# OPTIMUM LOCATIONS FOR A RURAL FIRE SYSTEM: A STUDY OF MAJOR COUNTY, OKLAHOMA*

Gerald A. Doeksen and Robert L. Oehrtman

Extremely dry conditions in the Great Plains during Spring and Summer of 1976 have greatly increased the awareness of rural residents and decision-makers of the need for increasing rural fire protection. In addition, increasing investments in farm machinery, buildings, crops and livestock, and urban sprawl have increased the need for improved rural fire protection. Oklahoma farmers have six billion dollars invested in farm property and annually produce crops and livestock worth about 1.9 billion dollars. More than one-third of the state's population lives in rural areas. These large agricultural investments, movements of urban people to small acreages and extremely dry conditions have induced rural residents to pressure county and community officials to improve fire protection. The usual procedure is to approach county commissioners and ask them for funds. Commissioners are acutely aware of the problem, but have several crucial needs competing for limited funds. If they decide to invest in fire equipment such as providing rural truck(s) for an existing department(s) to operate, the problem of optimum placement becomes very important.

## OBJECTIVE

The overall objective of this paper is to illustrate the importance of decisions regarding location of emergency rural fire service facilities. More specifically, the objectives are:

1. To illustrate a model which can be used to derive optimum location
2. To apply the model and specify locations of one, two or three rural trucks given various objective functions
3. To illustrate two quality aspects of truck locations by specifying maximum distance to most distance fire and average distance to a fire and
4. To derive annual operating and capital costs for each alternative.

To the authors' knowledge, little research has been completed regarding optimum location of fire services in rural areas. Conditions in rural areas and equipment needs make this a unique problem which should be analyzed differently from urban problems.[1] Decision-makers need to know the optimum location given their objective function, quality of fire service for each alternative and costs of each alternative.

## THEORETICAL MODEL

To derive optimum locations for placement of rural fire equipment under alternative objectives, the general transportation model was used. It should be pointed out that the model can be used for location problems regarding all emergency services, not just rural fire facilities. The specific method used is the transportation procedure model.[2] This represents a

Gerald A. Doeksen is Economist with Economic Development Division, ERS, Oklahoma State University. Robert L. Oehrtman is Assistant Professor of Agricultural Economics, Oklahoma State University.

*Oklahoma State Agricultural Experiment Station Journal Article No. J-3169. Comments of Tom Hady, Stan Daberkow, Joe Schmidt, Dean Schreiner, Evan Drummond and Jim Nelson were very helpful.

[1] A summary of methods used for allocating urban emergency units is presented in [1].

[2] For a more complete discussion of the model see [3]. For extremely large problems which have, for example, 1,000 demand locations, other solution techniques such as nonlinear programming may be more efficient in terms of computer time.

special class of linear programming problems, and the computing routine to solve the problem is efficient. Given (1) a service capacity for various locations of fire facilities, (2) demand for these services at each consuming center and (3) associated costs stated in any terms such as miles, dollar cost or response time in minutes, this procedure can be used to determine both service capacity and its optimum placement to serve each consuming center.

**The General Transportation Model**

The objective of the general transportation model is to minimize a linear objective function with respect to specific linear constraints. In the model,

m = number of locations of fires facilities
n = number of locations of fire facility users
$a_i$ = fire service capacity at the $i^{th}$ fire service facility
$b_j$ = amount of fire services demanded by the $j^{th}$ location of fire service users
$X_{ij}$ = amount of fire services supplied by the facility at location i to fire service users at location j that minimizes, for example, total transportation costs, and
$C_{ij}X_{ij}$ = cost of supplying $X_{ij}$ units of services from any facility location i to any user location j.

