knowledgeable individuals within the department.

The methodology requires the assessment of value judgments regarding trade-offs between such considerations as safety, protection of investment, aesthetics, and environmental pollution. A Delphi procedure was used in Louisiana to obtain group consensus regarding trade-offs from a number of individuals who are responsible for selecting levels of service both in the field and at headquarters. Certain improvements in the implementation of the Delphi procedure would seem desirable based on the experience in Louisiana. However, the types of assessment questions that need to be asked in the Delphi procedure are certainly practical and relevant to individuals involved in highway maintenance.

It would be desirable to provide certain types of objective data to the participants in the Delphi exercise in order to obtain more consistent and reliable value judgments. Examples of such data include statistics on accidents resulting from driving over the edge of the traveled way at various depths of drop-off and surveys of user opinions regarding aesthetics of roadside vegetation under varying levels of service. These kinds of data are currently not available. The initial implementation of the methodology will identify the critical parameters on which objective data would be most useful. Limited studies to collect these data can be undertaken. The reliability of the results of the methodology would be expected to increase with the availability of additional data.

The computer program prepared for the use of the methodology facilitates the analysis significantly. The program is designed so that the assessed data can be directly input, and all parameters (such as value coefficients, relative weights, and regression coefficients) are computed internally in the program. This relieves the user of the burden of making external calculations, which would require some theoretical background in decision analysis techniques.

The demonstration example in Louisiana involved only 2 maintenance conditions--edge of traveled-way drop-off and roadside vegetation growth. However, a complete system of highway maintenance could involve 20 to 25 maintenance conditions of practical significance.

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Abridgment

Location of District Maintenance Centers by Least Transport Cost

Z. ANDREW FARKAS

The largest and most difficult cost to determine in the economic life of a U.S. Forest Service ranger district maintenance center is usually the transportation cost of personnel to the work sites. Decreasing this cost through optimum location of centers presents one of the best opportunities for energy conservation and increased efficiency. The method described here permits the determination of the total transport cost to each work site so that costs can then be contoured; the least-cost contour delimits an area that may be analyzed for site location. Location analyses of five districts estimated savings from relocation in three districts that ranged from $12 700 to $32 000 over the life of the facility.

Government regulations have mandated that investments in government facilities must be cost effective and must conserve energy. The Energy Policy and Conservation Act of 1975 requires a 20 percent reduction in all federal agencies' energy consumption by 1985, during a time of increasing demands on public resources. The U.S. Department of Agriculture Forest Service, the agency primarily responsible for managing federal timber lands, consumes a great deal of its energy allotment in the construction, operation, and maintenance of support facilities for land management.

The smallest administrative unit in national forests, the ranger district, is responsible for maintenance of roads on the forest road system and of recreation areas, trails, timber stands, and fire-prevention facilities. Ranger district maintenance operates out of a work center that may or may not be in close proximity to the ranger's office. Location of the ranger's office must take account of administrative and public access considerations, but the location of the maintenance center must be influenced by the spatial distribution of the work sites. In most cases the largest and most difficult cost to determine in the economic life of a ranger district maintenance center is the transport cost of personnel to the work sites. Decreasing this cost through optimally locating maintenance centers presents one of the best opportunities for energy conservation and increased efficiency.

Studies of the location of industries and public service facilities abound in the literature, and the concepts involved may be applied to the location of maintenance centers (1,2). If there were only one work site in a ranger district, location of the maintenance center to minimize transport cost would be simple: The maintenance center would be located at the site and the transport cost would be zero. However, when several sites "pull" at this maintenance center location, some analysis must be made to determine the location that will minimize transport costs to all sites. Each site exerts a pull that is a function of trip cost and the number of trips to the site. By hypothetically locating a maintenance center on each work site and by calculating the transport costs to every other work site, one can determine the total transport cost at each location. Contours of total cost (isocost lines) may then be derived. These total-cost contours would actually be the interpolated result of combining all the transport isocost lines emanating from each location. Once total-cost contours are formed from these several locations, the least-cost contour delimits an area that may then be analyzed for site location.

Contours of transport cost connect points of equal value. The least-cost contour serves as a boundary of an area in which, theoretically, transport costs are at a minimum. It should be noted that the only relevant portions of contours are at intersection points with the transportation network. Obviously, where no roads exist, transport costs would be much higher.

