Optimization of the location of production centers (slaughter points) of reindeer farms using iterative methods

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Abstract. The article deals with options for the most effective placement of slaughter points, the location of which would reduce the distance of deer drive to the places of slaughter from reindeer herding farms. When using different criteria, the location of the deer slaughtering production center shifts towards those organizations that have the largest number of deer and the economic efficiency of optimal placement of the slaughter points depends on the number of conditions used in the criterion.

1. Introduction
The first models of production location on the farm territory, optimization models of the sectoral structure were developed by N.Ya. Kuvshida. The most well-developed was the model of optimal combination of industries in agricultural enterprises, the formulation of this task belonged to R.G. Kravchenko and I.G. Popov, on which various modifications were subsequently created - the placement and specialization of agricultural production.

Under the leadership of M.I. Korobochkin, a complex work was conducted on the creation of mathematical models, consisting in the development of linear models of minimizing the amount of work and minimizing the costs of moving, which were later reflected in his doctoral thesis "Models and methods of optimal geodetic design of vertical planning" (1974).

The tasks had a very large dimension and in order to ensure their practical solution, well-known methods of linear programming were significantly modified; special methods of quadratic programming were developed. Based on these developments, in 1973 E.G. Larchenko the book "The use of mathematical methods in land management" was published, which served as a guide for the application of economic and mathematical methods in the design land management calculations [1].

In the period from 1974 to 1977 in the work of S.N. Volkova, “Some theoretical questions of mathematical modeling in land management” for the first time the presented classifications of mathematical methods and models for grounding land management projects were reflected [2].

When drafting the land management projects, it is often necessary to solve problems related to the placement of various industrial infrastructure facilities associated with a specific resource base in the territory. For example, slaughter points are located in such a way that they are as close as possible to reindeer herding, in order to reduce the distance of the reindeer drive to the places of slaughter.

The basic rule is that the slaughter point should be located in the center of gravity of deer pastures, affected farms. At the same time, the slaughtering point will shift towards those organizations where the most deer are located.
2. Materials and methods
To solve this problem, we suggest applying an iterative method (the method of successive approximations), which involves the gradual achievement of the initially chosen location of the slaughter point to its optimal value.

Let us determine the settlement procedure when optimizing the location of the slaughter points of several reindeer herding farms located in the territory of Taimyr (Dolgano-Nenets) municipal district. The task deals with the following: to establish the coordinates of the slaughter point location at which the total distance of the deer driving to the slaughter point will be minimal. The methodology of calculation and the problem solving sequence are reduced to the following actions.

1. Determine the need in food for livestock of deer, intended for slaughter.

It is assumed that a deer’s daily need in feed during the summer is 20 kg of green feed and 11 kg of moss during the winter. The number of days in the summer period is 122, and of the winter period - 243. Thus, the volume of feed consumed by one deer when it is transported to the slaughter point is 2440 kg in the summer period and 2673 kg in the winter season (Table 1) [3].

2. Establish the number of deer, intended for slaughter, in each reindeer herding.

For this purpose you can use the following data. In 2017, the Taimyr (Dolgan-Nenets) municipal district in 2017, there were 17 private reindeer herding organizations (Table 2) [1]. According to the methodological recommendations on the integrated survey, assessment and use of land in areas of northern reindeer herding, including the territories of traditional nature management of the indigenous peoples of the North, Siberia and the Far East of the Russian Federation (edited by Titova EA, Kurakina VI, Gavriloova M. A., Ph.D., Gladkova A.A. and others), the average allowable slaughter rate is 65-70% of the annual offspring or 22-23% of the total herd [4]. This indicator is determined on the basis of calculations of the movement of the livestock of deer in pasture seasons and the planned annual turnover of the production herd of deer of commercial and reindeer herding farms of the Nenets, Yamal-Nenets and Taimyr Autonomous District. Thus, the total number of deer for slaughter is 27,739 th. heads [5].

3. Calculate the gravity centers coordinates of the economic centers of the reindeer herding farms, from which they will drive the reindeer to the bottom. For this, you can use the local coordinate system or determine it in a conventional coordinate system graphically. After that, develop the initial matrix to optimize the placement of the bottom-hole point (tables 3 and 4).

4. Solve the problem according to a special algorithm using the iterative method (the method of successive approximations).

The amount of work Z on the movement of deer to the point of slaughter Pi from given points (reindeer enterprises) M (xi, yi) (i = 1, 2, ..., m) to point N (X, Y) can be expressed by the formula:

\[ Z = \sum_{i=1}^{m} P_i \cdot R_i, \]  

where Z is the total distance traveled by deer, thous. Km; Ri is a distance from the point of slaughter to reindeer enterprises; Pi is a number of deer, thous. heads [6]. Expressing the value of R through the coordinates, we get

\[ Z = \sum_{i=1}^{m} P_i \cdot \sqrt{(X - x_i)^2 + (Y - y_i)^2} \rightarrow \text{min}, \]  

where X и Y are the coordinates of the slaughter point; xi and yi are coordinates of the reindeer enterprises location in the local coordinate system [7].
Thus, it is required to determine the coordinates of the point N (X, Y) at which the value of Z will be minimal [8]. In this case, for the points of departure Mi (xi, yi), the coordinates of the settlements centers where the household centers of reindeer enterprises are located are taken.