Mathematical relationships of the transportation problem can be drawn from the tableau and may be stated as follows:

Minimize

$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} \qquad (1)$$

Subject to the constraints

$$\sum_{j=1}^{n} X_{ij} = a_i \qquad i=1,2,\ldots,m \qquad (2)$$

$$\sum_{i=1}^{m} X_{ij} = b_j \qquad j=1,2,\ldots,n \qquad (3)$$

$$X_{ij} \geq 0 \qquad (4)$$

$$\sum_{i}^{m} a_i = \sum_{j}^{n} b_j \qquad (5)$$

As stated before, problems other than those of transportation can be handled by the transportation method, but they must, as do transportation problems, satisfy certain assumptions. These are:

1. Services being provided by each of the various facility location origins are homogeneous. In other words, availability of services at each origin will equally satisfy the demands in any service user location (equation 2).
2. Service capacities at various origins and demands of various locations of service users are known and total demand must equal total capacity (equation 5). When discrepancies occur between service capacity and user demand, a dummy service capacity or user demand vector is used to produce equality. This dummy vector is used to signify unused capacities or unsatisfied demands.
3. Costs of providing services by any one origin to other locations of service users are known and are independent of the amount of services provided. That is, a constant per unit cost of service rate regardless of the amount of service provided between locations is assumed.
4. There is an objective function to be maximized or minimized (equation 1).
5. The activities cannot be executed at negative levels (equation 4).

## EMPIRICAL APPLICATION

County commissioners in Major County, Oklahoma requested assistance in their decision as to optimum location of rural fire truck(s). The economy of this Northwest Oklahoma County is mainly agricultural and petroleum-based. Fairview, the county seat, is located in about the center of the county (Figure 1) and had a population of 2,894 in 1970. The other communities are extremely small, Cleo Springs being the next largest with 344 inhabitants in 1970.

## ASSUMPTIONS AND OBJECTIVE FUNCTIONS

The assumption was made that there exist six possible communities with existing fire fighting facilities in which to locate a rural fire truck. These included Bouse Junction, Orion, Cleo Springs, Ringwood, Fairview and Ames. Another assumption was that the same quality of on-site fire service could be provided from each supply point. Since all present departments are volunteer, this assumption appeared reasonable.

Thirty demand areas were delineated with township lines serving as boundaries (Figure 1). Mileage

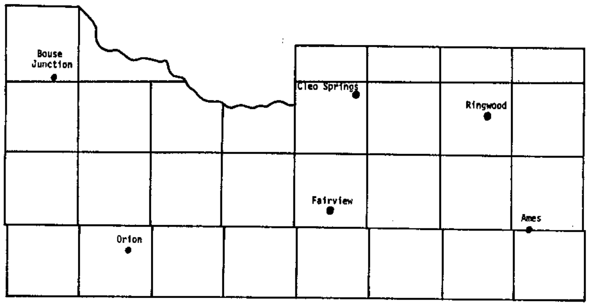


FIGURE 1. SUPPLY POINTS AND DEMAND AREAS, MAJOR COUNTY, OKLAHOMA

data were calculated from the centers of the 30 demand areas to the six possible community locations. Three alternative objective functions were evaluated. These included:

I. Minimum response time to reach a fire
II. Minimum total mileage for fighting (a) rural fires only[3] or (b) all county fires (rural and urban)[4] and
III. Maximum protection per dollar's worth of burnable property (a) in rural areas or (b) the complete county.

Using the six possible communities in which to locate a rural fire truck, transportation solutions for optimum locations were derived for each objective function determining the placement of first one fire truck, then two and finally as many as three trucks in the county. These locations were derived from the complete enumeration of transportation model objective functions.

Specifically, the solution for the first objective function required that all possible combinations of problems be computed for one, two and three fire trucks, respectively. These combinations for the first objective are: $\binom{6}{1}=6$, $\binom{6}{2}=15$, and $\binom{6}{3}=20$, or a total of 41 combinations. Solutions for objective functions 2—a, 2—b, 3—a and 3—b, each required the same number of combinations of problems to be computed. Complete enumeration yielded 205 transportation problems. From this enumeration, first, second and third choices of locations were selected for each objective function. After each alternative location, quality of service variables and costs were derived.

