EFFICIENT VEHICLE ROUTING

A MILK DISTRIBUTION EXAMPLE

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Information contained herein is available to all persons without regard to race, color, or national origin.

EFFICIENT VEHICLE ROUTING:
A Milk Distribution Example*

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INTRODUCTION

THE PROBLEM of transporting goods to market as efficiently and inexpensively as possible has been with man since he evolved from the subsistence type economy and became dependent upon others for food and fiber.

A large portion of the total marketing bill goes for transportation and is generated by vehicles that follow regular, established distribution or assembly routes. Increased efficiencies in this area of the total transportation process could very likely result in substantial cost savings. However, development of the most efficient and least cost routes for a fleet of vehicles serving a given network of stops is a very complicated, time-consuming task. In most cases, the availability of many alternative routing patterns makes it virtually impossible for a route manager to effectively evaluate all possibilities. Because of this, the probability of achieving the most economically efficient routing system is remote.

A major objective normally considered in attempts to organize a distribution or assembly system providing a given level of service to a specified set of customers is that of minimizing the total cost of the operation. This goal can be attained by having the minimum number of vehicles, traveling the shortest distance, in the least amount of time. Quantitative methods varying from

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simple hand calculations to sophisticated techniques requiring computer assistance are available to aid the route manager in developing an efficient routing network.

RESEARCH OBJECTIVE

The major objective of the study presented in this report was to illustrate how one of the more commonly used computerized routing and vehicle scheduling techniques, the "lockset method of sequential programming," could aid in improving the existing delivery system for a selected case study firm (3). The routing network chosen for analysis was that of a fluid milk processor in Alabama; however, the methodology used in the analysis could apply equally well for other types of routing systems such as the delivery of soft drinks, beer, and bread, or the operation of school buses or garbage trucks.

METHOD OF ANALYSIS

The "lockset method of sequential programming," first presented by Clark and Wright (1) and Schruben and Clifton (4) was used for the routing analysis in this study. This method does not guarantee an optimal routing pattern, but usually aids in developing systems that are better than those developed by other means. The computer program used for this analysis was written by Hallberg and Kriebel (2).

The basic objective of the "lockset method" is to minimize total delivery distance and/or time for distributing products from a single distribution center to several customers, each of which may require different quantities of the product. Results of a "lockset" analysis indicate the number of routes as well as the sequence of stops on each route. With minimization of transportation cost being the major objective of this study, emphasis was placed on distance data, with distance traveled serving as a surrogate measure of travel cost.

Various restrictions may be included in routing or vehicle scheduling analyses to fit actual delivery constraints and customer requirements. Availability and capacity of vehicles are the most prominent limitations. In addition, there could possibly be constraints on the distance and/or length of time that each vehicle can spend on a given route. From the customer viewpoint, there may be restrictions on the times of the day that delivery can be made or on the type and size vehicle that may be used to serve certain customers.

For this analysis, however, only three restrictions were included. These were: (1) limited availability of various size vehicles; (2) limited capacity of each vehicle; and (3) limited times of day that delivery can be made to certain customers. By limiting the capacity of each carrier, restricting the distance each could travel and the time each could spend on a route should be unnecessary. It was also assumed that customers could be serviced equally well by any of the vehicles.

A Hypothetical Routing Problem

The "lockset method" uses an iterative procedure to link customers on a route so that total travel distance might be minimized. If any two customers can be linked together on the route, then fewer trips to and from the distribution center would be necessary. For example, if customers X and Y are linked together on a single route instead of on individual routes, then a trip from customer X to the distribution center and a trip from the distribution center to customer Y could be eliminated. A trip between customer X and customer Y would need to be added to make the route complete.

