Optimal routes choice for maintenance units moving to service electrical equipment of agricultural facilities

V G Zhdanov, E A Logacheva, V A Yarosh and A V Ivashina

Stavropol State Agrarian University, 12, Zootekhnichesk Ln., Stavropol, 355017, Russia

E-mail: Jdanow.valery@yandex.ru

Abstract. In the conditions of agricultural production, electrical equipment is affected by a large number of unfavorable factors; therefore, the role of its technical operation increases sharply. Maintaining the operational reliability of electrical equipment at the required level is ensured by the timely implementation of their scheduled maintenance and repairs. The implementation of these measures in the conditions of agricultural enterprises is associated with certain difficulties, since electrical equipment is located in a number of areas in agriculture, remote from one another at a considerable distance. Statistical data show that a significant amount of working time is spent on transitions and transfers, which sharply reduce the labor productivity of workers in maintenance units. The article deals with problems of using mathematical programming methods for choosing the optimal routes to transport maintenance units to service electrical equipment. The method for finding the shortest route for moving maintenance units to service electrical equipment of agricultural facilities has been developed.

1. Introduction

Because of the large number of unfavorable factors affecting electrical equipment in agriculture, the role of its technical operation is sharply increasing. Due to the timely implementation of scheduled maintenance and repairs, it is possible to maintain the required operational reliability of electrical equipment. However, the implementation of these measures in agriculture is associated with certain difficulties.

In industry, the same-type of electrical equipment is concentrated in relatively small production areas and there is a possibility of scheduled maintenance of the entire electrical equipment fleet at the same time. But in agriculture, electrical equipment within one farm is dispersed over a number of areas that are remote from one another at considerable distances (up to 15 ... 30 km) [1].

Due to the uneven distribution of electrical equipment over a large area, electro technical personnel are forced to move around the facilities. Statistical data show that from 15 to 40% of working time is spent on transitions and transfers. This drastically reduces the productivity of electricians.

Among the problems of rural electrification, which must be solved using mathematical programming methods, the problem of choosing the optimal routes for the movement of maintenance units for the maintenance of electrical equipment should also be included [1, 2].
2. Materials and methods
The essence of the model for choosing the optimal (shortest) route is as follows. A network is given, each arc of which corresponds to a certain distance. It is necessary to find the shortest route to a given node from any other node on the network.

The agricultural objects to be serviced are represented in the form of the network consisting of a set of nodes, some pairs of which are connected by oriented arcs (i.e., segments on which the direction is given). The example of such a network is shown in Figure 1. Typically, one node is allocated in the network, called an exit (destination point). The problem is to find the shortest route to a destination node from at least one intermediate node, and sometimes from all other nodes. Variable $c_{ij}$ determines the length along the arc outgoing from node $i$ and entering into node $j$.

![Figure 1. Example of a network model for choosing the shortest route](image-url)

In other versions of the problem statement, the variable of $c_{ij}$ can be measured in units other than units of length. So, for example, $c_{ij}$ can represent the cost of moving from node $i$ to node $j$. In this case, the problem is to find the lowest cost of a route. In addition, $c_{ij}$ can also determine the travel time from one node to another. In this instance it is required to find a route of the minimum duration.

Quite often there are situations when $c_{ij}$ is not equal to $c_{ji}$. In addition, some nodes may not be connected directly, which can be formally taken into account by setting $c_{ij} = \infty$.

A network similar to the one shown in Figure 1 can contain routes that are closed or cycled. This means that for two or more numbers, a route, outgoing from some node and returning or going into it, can be found. The network (Figure 1) has many cycles, one of which starts at node 2, passes through nodes 7 and 3, and ends again at node 2.

Let us assume that the problem comes down to finding the optimal route from a single starting node (source) to an end node (drain). In this case, the mathematical formulation of the shortest route problem will have the form:

$$\sum_{(i,j) \in \text{network}} \sum c_{ij} x_{ij} \rightarrow \text{min}$$

under constraints:

$$\sum_{(k,j) \in \text{network}} x_{kj} - \sum_{(i,k) \in \text{network}} x_{ik} \begin{cases} 1, & k = s \text{ (source)}, \\ 0, & \text{for all other } k, \\ -1, & k = r \text{ (drain)}, \\ \geq 0 & \text{for all } (i,j) \in \text{of the network}. \end{cases}$$

It is easy to demonstrate that this problem in the mathematical sense, i.e. formally, is equivalent to the assignment problem. To make sure of this, on the network (Figure 2), node 1 will be considered as
final and node 8 will be considered as initial one. The next step is to consider a common transportation problem with transit points in which there is a surplus unit at node 8 (source) required at node 1 (drain). All other nodes on the network are considered intermediate points. It should be noted also that the shortest route problem is a special case of the assignment problem for which the coefficients of the objective function $c_{kk} = 0$ are located in the so-called sub diagonal of the matrix.