Data needed to estimate the number of fires for each demand area in Major County and for estimating capital and operating costs were obtained from a detailed analysis of 10 counties in Northwestern Oklahoma [2]. Data on all fires occurring in 1974 were collected from the 42 departments in the study area. From the data, fire frequency coefficients were derived. For example, it was found that one grass fire occurred for every 13,155 acres. In addition to the grass fire coefficient, fire frequency coefficients were derived for vehicles, businesses, mobile homes and housing units. Based on these coefficients and existing conditions in Major County (number of houses, vehicles, buildings, acres of grassland, etc.), an annual estimate of number of fires in each demand area was made.

Cost data were obtained from (1) records of fire chiefs in the study area and (2) fire equipment dealers. From the records of fire chiefs, operating expenses such as vehicle miles per gallon of gasoline were obtained. From fire equipment dealers, costs of capital items were obtained. Assumptions necessary for calculation of costs were based on existing conditions in Major County. The assumptions were (1) the trucks considered for each location are specially-designed rural fire trucks costing $11,450[5]; (2) they have an average life of 15 years; (3) each community has a place to store the truck; (4) each community has some sort of communication system; (5) the system will be operated by volunteers who are paid $3 per fire attended and $2 per meeting attended; (6) an average of three firemen attend each fire; (7) fire suits purchased for 12 firemen cost $100 each and have an average life of 10 years; (8) a loan is obtained from FmHA to finance capital expenses; (9) operating expenses are based on number of miles a vehicle is expected to travel and number of fires attended and (10) fire trucks will travel on the average 60 miles per hour.[6] With these assumptions, the transportation model was run for each objective and results analyzed.

The probability that there will be fires in more than one location at the same time was considered. From data obtained from all 42 departments in a 10-county area in Northwest Oklahoma, it was found that the mean time a fire truck was away from the fire station to fight all fires (rural and community) was 58 minutes. The mean had a standard deviation of 60 minutes. Thus, 95 percent of the time, the fire truck will return to the station with three hours. The

[3] In many cases, communities have their own fire truck which is adopted for fighting community fires. If so, the rural truck would fight only fires outside the community.

[4] Rural is defined for this study as fires outside city limits of the communities in this study.

[5] For exact specifications of truck, see [2].

[6] Sixty miles per hour may be a little high, but it was chosen for convenience in presenting the results. If a slower speed is more appropriate, each response time will be lengthened accordingly.

probability that a total of two or more fire calls will be received during any one-hour period is .014. The probability that a total of two or more fire calls will be received during any three-hour period is .068. Thus, if one fire truck is used to fight all fires in Major County, one would expect that on two occasions during the year, two or more fire calls may occur during a one-hour interval, and on eight occasions, two or more such calls may occur during a three-hour interval. If the fire truck fights only rural fires, it can be expected from our data that, once during a year, two or more fires would occur during a one-hour interval. Five times during a year, two or more fires would be reported within a three-hour interval. With two fire trucks located in the county, the probability of a fire occurring while both trucks are away from the fire station is very low. From our data, the probability that three or more fire calls would be received is .003 and .024 in any one-hour and three-hour period, respectively. Since the probabilities are low for two or more fires at the same time, and since several existing communities within the county and in surrounding counties have trucks available and cooperate if any emergency arises, it was felt a stochastic model was not needed.

## RESULTS

Optimum locations, given the various objective functions, are presented in Table 1. For each objective function and each number of trucks, the first three choices are presented. Two quality of service variables are represented by maximum distance and average distance a truck has to travel to get to a fire (Table 2). Objective I places quality of service emphasis on a minimum of maximum response time. Thus, a demand area with few fires is given the same consideration as a demand area with a large number of fires. Objective II places quality of service emphasis on minimum total mileage, thus providing more emphasis to demand areas with a large number of fires. Objective III provides maximum quality of service emphasis to demand areas with high value of burnable property. Given these objective functions, the decision-maker will have to judge which is most appropriate and act accordingly. Annual capital and operating costs of each alternative are presented in Table 3.