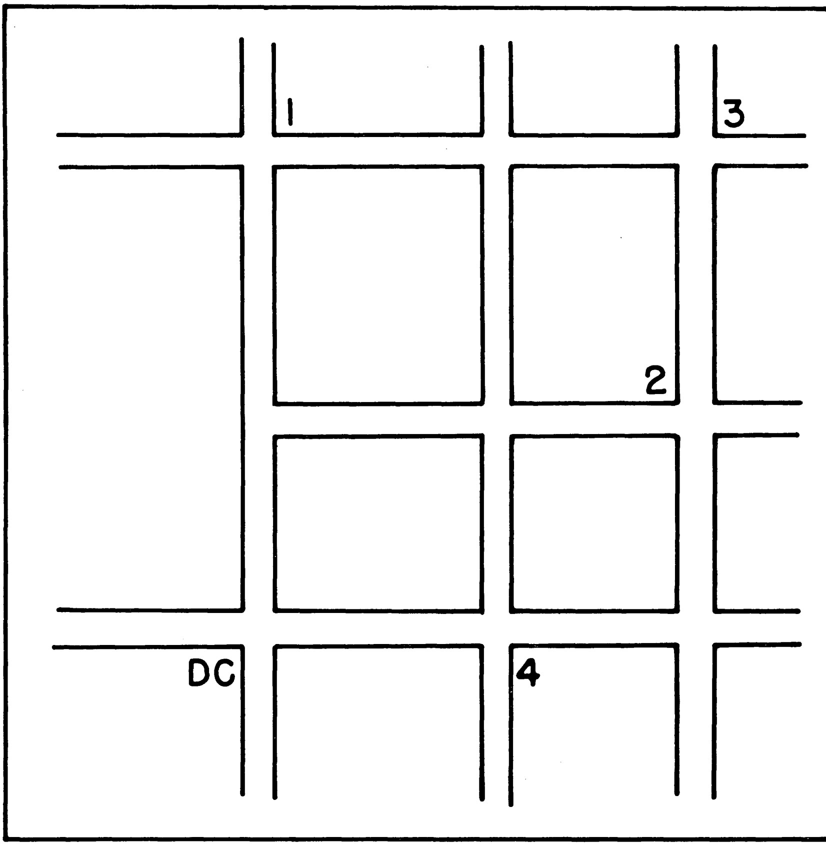
Three conditions must be met before customers can be linked on the same route using the "lockset method." These are: (1) both customer X and Y must still be linked to the origin; (2) customer X and Y were on separate routes prior to linking; and (3) all operational restrictions (number of vehicles available, vehicle capacity, etc.) that have been imposed on the problem are satisfied.

The following simplified problem will be used to illustrate the basic logic of the "lockset method." For this example, no vehicle, distance, or time restrictions are considered. The location of four customers and a single distribution center for the hypothetical problem are illustrated in the figure.

The first step is to establish a distance or cost matrix. Table 1

TABLE 1. DISTANCE BETWEEN CUSTOMERS AND THE DISTRIBUTION CENTER FOR HYPOTHETICAL ROUTING PROBLEM

From customer	To distribution center	To customer 1	2	3	4
Number	*Miles*	*Miles*			
1	20	0	24	17	27
2	25	24	0	9	15
3	37	17	9	0	24
4	13	27	15	24	0



An illustration of customers and distribution center locations for hypothetical problem.

illustrates distances between each of the four customers and between each customer and the distribution center. It was assumed initially that each customer was on a separate route, giving the highest cost solution for the routing network, total travel of 190 miles.

The second step is to calculate the distance saved coefficient (DSC) for each possible combination of two stops. The DSC is the distance to be saved if customers X and Y are served on the same route rather than on separate routes. The DSCs are calculated with the following formula:

$$DSC = D_{dx} + D_{yd} - D_{xy}$$

where:

D_{dx} represents the distance between the distribution center and customer X;

D_{yd} represents the distance between customer Y and the distribution center; and
D_{xy} represents the distance between customer X and Y.
The DSCs for each customer combination are given in table 2.