The amount of feed consumed (Pi) is determined according to the number of deer found in reindeer enterprises placed in one locality [9]. Considering six locations of reindeer enterprises, m = 6. Then he formula takes a detailed form:

\[ Z = P_1\sqrt{(X - x_1)^2 + (Y - y_1)^2} + P_2\sqrt{(X - x_2)^2 + (Y - y_2)^2} + P_3\sqrt{(X - x_3)^2 + (Y - y_3)^2} \\
+ P_4\sqrt{(X - x_4)^2 + (Y - y_4)^2} + P_5\sqrt{(X - x_5)^2 + (Y - y_5)^2} + P_6\sqrt{(X - x_6)^2 + (Y - y_6)^2} \rightarrow \text{min} \]  

(3)

To reduce the number of iterations, A.A. Starkov and E.G. Larchenko suggested the following formulas for the approximate determination of the gravity center of the array, taking into account the initial (zero) approximation.

\[ X^{(0)} = \frac{\sum_{i=1}^{m} x_i P_i^1}{\sum_{i=1}^{m} P_i^1}, \]  

(4)

\[ Y^{(0)} = \frac{\sum_{i=1}^{m} y_i P_i^1}{\sum_{i=1}^{m} P_i^1}, \]  

(5)

where \(X^{(0)}, Y^{(0)}\) are approximate coordinates of the location of the slaughter point; \(x_i, y_i\) are coordinates of reindeer enterprises; \(P_i\) is the number of deer, thous. heads. We used these formulas to calculate the initial (zero) approximation.

**Table 2.** Characteristics of reindeer farms in the territory of the Taimyr (Dolgano-Nenets) municipal district

| №  | Name of farms                  | Location of the center of the reindeer husbandry | The total number of goals on 01.01.2016 | The total number of goals on 01.01.2017 | The number of goals for slaughter 01.01.2017 |
|----|--------------------------------|-----------------------------------------------|----------------------------------------|----------------------------------------|--------------------------------------------|
| 1  | MUE "Ust-Yeniseets"            | Karaul                                        | 11,983                                  | 12,956                                  | 2,915                                      |
| 2  | RAPC "Suzun"                   | Tuhard                                        | 14,227                                  | 12,167                                  | 2,738                                      |
| 3  | RAPC "Yara-Tanama"            | Nosok                                         | 48,921                                  | 50,886                                  | 11,449                                     |
| 4  | ARIPC "Tundrovik"             | Khatanga                                      | 5,541                                   | 5,059                                   | 1,138                                      |
| 5  | ACSc "Nerm Nenecha"           | Dudinka                                       | 0                                       | 2,770                                   | 623                                        |
| 6  | IE-chief Peasant farm Ilkiv L.B. | Dudinka                                      | 12,407                                  | 16,313                                  | 3,670                                      |
| 7  | IE-chief Peasant farm Ilkiv R.P. | Dudinka                                      | 14                                      | 14                                      | 3                                          |
| 8  | IE-chief Peasant farm Yadne G.A. | Nosok                                         | 9,926                                   | 11,043                                  | 2,485                                      |
| 9  | IE-chief Peasant farm Sabelfeld E.V. | Dudinka                                      | 1,360                                   | 1,379                                   | 310                                        |
| 10 | IE-chief Peasant farm Schukin G.K. | Dudinka                                      | 1,802                                   | 1,804                                   | 406                                        |
| 11 | IE-chief Peasant farm Stepin A.V. | Dudinka                                      | 10                                      | 12                                      | 3                                          |
| 12 | IE-chief Peasant farm Tsygankova V.A. | Dudinka                                      | 3,153                                   | 3,287                                   | 740                                        |
| 13 | IE-chief Peasant farm Bolin S.Y. | Potapovo                                      | 5                                       | 6                                       | 1                                          |
| 14 | IE-chief Peasant farm Vengo V.N. | Nosok                                         | 0                                       | 583                                     | 131                                        |
| 15 | IE-chief Peasant farm Porotova A.I. | Dudinka                                      | 0                                       | 5                                       | 1                                          |
| 16 | IE-chief Peasant farm Nikiforov P.T. | Dudinka                                      | 3,583                                   | 3,585                                   | 807                                        |
| 17 | IE-chief Peasant farm Yamkina E.A. | Nosok                                         | 0                                       | 1,416                                   | 319                                        |
|    | Total                          |                                               |                                        |                                        | Total                                      |
|    |                               |                                               |                                        |                                        | 27,739                                     |
3. The study of the structure

The existing slaughter point is located near Dudinka. To determine the economic efficiency of its location relative to the reindeer enterprises, let us calculate the coordinates of the slaughter point location in the conventional coordinate system in a graphical way: X = 138.30 km; Y = 165.96 km.