### Objective I—Minimize Response Time

This objective required selection of location(s)

**TABLE 1. OPTIMUM LOCATIONS FOR VARIOUS NUMBER OF TRUCKS FOR EACH OBJECTIVE FUNCTION**

| Objective Function | Choices | | |
|---|---|---|---|
| | First | Second | Third |
| I. Minimize response to get to a fire for location of: | | | |
| a. one truck | Fairview | Cleo Springs | Orion |
| b. two trucks | Ringwood, Orion | Fairview, Orion | Fairview, Bouse Junction |
| c. three trucks | Ringwood, Fairview, Bouse Junction | Fairview, Ringwood, Orion | Cleo Springs, Ames, Orion |
| II. Minimize total miles | | | |
| a. to fight all fires for location of: | | | |
| 1. one truck | Fairview | Cleo Springs | Ringwood |
| 2. two trucks | Fairview, Ringwood | Ames, Fairview | Fairview, Orion |
| 3. three trucks | Fairview, Ringwood, Orion | Ringwood, Fairview, Bouse Junction | Ames, Fairview, Orion |
| b. to fight rural fires for location of: | | | |
| 1. one truck | Fairview | Cleo Springs | Ringwood |
| 2. two trucks | Ringwood, Orion | Ames, Orion | Fairview, Orion |
| 3. three trucks | Ringwood, Orion, Fairview | Ames, Orion, Fairview | Ringwood, Fairview, Bouse Junction |
| III. Maximum protection | | | |
| a. per dollar's worth of burnable total property | | | |
| 1. one truck | Fairview | Ringwood | Ames |
| 2. two trucks | Fairview, Ringwood | Fairview, Ames | Fairview, Cleo Springs |
| 3. three trucks | Fairview, Ringwood, Orion | Fairview, Ames, Ringwood | Ringwood, Fairview, Bouse Junction |
| b. per dollar's worth of burnable rural property | | | |
| 1. one truck | Ames | Ringwood | Fairview |
| 2. two trucks | Ringwood, Orion | Fairview, Ringwood | Fairview, Ames |
| 3. three trucks | Fairview, Ringwood, Orion | Fairview, Orion, Ames | Cleo Springs, Ames, Orion |

## TABLE 2. RESPONSE TIME IN MILES FOR VARIOUS NUMBER OF TRUCKS FOR EACH OBJECTIVE FUNCTION

| Objective Function | Choices | | | | | |
|---|---|---|---|---|---|---|
| | First | | Second | | Third | |
| | Maximum Distance | Average Distance | Maximum Distance | Average Distance | Maximum Distance | Average Distance |
| I. Minimize response time to get to | | | | | | |
| a. all fires for location of | | | | | | |
| 1. one truck | 34 | 12.2 | 37 | 15.8 | 44 | 23.2 |
| 2. two trucks | 24 | 13.6 | 26 | 9.8 | 26 | 9.9 |
| 3. three trucks | 20 | 6.7 | 24 | 6.5 | 24 | 8.9 |
| b. rural fires for location of | | | | | | |
| 1. one truck | 34 | 17.0 | 37 | 19.6 | 44 | 23.6 |
| 2. two trucks | 24 | 11.7 | 26 | 13.0 | 26 | 13.3 |
| 3. three trucks | 20 | 9.3 | 24 | 9.1 | 24 | 9.5 |
| II. Minimize total miles | | | | | | |
| a. to fight all fires for location of | | | | | | |
| 1. one truck | 34 | 12.2 | 37 | 15.8 | 54 | 20.9 |
| 2. two trucks | 34 | 9.0 | 34 | 9.1 | 26 | 9.8 |
| 3. three trucks | 24 | 6.5 | 20 | 6.7 | 24 | 6.7 |
| b. to fight rural fires for location of | | | | | | |
| 1. one truck | 34 | 17.0 | 37 | 19.6 | 54 | 22.9 |
| 2. two trucks | 24 | 11.7 | 29 | 12.7 | 26 | 13.0 |
| 3. three trucks | 24 | 9.1 | 24 | 9.1 | 20 | 9.3 |
| III. Maximum protection | | | | | | |
| a. per dollar's worth of burnable total property | | | | | | |
| 1. one truck | 34 | 12.2 | 54 | 20.9 | 56 | 23.2 |
| 2. two trucks | 34 | 9.0 | 24 | 9.1 | 33 | 10.4 |
| 3. three trucks | 24 | 6.5 | 24 | 7.8 | 20 | 6.7 |
| b. per dollar's worth of burnable rural property | | | | | | |
| 1. one truck | 56 | 24.8 | 54 | 22.9 | 34 | 17.0 |
| 2. two trucks | 24 | 11.7 | 34 | 13.0 | 26 | 13.1 |
| 3. three trucks | 24 | 9.1 | 20 | 9.1 | 24 | 9.5 |

