unmodified model. From this starting point, dollar saved coefficients, as suggested by Hallberg and Kriebel [6, 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 then is recorded so that this dealer later can 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, to 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 the 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 minimum cost routing, route structures can be manually 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 [8, p. 858; 6, 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 noncontrollable parameter once a particular size of carrier is assumed. Assigning various maximum capacities provides researcher control in simulating average capacity, which is controllable. Two firms using equal capacity tractor trailers could easily have different sized average loads because of different product densities, bulk, shape, or combinations. Therefore, lockset validation also requires an iterative search for the 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 restrictive management policies 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 [8, p. 855].

In the modified lockset procedure a form of Hallberg and Kriebel's [6, p. 6] dollar saved coefficients (MSCs) were used rather than the original lockset's distance saved coefficients (DSCs). MSCs 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. In such a case, $r * DSC \neq MSC$; instead $MSC = r * DSC + C$, where C is a constant added to account for 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.

Applications

The need to manipulate maximum capacity arose in the farm supply research. Initial application of the modified model with actual truck capacities provided routing configurations that would have reduced actual weekly transportation costs by as much as 30 percent. Average cubic capacity utilization of more than 80 percent was necessary to capture that

[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 also can be accomplished (1) if the model can predict the future and (2) by insisting that the modeled relationships conform to both routing and economic theory. The farm supply logistics model was validated by forcing it to simulate history and by requiring that it conform to theory.

savings. Apparently, cooperative dispatchers regularly underutilized their cubic truck capacity. Investigation of the motivation for 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 are incurred in the loading effort as larger and larger proportions of the total capacity are utilized (Figure 2).[7] In other words, as the LS/CC ratio increases, the loading time and therefore the loading cost (LC) increase 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 cost (DC). 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 were greater than the increase in DC. This was apparently the case in the cooperative's situation.

The farm supply firm's management was adding a route to a weekly distribution system despite an average carrier utilization of less than 50 percent in cubic measure. The transportation manager justified the added route in terms of loading times. If one assumes that managers tend to turn first attention to what currently seems to be their most troublesome areas, the cooperative's distribution situation possibly had proceeded to the right of point b in Figure 2 before the need for change was realized. Iterative capacity manipulation allowed for a perfunctory load size/loading time trade-off analysis within the modified model that tended to verify management's intuitive evaluation of the trade-off (see Table 2). Addi-

FIGURE 2. HYPOTHETICAL RELATIONSHIPS BETWEEN LOADING AND DELIVERY COST PER CARRIER TRIP AS THEY RELATE TO DEGREE OF TOTAL CUBIC CARRIER CAPACITY UTILIZATION

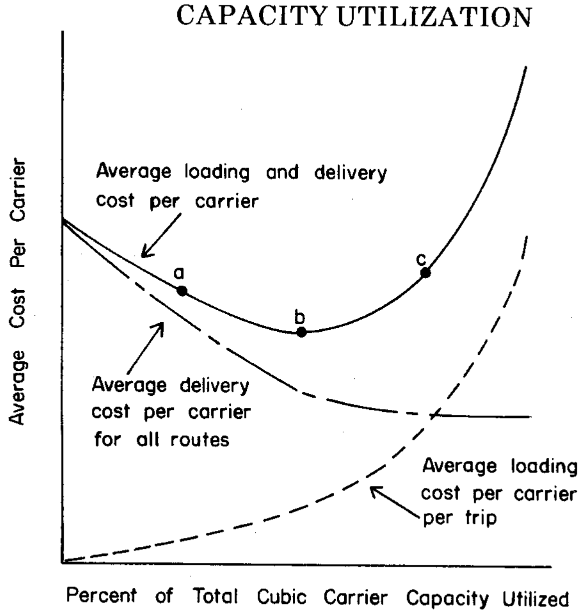


TABLE 2. WEEKLY DISTRIBUTIONAL COST CHANGES RESULTING FROM DIFFERENTIAL CAPACITY UTILIZATION

Average Truck Capacity Utilization	Truck Load Required For Distribution	Change in Loading Costs Compared To Actual Costs: Per Truck	Change in Loading Costs Compared To Actual Costs: Total	Change In Distribution Costs	Total Net Change In Costs
80%	13	+$80	+$1,040	-$894	+$146
65%	15	+ 25	+ 375	- 312	+ 63
50%	17	-------ACTUAL COSTS INCURRED---------			
35%	25	- 10	- 250	+567	+ 317

[7]The cost relationships shown in Figure 2 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.

tional firm-level research on this aspect of the problem could be very valuable to decision-makers.

More research is necessary to confirm productivity values associated with truck loading to achieve the varying average utilizations and to specify more closely the total minimum cost point. The effort reported in Table 2 is perfunctory because the main objective was to simulate rather than improve upon existing cost structures. Once sizable capacity utilization improvements had been dismissed as improbable, further analysis to gain precision was not necessary.