TABLE 2. DISTANCE SAVED COEFFICIENTS FOR THE HYPOTHETICAL ROUTING PROBLEM

Customer combination X	Customer combination Y	Distance from distribution center to customer X	Distance from distribution center to customer Y	Distance from customer X to customer Y	Distance saved coefficient
No.	*No.*	*Miles*	*Miles*	*Miles*	*Miles*
1	2	20	25	24	21
1	3	20	37	17	40
1	4	20	13	27	6
2	3	25	37	9	53
2	4	25	13	15	23
3	4	37	13	24	26

After DSCs for all pairs of customers have been computed, route development can begin. At each iteration, customers are added to a route based on the value of their DSC. Customer combinations with the greatest values are added first if they meet the three necessary conditions stated earlier, i.e., each still linked to origin, each on separate routes, and no other constraints violated.

In the hypothetical problem, the customer combination with the highest DSC was the combination formed by stops 2 and 3. By linking these customers onto the same route, a savings of 53 miles was obtained. The new route is DC-2-3-DC. The customer combination which resulted in the next highest DSC was to combine customers 1 and 3. Since customer 3 was still connected to the distribution center, it was possible to combine customers 3 and 1 into the present route. A savings of 40 miles was obtained. The route is now DC-1-3-2-DC.

The next largest DSC was 26, from customer combination 3 and 4. Since customer 3 had already been linked with customers 1 and 2, linking customer 4 in the route with customer 3 would be in violation of one of the conditions imposed by the "lockset method". Customer 3 is no longer connected to the origin, therefore, acceptance of this combination into the route would result in an increase in distance traveled. This combination was omitted.

Customer combination of 2 and 4 had the next highest DSC. Since necessary conditions were met, it was possible to include this combination of customers into the route generating a savings of 23 miles. The final route sequence is DC-1-3-2-4-DC or reverse, assuming that travel could be made in either direction. By using the "lockset method," a savings of 116 miles was obtained. Total delivery distance was reduced from 190 miles with each customer on a separate route to 74 miles with a single route serving all customers.

Actual routes are far more complicated than the simple example just presented; however, the "lockset method" is just as effective in joining several stops so that the greatest savings can be realized.

DATA ASSIMILATION

The data used in this study were taken from the existing customer network of an Alabama fluid milk processing firm. The market area covered by the example firm includes eight Alabama counties, one major city, and several small towns and communities. An excess of 600 wholesale customers, which include grocery and convenience stores, restaurants, schools, churches, hospitals, service stations, and other businesses are served. The customers are served by 18 delivery routes with each receiving milk anywhere from one to five times per week. Data for each customer giving name and address, number of cases delivered, length of serving time, any special service requirements, and days that delivery is made were obtained from the firm. Other information necessary for the analysis included: (1) the distance between any two customers and between the distribution center and every customer; (2) the types of vehicles used and their capacity; and (3) vehicle operating cost and labor cost.

Distance Data

Data giving the distances between each stop and between each stop and the distribution center are necessary if routes are to be organized so that travel and transportation cost are minimized. Assimilation of this information is the most time-consuming and difficult part of a routing analysis. For this study, basic distance data for the existing routes were obtained by a rider who accompanied the driver on daily deliveries. Additional necessary distances were derived by pin-pointing each stop on a map and measuring the distance from each stop to each adjoining stop and to the distribution center. If necessary, all distances could be obtained by measuring travel on a map. These data, along with the basic distance data obtained from the existing routes, served as input for a computer program which facilitiated calculation of distances connecting all stops. Computer assistance was necessary because of the number of distances that were considered. For example on Monday, 313 stops were served in the city area requiring calculation of nearly 49,000 distances ($313^2/2$).

Vehicle Data

Basic information concerning vehicles used in the wholesale routes was obtained by a questionnaire, which was divided into three different sections: general vehicle information, both fixed and variable operating cost, and labor cost.

Trucks were grouped into eight different categories based on their carrying capacity, which ranged from 224 to 468 cases. Nineteen trucks were used for serving the routes, with 13 of these having a carrying capacity of 288 cases or less. Standby trucks, which could be used if needed, were also available.