## TABLE 3. ANNUAL CAPITAL AND OPERATING COSTS FOR VARIOUS NUMBER OF TRUCKS FOR EACH OBJECTIVE FUNCTION

| Objective Function | Choices | | |
|---|---|---|---|
| | First | Second | Third |
| I. Minimize response time to get to | | | |
| a. all fires for location of | | | |
| 1. one truck | $5,075 | $5,284 | $5,480 |
| 2. two trucks | 7,363 | 7,193 | 7,186 |
| 3. three trucks | 9,168 | 9,159 | 9,267 |
| b. rural fires for location of | | | |
| 1. one truck | 4,161 | 4,251 | 4,369 |
| 2. two trucks | 6,267 | 6,314 | 6,306 |
| 3. three trucks | 8,301 | 8,295 | 8,306 |
| II. Minimize total miles | | | |
| a. to fight all fires for location of | | | |
| 1. one truck | 5,075 | 5,284 | 5,466 |
| 2. two trucks | 7,135 | 7,149 | 7,186 |
| 3. three trucks | 9,159 | 9,168 | 9,168 |
| b. to fight rural fires for location of | | | |
| 1. one truck | 4,161 | 4,251 | 4,362 |
| 2. two trucks | 6,267 | 6,303 | 6,306 |
| 3. three trucks | 8,295 | 8,295 | 8,301 |
| III. Maximum protection | | | |
| a. per dollar's worth of burnable total property | | | |
| 1. one truck | 5,075 | 5,466 | 5,683 |
| 2. two trucks | 7,135 | 7,149 | 6,836 |
| 3. three trucks | 9,159 | 9,214 | 9,168 |
| b. per dollar's worth of burnable rural property | | | |
| 1. one truck | 4,415 | 4,362 | 4,161 |
| 2. two trucks | 6,267 | 6,210 | 6,306 |
| 3. three trucks | 8,295 | 8,295 | 8,306 |

such that maximum distance a fire truck would have to travel to reach a fire is minimized. The first choice location, given this objective, would be to locate a truck in Fairview (Table 1). As can be seen in Table 2, this has the lowest maximum distance in miles to travel to reach a fire in the area served. One fire truck located in the second or third choice location would have a longer maximum distance to travel. The maximum one-way distance a truck at the first choice location would have to travel is 34 miles, with an average distance of 12.2 miles to fight all fires and 17.0 miles being the average distance for rural fires only (Table 2).[7]

Distance figures are used to reflect quality of service at each location. Maximum response time, given specified assumption of a truck traveling 60 miles per hour, is 34 minutes. Annual capital and operating costs used to fight all fires for the truck at Fairview is $5,075, and if the truck is used for rural fires only, is $4,161 (Table 3). The second best location, with the objective of minimizing response time to reach a fire, is Cleo Springs. The maximum distance to the farthest fire is 37 miles versus 34 miles from Fairview (Table 2). The annual cost of operating a fire truck at Cleo Springs is $5,284, higher than Fairview by $209 (Table 3). Additional costs are due to larger annual mileage of a truck located at Cleo Springs versus Fairview. The third choice location to minimize response time is Orion. In this case, maximum response time is 10 minutes more than the first choice and costs are $405 higher.

If the objective includes location of two fire trucks for fighting all fires and minimizing response time, the best locations are Ringwood and Orion (Table 1). The maximum mileage with these locations is 24 miles, and average mileage is 13.6 (Table 2). The maximum mileage is 10 miles less than if one truck were operated. The average distance is larger if two trucks instead of one are used for all fires, due to expected high frequency of fires in Fairview. Annual costs increase from $5,075 for one truck, to $7,368 for two (Table 3), because of increased capital costs of purchasing the second truck. The question, then, is whether reduction in maximum mileage (increase in quality of service) is worth added cost.