The first case study of this method occurred on the James River Ranger District of the George Washington National Forest in the mountains of western Virginia. The district is approximately 64 km (40 miles) long and 32 km (20 miles) wide. The objectives of the study were to test a method of analyzing the transport costs of work trips and to delimit an area of least transport cost for further site analysis of maintenance center location.

CASE-STUDY ANALYSIS

The location analysis of the maintenance center is based on the following formula:

$$C_i = \sum_{j=1}^{n} (D_{ij} \times V_c + W_a \times S_{ij})\, 2T_{ij} \quad (i = 1, \ldots, n) \qquad (1)$$

where

C_i = total costs of transportation from a maintenance center location i to every other work site j,
V_c = vehicle operating cost per unit of distance,
W_a = average wage rate per hour for average number of crew members,
S_{ij} = travel time between i and j,
D_{ij} = distance from i to j, and
T_{ij} = total number of trips from i to j.

Thus, the formula takes into account total vehicle operating cost and labor cost of work trips. The first major step to derive values for the formula is to code the transportation network of the ranger district into links and nodes. The second step is to determine the lengths and travel times of the links. The nodes correspond to road intersections, changes in road standards, and work sites. In the third step, average wage rates, average number of work crew members, vehicle operating costs, and number of trips per unit of time to each work site must be determined. This information was estimated from district records and measured by field personnel.

The following assumptions were made for the James River study:

1. Each work trip is a single-destination trip to a work site.
2. The ranger's office, which is located for public access as well as for administrative needs, is a fixed location and is treated as a work site that attracts administrative trips.
3. Vehicle operating costs are assumed to be the same in both directions of travel.
4. Vehicle operating costs do not include the monthly fixed ownership rate, only the equipment-use rate, since the former does not vary by usage. Also, vehicle operating costs in this analysis do not vary by speed.
5. Several nearby work sites may be represented by one node, and trips are not differentiated by resource or activity purpose.
6. The number of trips to a work site is not affected by distance to the site.

The link values of length and travel time and the corresponding nodes were put into a matrix, and link speeds in kilometers per hour were calculated. By using the average number of persons in work crews multiplied by the average wage rate per hour and added to the vehicle operating cost per kilometer, a simple FORTRAN program calculated the cost per kilometer for link speeds from 8 to 89 km/h (5 to 55 mph). Following are the link speeds and transport costs for the James River Ranger District (1 km = 0.6 mile).

Link Speed (km/h)	Van Rate ($/km)	Pickup Rate ($/km)
8	3.19	1.52
16	1.69	0.85
24	1.19	0.62
32	0.94	0.51
40	0.79	0.44
48	0.69	0.40
56	0.61	0.36
64	0.56	0.34
72	0.52	0.32
81	0.49	0.31
89	0.46	0.29

The van rate represents the vehicle-use cost of $0.185/km ($0.296/mile) plus the crew cost for an average of four crew members at $6.00/h each divided by the average link speed. The pickup rate represents the vehicle-use cost of $0.170/km ($0.272/mile) plus the crew cost for an average of two crew members at $5.40/h each divided by the average link speed.