Variation in the number of items transported, kinds of products, and types and sizes of containers existed for the various routes. For example, milk products were delivered in gallon, half-gallon, quart, pint, and half-pint containers. Thus, a standard unit of measure was required. For this reason, the capacity of all trucks was measured with a standard load unit in terms of cases.

Cost Data

Information on costs of operating vehicles was necessary to permit a comparison between present routes and those designed by the "lockset method." Depreciation of vehicles and associated buildings, insurance, relevant taxes, interest, pro-rata management, and administrative expenses were all required to estimate fixed cost. Variable expenses included cost of tires; fuel; oil; fuel, air and oil filters; lubrication; washing; tuneups; and other minor operating expenses.

Fixed Costs

Total fixed cost was calculated by use of the following formula [5]:

$$FC = D + I + R + T + E + A$$

where:

FC = annual fixed cost,
D = depreciation per year,
I = insurance per year,
R = interest per year,
T = taxes per year,
E = management expenses per year,
A = administrative expenses per year.

The representative truck had a purchase price of $14,238 (a chassis cost of $7,928 and 16-foot body which was built at the fluid milk processor's shop costing $6,310). A salvage value of 10 percent of purchase price and useful life of 4 years were assumed. Using straight line depreciation, annual depreciation on each truck was $3,203.55.

Truck insurance rates (liability, collision, fire, theft, and uninsured motorist) were obtained from the fluid milk processor's insurance company. These total charges averaged $527.00 a year on each truck.

Interest on investment was included to show the opportunity cost of money invested in trucks. Interest charges were based on 9 percent of the midlife value of the representative truck and calculated to be $704.78.

Taxes, which included license fees, tags, etc., were obtained from truck records and totaled $84.32 for the representative truck.

The cost of management and office salaries and administrative expenses were assumed to be 12 percent and 8 percent respectively of total fixed cost. These figures were based on a report by the Economic Research Service of the U.S. Department of Agriculture concerned with the cost of transporting milk in three different regions of the United States (5). Cost of management and office salaries for the representative truck were $636.30 while administrative expenses which included supplies, legal fees, utilities, etc., were $424.20.

With these values, the actual calculation of fixed cost per truck was as follows:

$$FC = \$3{,}203.55 + 527.00 + 705.78 + 84.32 + 636.30 + 424.20$$
$$= \$5{,}580.15 \text{ per year.}$$

With the existing delivery network, each truck averaged 19,753 miles of use per year giving fixed cost per mile, (FC_m) of $.282.

Variable Cost

Variable cost per mile was calculated by use of the following formula:

$$VC_m = P + W + M$$

where:

P = fuel cost per mile,
W = tire cost per mile, and
M = maintenance cost per mile.

One month's fuel record was used to estimate the mileage and fuel consumption for a typical vehicle. With an average of 4.45 miles per gallon of diesel fuel, and a cost of $.509 per gallon, fuel costs $.114 per mile.

Information needed for deriving tire cost was the number of tires per truck, expected mileage from each tire and cost of each tire. The firm's records indicated that a cost of $.003 per tire per mile could be expected, giving a per mile tire cost of $.018 per truck since each had six tires.

Maintenance expense included oil changes, filters, washing, tune-ups, etc., with the work being done at the fluid milk processor's shop. It was estimated that the cost per mile for these items was $.058.

Total variable cost per mile was calculated as follows:

$$VC_m = .114 + .018 + .058 = \$.19$$

Total Vehicle Cost

Total cost per mile is simply total fixed per mile cost plus total variable cost per mile (5):

$$TC_m = FC_m + VC_m$$
$$= .282 + .190$$
$$= \$.472 \text{ total cost per mile.}$$

Labor Cost

Labor cost included the driver's salary received for his weekly services plus social security, unemployment compensation, insurance, etc. The driver's salary was not included in variable cost since a portion of the payment was on a commission basis and not directly related to hours worked or miles traveled. Cost of labor was therefore assumed to be separate from either fixed or variable vehicle cost. An average driver's salary plus benefits for a week was $270.25. Of this amount, $150 was assumed to be the weekly base pay for each driver, while the remainder of the salary was from a commission on sales plus benefits received. Any labor savings realized from a reduced number of drivers would be at the $150 weekly rate since the commission would probably be paid to another driver.