Under these conditions, the optimization model is written as follows:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij} x_{ij} \rightarrow \min$$

under constraints:

$$\sum_{j=1}^{n} x_{ij} = 1, \quad i = 1, 2, ..., n,$$  (4)

$$\sum_{i=1}^{n} x_{ij} = 1, \quad j = 1, 2, ..., n,$$  (5)

$$x_{ij} = 0 \text{ or } 1 \text{ for all } i \text{ and } j.$$  (6)

The problem can be generalized for $n \times n$ matrices. For each such matrix, the problem is to choose $n$ elements - one in each row and one in each column, such that their sum is minimal.

Let us construct a matrix corresponding to (3) and (6) on the network in Figure 1. This matrix contains one equation for each node and one variable for each arc. So for $k = s = 8$ in accordance with (2) we have:

$$x_{85} + x_{86} + x_{87} = 1 \text{ (node 8 – the source),}$$

and for $k = 7$:

$$x_{72} + x_{73} + x_{76} - x_{27} - x_{87} = 0 \text{ (node 7).}$$

![Figure 2. Matrix representation of conditions of the shortest route problem](image)

In the technical literature, the two methods for solving the assignment problem are the most widespread. The Hungarian method is based on some rather difficult and nontrivial combinatorial properties of matrices [3, 4]. It is rather difficult to program, and it is used extremely rarely. More often the Mack’s method is used [5, 6], which has the advantage of a simpler intuitive justification.
3. Results and discussion

To optimize transport costs for $C_T$ the methodology for solving the problem of choosing the optimal routes in relation to the maintenance and repair of the elevator’s electrical equipment is used.

The data for solving the problem are given in Table 1.

**Table 1. The given data for transport costs optimization**

| Node | Object                                      | Route marking | Route length, km |
|------|---------------------------------------------|---------------|------------------|
| 0    | Central maintenance point                   | –             | –                |
| 1    | Grain storage RZS-1-63                      | $C_{31}$      | 0.4              |
|      | Grain dryer DSP – 32 from No. 1             |               |                  |
| 2    | Grain storage LV – 2 x 100                  | $C_{12}$      | 0.8              |
|      | Grain dryer DSP – 32 from No. 2             |               |                  |
| 3    | Cleaning and drying tower SOB - 32          | $C_{03}$      | 1.0              |
|      | Loading-and-unloading tower POB - 1         |               |                  |
| 4    | Loading-and-unloading tower POB - 9         | $C_{24}$      | 0.2              |
|      | Elevator tower No.1                         |               |                  |
|      | Total:                                      | –             | 2.4              |

Based on the initial data, the network corresponding to the method for solving the assignment problem with a dimension of $4 \times 4$ will be formed (Figure 3).

**Figure 3.** The network corresponding to the method for solving the assignment problem with a dimension of $4 \times 4$

The shortest route selection algorithm is applied to find the best route from node 0 to node 4 using Mack’s method. To solve the problem, the network is represented in the form of Table 2.

**Table 2. Network representation in tabular form**

|    | 1  | 2  | 3  | 4  |
|----|----|----|----|----|
| 1  | 1.5| 2.4| 1.0| 2.6|
| 0  | 0  | 0.8| 0.2| 1.3|
| 0.8| 0  | 0.9| 0.2|    |
| 0.4| 1.7| 0  | 1.9|    |

In this case, the matrix of the problem has the form:

| 1.5 2.4 1.0 2.6 |
| 0 0.8 0.2 1.3    |
| 0.8 0 0.9 0.2    |
| 0.4 1.7 0 1.9    |
The results of solving the problem are shown in Table 3.

**Table 3.** Network representation in tabular form

| Route | Route length, km |
|-------|------------------|
| C_{03} | 1.0              |
| C_{31} | 0.4              |
| C_{12} | 0.8              |
| C_{24} | 0.2              |

The network diagram shown in Figure 4 corresponds to the optimal solution to the original problem.

![Network diagram](image)

**Figure 4.** Optimal route determination graph

4. Conclusion
Finding the optimal route for the movement of maintenance units to service electrical equipment is a typical transport shortest route problem. Implementation of it by Mack’s method made it possible to obtain a graph of optimal routes for the analyzed objects.

References

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