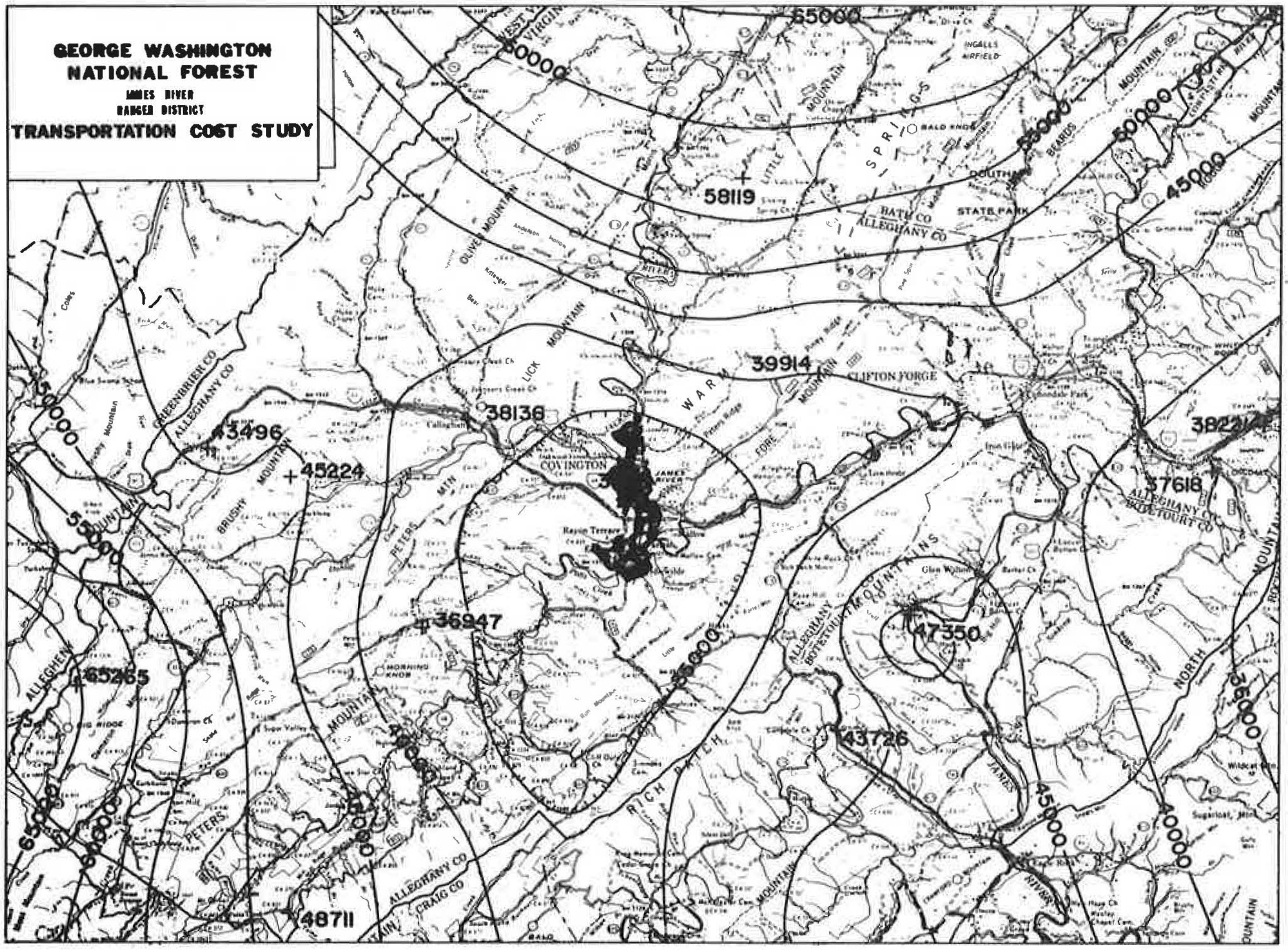
A linear programming transportation analysis determined the minimum-distance links from each work site to every other work site (3). The model multiplied link distances by each link's cost per kilometer and by number of trips to and from each work site. These calculations produced a location's total transport cost for work trips to every other site.

The transport cost calculations were made for two types of vehicles (pickup trucks and vans) and two average numbers of crew members. Costs were calculated from the maintenance center's record of the past five years of operation and converted to a yearly average. Thirteen nodes were selected as points for mapping contours on the basis of number of trips attracted and spatial distribution. The mapping of the contours was performed by the Topographical Analysis System (TOPAS), an in-house computer mapping program.

LOCATION STUDY FINDINGS

In the James River district analysis, the plot of the isocost lines indicates that the least-cost contour is centered on the town of Covington,

Figure 1. Total transport cost contours for James River Ranger District.



Virginia, where the ranger's office is located (Figure 1). The present maintenance center is located on the southeastern side of Covington and is within the least-cost contour. One may conclude at this point that this exercise only quantified what was intuitively obvious to some past decision maker. The advantage to the procedure in this case is that we now know that other locations should minimize the cost of transportation. Also, if the ranger's office were not fixed, then several alternative locations of the office could shift the most efficient location of the maintenance center significantly, and these locations may not be so obvious.

The area within the least-cost contour is, in reality, not equally accessible. Although the contour shifts south of Covington, the transportation network in the south is minimal. The contours spread outward along the east-west Interstate highway through Covington. Therefore, the best locations would probably be in the southern half of the city and along the Interstate highway. Site-specific costs, property ownership, construction, and site preparation would be some of the relevant factors to consider in final site selection. If alternative locations that lie outside the least-cost contour must be considered, then the closest contour value to the alternative sites may be used in a present-worth-of-costs analysis.