If three trucks are going to be purchased to fight all fires, optimum locations are Ringwood, Fairview and Bouse Junction. Maximum distance for a truck to travel decreases to 20 miles (Table 2) and annual costs increase to $9,168 (Table 3). Average mileage, assuming only one truck at a time attends all fires, is 6.7. If the trucks attend only rural fires, average mileage is 9.3 (Table 2).

#### Objective II—Minimize Total Miles

This objective minimizes total miles which a fire truck(s) is expected to travel. In essence, weight is given to each demand area, depending upon expected number of fires and distance from each location. For one truck fighting all fires or rural fires only, the first choice location is Fairview, second choice being Cleo Springs and third choice Ringwood (Table 1). For two trucks fighting all fires, the best locations are Fairview and Ringwood; for fighting only rural fires Ringwood and Orion are best. For three trucks, with the objective of minimizing total mileage, first choice locations for fighting all fires or only county fires are Fairview, Ringwood and Orion. Comparing results with Objective I, the maximum distance a truck would have to travel is either the same or greater, whereas average distance is either the same or smaller. This is resultant because the objective function picks locations which minimize total mileage, thus giving greater attention to demand areas with higher frequency of fires. Likewise, costs (Table 3) are the same or smaller due to decreased annual mileage under this objective versus Objective I.

#### Objective III—Maximum Protection per Dollar's Worth of Property

Objective III considers the value of burnable property in each demand area and locates truck(s) to maximize protection. This objective function locates fire fighting facilities near high-value property. It allows decision-makers to put high values on structures to which they desire to give special attention—such as schools, hospitals and nursing homes. By this objective function, if one truck were to be located to fight all fires, the first choice location would be Fairview, with Ringwood second and Ames third. If used for rural fires only, the first choice is Ames, the second Ringwood and the third Fairview. For two trucks fighting only rural fires, first choice locations under this objective function are Ringwood and Orion, whereas first choice locations for three trucks are Fairview, Ringwood and Orion. Response times and costs by this objective function are generally larger than those under the other two objective functions.

### IMPLICATIONS

These empirical results illustrate the importance of long-range planning and careful consideration of an

[7]The first, second and third choices would be the same regardless if the fire truck(s) was used to fight only rural fires or all county fires. However, average mileage and annual costs would differ if used to fight only rural fires as compared to all county fires.

objective function when making capital outlay decisions regarding location of emergency services in rural areas. Using the location of fire truck(s) as an example, if decision-makers are planning to buy only one rural fire truck, their location decision should differ from that of buying two or three. In addition, if they decide to buy one truck this year and another a few years later, they need to include this in their location decision. Likewise, optimum location(s) differs as to whether or not decision-makers want to minimize vehicle response time to get to a fire, minimize average response time or provide maximum fire protection per value of burnable property to protect. Finally, it is important for decision-makers to consider whether or not the fire truck will be used to fight all fires in the county or only rural fires.

Quality of alternatives is reflected and estimated by both maximum and average mileage to get to a fire. Costs for each alternative are likewise estimated. Thus, decision-makers can make a judgment based on costs and quality of service. The tradeoff between costs and quality (reduced response time) are indicated by the model and should assist in final decisions.

## REFERENCES

[1] Chaiken, Jan M. and Richard C. Larson. "Methods for Allocating Urban Emergency Units: A Survey," *Management Science*, Volume 19, No. 4, December, Part 2, 1972, p. 110-130.

[2] Childs, Dan, Gerald A. Doeksen and Jack Frye. "The Economics of Rural Fire Protection in the Great Plains," Agricultural Economics Report in process, ERS-USDA.

[3] Heady, Earl O. and Wilfred Candler. *Linear Programming Methods*, Ames, Iowa: The Iowa State University Press, 1958, pp. 332-377.