ROUTE REORGANIZATION

The delivery system currently used by the firm under study was developed on the premise of a weekly route network with trucks following basically the same route each day. The number of stops on a route is different each day, however, since all customers do not require daily service. Schools required the most service, with nearly all receiving five deliveries per week.

Two rerouting alternatives were considered in using the "lockset method" to develop a more efficient delivery network for the firm. First, the assumption of weekly routes, with each truck following the same basic route each day was maintained. With this system, each customer would always be served by the same driver. This assumption was violated somewhat, however, on Tuesdays and Thursdays since the limited number of customers, mostly schools, made it reasonable to combine some routes.

The second alternative was to treat each service day independently. With this assumption, the routes run on one day would have no influence on those run on other days. Also, customers might be served by several different drivers during the week. Under both rerouting alternatives, it was assumed that all customers would continue to receive their current level of service, having deliveries on the same days and within any specified delivery time constraints.

The delivery system operated by the firm served 1,888 customers per week and required over 6,800 miles of travel, table 3. An excess of 735 hours was required to serve the customers each week, with the average route being a little more than 8 hours long.

Variable cost for a week's operation was $1,299.15 which covers the cost of fuel, tires and maintenance for the delivery fleet. Daily labor cost was obtained by dividing the average driver's weekly salary, $270.25, by six, representing the number of service days per week and multiplying that by the number of routes on each day. Total weekly labor cost for the existing operation was $4,053.60.

Annual fixed cost associated with each vehicle was presented earlier to be $5,580. Total annual fixed cost for the delivery fleet based on 18 operational vehicles and two spares would thus be $111,600. When combined with the variable operating and labor costs, $278,343, the total annual cost of operating the existing delivery network if $389,943.

Table 4 presents information on the improved routes that were derived using the "lockset method" with routes developed on a weekly schedule. With the assumption of weekly routes, each truck follows basically the same pattern each day with some variation in the number of customers served. Customers are always served by the same driver. Because of the small number of customers on Tuesday and Thursday, some routes were combined.

With the improved routing network, it was estimated that all customers could be served by 84 daily routes in a little more than 532 hours per week, giving an average time per route of 6.3 hours and average length of 60.2 miles. Variable cost per week for operating the fleet was projected to be $961.54 with a labor cost of $3,783.55.

When routes were reorganized with each day treated independently and having no influence on the routes of other days, total time required for delivery was estimated to be 520 hours, table 5. The average time per route was 7 hours and average length of 60.7 miles. Variable cost for this delivery system was estimated to be $852.29 and labor expense is $3,333.09 per week.

A comparison of the characteristics of the existing delivery network with the two improved systems is presented in table 6. It is obvious from the data that substantial savings in travel, travel time, and cost are possible through route reorganization. When the constraint of a weekly routing pattern was imposed with each customer being served by the same driver, total delivery time per

TABLE 3. — ROUTES FOR EXISTING WHOLESALE DELIVERY SYSTEM FOR EXAMPLE CASE STUDY FIRM

	Number of routes	Total miles	Average miles/ route	Total customers	Average customers/ route	Total time	Average time/ route	Variable cost	Labor cost
	Number	*Miles*	*Miles*	*Number*	*Number*	*Hours*	*Hours*	*Dollars*	*Dollars*
Monday	18	1,631	90.6	549	30.5	181.0	10.1	309.83	810.72
Tuesday	11	477	43.4	46	4.2	43.4	3.9	90.69	495.44
Wednesday	18	1,469	81.6	488	27.1	178.5	9.9	279.17	810.72
Thursday	11	477	43.4	46	4.2	43.4	3.9	90.69	495.44
Friday..........	18	1,604	89.1	525	29.2	184.7	10.3	304.68	810.72
Saturday.......	14	1,179	84.0	234	16.7	104.7	7.5	224.09	630.56
Total/ average......	90	6,837	76.0	1,888	20.9	735.7	8.2	1,299.15	4,053.60