Location analyses of four other ranger districts in the George Washington National Forest in Virginia yielded varying results. In one district, the present maintenance center is within the area of least transport cost. In three districts, the annual transport cost savings of moving the maintenance centers to the least-cost area range from $1500/year to $4000/year. Although the present worths of these amounts at 10 percent for 20 years range from $12 700 to $32 000, moving these centers would probably be worthwhile only if the physical lives of the existing centers were expended. In one of these districts, moving the maintenance center would result in an additional 32-km (20-mile) commute one way for the present maintenance employees. The benefit from moving the center must be weighed against the additional employee transport cost or the cost of an agency commuting program.

CONCLUSIONS

The location study resulted in an analysis technique that used available computer programs and readily determined data. The technique visually displays in terms of transport costs an area of optimal maintenance center location that can be further analyzed in detail for site selection. At the very least the technique has helped justify location decisions that were made with little knowledge of the costs of location. In several cases the technique has quantified substantial monetary savings and, concomitantly, savings in energy use that could be gained from future relocation of maintenance centers.

The economic analysis of transport costs of maintenance operations addresses an important consideration of maintenance center location. As is true of any economic analysis, it is merely a tool to provide the decision maker with the information to make effective decisions, not to provide the decision itself. Many other considerations must enter into the location decision: ease of center administration, the pattern of private and federal land ownership, distance to employee's existing residential locations, other facility location costs, and location of personal and agency services to employees.

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Highway Maintenance Game: A Manual Simulation Model for Training Maintenance Crews

G. L. RAY AND JOHN M. MELANCON

A manual simulation procedure was developed to supplement highway maintenance training in Louisiana. The game was designed with emphasis on the planning and scheduling of activities in order to train first-line administrators by simulating the performance of one week's work. This method appears to be effective on the basis of administration of the training package in four districts. Plans are being made to refine and automate this concept to better train maintenance supervisors.

Since the implementation of Louisiana's maintenance management system in 1969, field studies have revealed several scheduling problems that have limited the effectiveness of maintenance crews. Typical scheduling problems were related to lack of adequate forethought in order to achieve the most efficient use of available resources. For example, an extensive leveling job was scheduled without consideration of equipment availability. After five truckloads of hot mix had been delivered, the foreman realized that the roller was inoperative and that the hot mix could not be effectively applied. In numerous cases, additional people were assigned to activities simply because it was convenient, even though additional labor was not required.

Maintenance specialists who were charged with assisting parish superintendents to plan and schedule maintenance operations were surveyed. The survey led to the realization that only 50 percent of the superintendents were scheduling at all. Discussion with maintenance superintendents produced such comments as "maintenance cannot be scheduled", "scheduling time is wasted when things go wrong", and "scheduling takes too long".

Work was then begun to respond to these concerns through the development of a training course that included simulation of maintenance activities as a means to change the superintendents' attitudes and to improve planning skills. The training course was developed for presentation to first-level administrators--parish maintenance superintendents, foremen, and clerks. The course was designed to teach techniques that should help reduce the time required for scheduling maintenance. The roles of superintendent, foreman, and clerk were presented to show how each individual was expected to assist in the scheduling process. Realization that the superintendent is not expected to schedule all operations without assistance from his principal aides was expected to further speed the scheduling process. Finally, a manual simulation procedure was developed to accomplish five basic objectives:

1. Exercise techniques learned in the training course,
2. Examine the benefits of proper roles and interactions among key members of the parish organization,
3. Reduce the time required to perform scheduling tasks,
4. Demonstrate the feasibility and effectiveness of work-order scheduling techniques, and
5. Measure the level of potential effectiveness of the training process.

The manual simulation forced interaction among the three team members in a real-time enactment of the scheduling function; accomplishment of the work was handled in a quick-time fashion. A measurement procedure was also included in the simulation to determine how well the student had applied the techniques learned or acquired prior to the training.

MECHANICS OF THE GAME

A major effort was made to reinforce the idea that coordination and interaction among the three key people in the parish organization is necessary. Role-playing techniques were used during simulation of maintenance work to physically illustrate how