Analysis of the two-warehouse distribution system and the seven proposed alternative one-warehouse systems by means of the lockset model as modified provided two important insights. First, current and predicted distribution costs for each proposed one-warehouse location were neither substantially different from one another nor higher than those for the two-warehouse system. Despite prior beliefs to the contrary, distribution costs were not important to the firm's selection of a warehouse site. Relatively more importance could be transferred to other site selection variables.

Second, before lockset was implemented, distribution cost increases were expected to be proportional to the increase predicted for dollar demand. Dollar sales were expected to more than double in seven years but the lockset analysis found that variable distribution costs would increase by only one-third. Subsequent investigation revealed that although dollar volume was expected to double, the largest increases were expected from high dollar density items resulting in a substantially lower physical volume movement. The explanation that was so obvious *ex post* was not obvious *ex ante*.

Visit Frequency Potential

Implicitly, the lockset and modified lockset models, like most distribution routing models, assumes 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 in comparison with a solution that requires uniform regular delivery.

Frequency manipulation is at least a potential for savings through distribution routing. A sample lockset problem is presented in Figure 1 and 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 one every four or eight weeks, adding C to the weekly route would be suboptimal. In this particular example, up to two round trip deliveries to C would be less expensive than including C in the total route every week (Figure 3, Table 3). 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 costs.[8] Replacing less frequent round trips to C with occasional full route trips whenever possible, e.g. OABO three times a month and OACBO once a month, saves even more travel (Figure 3, Table 3).

An immediate solution to the visit frequency opportunity area is not apparent. For small problems or even large problems where only a small number of the dealers have 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 geographically the dealers with demands of similar size. The second would assign visit frequencies and the third would establish routes for each frequency. For example, if 20 dealers were to be visited once, 30 dealers twice, and 50 dealers four times a month, three routings would be required. One sequencing would be established for the two weeks when only 50 dealers were to be visited. Another sequencing would be required for the one or two weeks when 80 or more dealers were to be visited. The final routing would be for the one week when carriers visit 90 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.

The modified model also has the capacity to analyze the trade-off between load size and loading time. Average carrier capacity parameters are searched iteratively until the most efficient load size, in total systems' terms, is

[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.

discovered. The farm supply or modified lockset algorithm, by directly evaluating the load size/loading time trade-off, avoids the pitfalls of the usual assumption that more complete carrier capacity utilization is better.

Research into additional 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 be too restrictive in that round trips to reduce the demand to less than one carrier's capacity are forced into the solution.

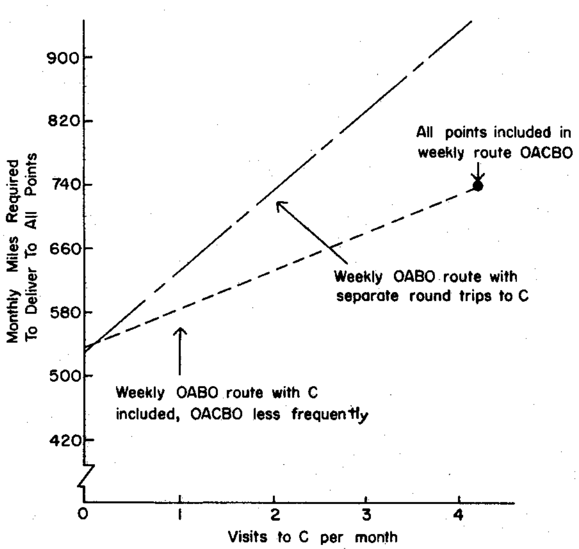
Similarly, the entire notion of visit frequency has been essentially ignored in the operations research literature. The assumption that all dealers will be visited on a regular interval basis is often injected into routing analyses without inspection of the implication. The **sample problem demonstrates large potential** savings if regular time interval visits are not required and assumed.

The central issue is not determining what aspect of the frequency question is most important to routing research, but to provide an awareness of visit frequency's savings potential. More researchers and decisionmakers are likely to explore the sufficiency of returns from frequency considerations if they are generally more aware of the possibility. The few algorithms that only implicitly include one aspect or another of visit frequency overlook an important contribution.

Until a routing model becomes readily available that will determine visit frequency internally, visit frequency allocation decision's must be made externally. Because current lockset algorithms that exclude frequency considerations do as well or better than manual routing schemes, one must assume either that apparent conceptual advantages of frequency allocation do not exist, or that managers have overlooked a large potential source of transportation cost saving. More investigation is needed. More awareness should motivate more investigation.

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

FIGURE 3. SAMPLE PROBLEM'S TRADE-OFF BETWEEN SEPARATE ROUND TRIPS, LESS FREQUENT VISITS, AND EQUAL VISIT FREQUENCY TO C IN MILES TRAVELED PER MONTH



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Routing Plan	Visit Frequency Per Month				Total travel per month (miles)
		Route stop sequence[a]			
	to C	OACBO[b] (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

[a]Route mileage given in parentheses.

[b]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.

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