TABLE 4. — IMPROVED ROUTES USING "LOCKSET METHOD" WITH ROUTES ON A WEEKLY BASIS

	Number of routes	Total miles	Average miles/ route	Total customers	Average customers/ route	Total time	Average time/ route	Variable cost	Labor cost
	Number	*Miles*	*Miles*	*Number*	*Number*	*Hours*	*Hours*	*Dollars*	*Dollars*
Monday	18	1,140	63.3	549	30.5	136.1	7.6	216.62	810.76
Tuesday	6	294	49.0	46	7.7	24.2	4.0	55.88	270.25
Wednesday	18	1,189	66.1	488	27.1	132.4	7.4	225.89	810.76
Thursday	6	294	49.0	46	7.7	24.4	4.0	55.88	270.25
Friday..........	18	1,185	65.8	525	29.2	135.9	7.6	225.18	810.76
Saturday.......	18	958	53.2	234	13.0	79.6	4.4	182.09	810.76
Total/ average......	84	5,060	60.2	1,888	22.5	532.4	6.3	961.54	3,783.55

TABLE 5. — IMPROVED ROUTES DEVELOPED USING "LOCKSET METHOD" WITH EACH DAY TREATED INDEPENDENTLY

	Number of routes	Total miles	Average miles/ route	Total customers	Average customers/ route	Total time	Average time/ route	Variable cost	Labor cost
	Number	*Miles*	*Miles*	*Number*	*Number*	*Hours*	*Hours*	*Dollars*	*Dollars*
Monday	17	1,082	63.6	549	32.3	133.8	7.9	205.64	765.71
Tuesday	6	292	48.7	46	7.7	24.1	4.0	55.52	270.25
Wednesday	17	1,043	61.3	488	28.7	129.2	7.6	198.11	765.71
Thursday	6	292	48.7	46	7.7	24.1	4.0	55.52	270.25
Friday.........	17	1,078	63.4	525	30.9	132.8	7.8	204.91	765.71
Saturday.......	11	708	64.4	234	21.3	75.9	6.9	134.59	495.46
Total/ average......	74	4,495	60.7	1,888	25.5	519.9	7.0	852.29	3,333.09

TABLE 6. — COMPARISON OF EXISTING DELIVERY ROUTES WITH IMPROVED SYSTEMS DEVELOPED USING "LOCKSET METHOD" FOR WEEK'S OPERATION

	Existing system	Improved weekly routes	Improved daily routes
Number of routes/week.....	90	84	74
Total miles/week...........	6,837	5,060	4,495
Average miles/route	76.0	60.2	60.7
Total time/week (hours)	735.7	532.4	519.9
Average time/route (hours)..	8.2	6.3	7.0
Annual variable cost (dollars)	67,555.80	50,000.08	44,319.08
Annual labor cost (dollars) ..	210,787.20	196,744.60	173,320.68
Annual fixed cost (dollars)...	111,600.00	111,600.00	106,020.00
Total annual cost (dollars)...	389,943.00	358,344.68	323,659.75

week was reduced by 203.3 hours, a 28 percent savings. Costs associated with delivery were also reduced significantly, $31,598.32 per year, an 8 percent decrease. The number of trips required to serve all customers each week was reduced from 90 to 84 and total weekly travel was decreased 26 percent to a little more than 5,000 miles.

Route development with each day considered independently made an even more efficient delivery network possible. The total number of trips was reduced to 74 and total travel to 4,495 miles, a 34 percent reduction from the existing level. Average miles per route was 20 percent less than the current system and slightly more than that projected for the improved weekly network.

Variable and labor costs associated with the system were 22 percent less than those currently being realized; generated through annual savings of $23,236.72 in variable cost and $37,466.52 in labor cost, an annual cost reduction of over $60,000. In addition, since the number of routes was reduced significantly, one less truck would be required, giving an annual savings of $5,580.

A comparison of the total annual costs of operating the existing delivery system and the two proposed improved networks indicates the savings that can be realized through more efficient vehicle scheduling and routing. The possibility for substantial savings by developing routes on an individual daily basis can also be seen. Total annual cost was reduced by 8 percent when the weekly route condition was imposed and by 17 percent when each day was considered independently.

SUMMARY

Rising prices for petroleum products and similar increases in wages and benefits for labor have put upward pressure on the costs of transportation. Because of these increased expenses, more emphasis is being placed on the transportation phase of the marketing process and that vehicles and personnel be used as efficiently and effectively as possible.

Some route and sales managers have reacted to increased transportation costs by eliminating low volume customers or by reducing the amount and type of service given. These changes in service could be a fewer number of deliveries per week or having the route man leave the product at dockside rather than placing it in the sales cases.

A more positive approach to treating the problem of increased transportation costs is to carefully examine the actual routes vehicles are traveling and the sequence of stops on the routes. The research results presented in this report represent such an effort and illustrate the possibility of substantial savings through route reorganization with all customers still being served and with the same type of service. Variable and labor costs for the example operation used in this analysis could be reduced as much as 22 percent, giving an annual savings of over $60,000. Cost reductions of this magnitude are significant and indicate that conscientious route managers should consider route reorganization as a means for reducing costs or possibly increasing service and customers for little additional cost.

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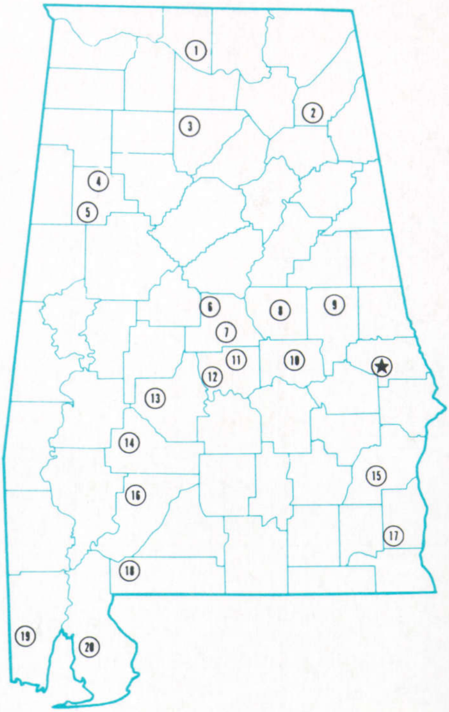
Alabama's Agricultural Experiment Station System
AUBURN UNIVERSITY

With an agricultural research unit in every major soil area, Auburn University serves the needs of field crop, livestock, forestry, and horticultural producers in each region in Alabama. Every citizen of the State has a stake in this research program, since any advantage from new and more economical ways of producing and handling farm products directly benefits the consuming public.



Research Unit Identification

★ Main Agricultural Experiment Station, Auburn.

1. Tennessee Valley Substation, Belle Mina.
2. Sand Mountain Substation, Crossville.
3. North Alabama Horticulture Substation, Cullman.
4. Upper Coastal Plain Substation, Winfield.
5. Forestry Unit, Fayette County.
6. Thorsby Foundation Seed Stocks Farm, Thorsby.
7. Chilton Area Horticulture Substation, Clanton.
8. Forestry Unit, Coosa County.
9. Piedmont Substation, Camp Hill.
10. Plant Breeding Unit, Tallassee.
11. Forestry Unit, Autauga County.
12. Prattville Experiment Field, Prattville.
13. Black Belt Substation, Marion Junction.
14. Lower Coastal Plain Substation, Camden.
15. Forestry Unit, Barbour County.
16. Monroeville Experiment Field, Monroeville.
17. Wiregrass Substation, Headland.
18. Brewton Experiment Field, Brewton.
19. Ornamental Horticulture Field Station, Spring Hill.
20. Gulf Coast Substation, Fairhope.