Table 3. Baseline matrix of optimal placement of slaughter points considering the mass of feed consumed

| № | Farm location | Number of reindeer, th heads | The volume of feed consumed, th tons (Pi) | Coordinates of reindeer herding enterprises, km | The distance from reindeer herding enterprises to the point of slaughter |
|---|--------------|-----------------------------|-------------------------------------------|-----------------------------------------------|---------------------------------------------------------------------|
| 1 | Karaul       | 2.915                       | 14.90                                     | 222.14                                        | 108.5 193.6 24,102.30 43,006.50                                      | 40.64                                                                  |
| 2 | Tuhard       | 2.738                       | 14.00                                     | 195.98                                        | 91.5 144.7 17,932.45 28,358.74                                      | 51.40                                                                  |
| 3 | Nosok        | 14.384                      | 73.55                                     | 5408.92                                       | 78.7 198.9 425,682.37 1,075,835.12                                   | 68.10                                                                  |
| 4 | Khatanga     | 1.138                       | 5.82                                      | 33.86                                         | 414.9 259.6 14,046.87 8,789.03                                      | 292.02                                                                |
| 5 | Dudinka      | 6.563                       | 33.56                                     | 1126.05                                       | 138.3 140.4 155,732.26 158,096.95                                   | 25.56                                                                  |
| 6 | Potapovo     | 0.0001                      | 0.00                                      | 0.00                                          | 146.3 112.5 0.00 0.00                                                 | 54.06                                                                  |
| Total |         | 27.7381                    | 141.82                                    | 6,986.95                                      | - 637,496.24 1,314,086.34                                            |                                                                      |

To analyze the dynamics of the objective function, we consider the matrix of optimal placement of the slaughter points, when the evaluation criterion consists only of the number of deer driven to the slaughter.

Table 4. Baseline matrix of optimal placement of the slaughter points considering changes in the criterion

| № | Farm location | Number of reindeer, th heads (Pi) | Coordinates of reindeer herding enterprises, km | The distance from reindeer herding enterprises to the point of slaughter |
|---|--------------|-----------------------------------|-----------------------------------------------|---------------------------------------------------------------------|
| 1 | Karaul       | 2.915                             | 108.5 193.6 24,102.30 43,006.50                | 40.64                                                                  |
| 2 | Tuhard       | 2.738                             | 91.5 144.7 17,932.45 28,358.74                | 51.40                                                                  |
| 3 | Nosok        | 14.384                            | 78.7 198.9 425,682.37 1,075,835.12            | 68.10                                                                  |
| 4 | Khatanga     | 1.138                             | 414.9 259.6 14,046.87 8,789.03                | 292.02                                                                |
| 5 | Dudinka      | 6.563                             | 138.3 140.4 155,732.26 158,096.95             | 25.56                                                                  |
| 6 | Potapovo     | 0.0001                            | 146.3 112.5 0.00 0.00                          | 54.06                                                                  |
| Total |         | 27.7381                           | -                                           | 24,385.18 50,265.77                                                  |                                                                      |

The method of successive approximations (iterations) was used to determine the coordinates of the optimal location of the slaughter for different criteria:
- taking into account the mass of feed consumed (table 5 and 6);
- considering only the number of deer (table 7 and 8).
Table 5. Calculation of the optimal location of the slaughter point by the method of successive approximations (1st iteration)

| №  | Farm location | The volume of feed consumed, th tons (Pi) | Coordinates, km | 1st iteration |
|----|---------------|------------------------------------------|-----------------|---------------|
|    |               | xi | yi | Ri(o) | Pi/Ri(o) | xi*Pi/Ri(o) | yi*Pi/Ri(o) |
| 1  | Karaul        | 14.90 | 108.5 | 193.6 | 18.12 | 0.82 | 89.24 | 159.23 |
| 2  | Tuhard        | 14.00 | 91.5 | 144.7 | 43.38 | 0.32 | 29.53 | 46.70 |
| 3  | Nosok         | 73.55 | 78.7 | 198.9 | 16.57 | 4.44 | 349.41 | 883.06 |
| 4  | Khatanga      | 5.82 | 414.9 | 259.6 | 331.47 | 0.02 | 7.28 | 4.56 |
| 5  | Dudinka       | 33.56 | 138.3 | 140.4 | 66.99 | 0.50 | 69.28 | 70.33 |
| 6  | Potapovo      | 0.00 | 146.3 | 112.5 | 93.51 | 0.00 | 0.00 | 0.00 |
|    | Total         |     |     |       |       | 6.10 | 544.74 | 1,163.88 |

X1/Y1 = 89.25, 190.69

Z1 = 6,272.33

Table 6. Calculation of the optimal placement of the slaughter point considering the mass of feed consumed by the method of successive approximations (2nd iteration)

| №  | Farm location | The volume of feed consumed, th tons (Pi) | Coordinates, km | 2nd iteration |
|----|---------------|------------------------------------------|-----------------|---------------|
|    |               | xi | yi | Ri(1) | Pi/Ri(1) | xi*Pi/Ri(1) | yi*Pi/Ri(1) |
| 1  | Karaul        | 14.90 | 108.5 | 193.6 | 19.47 | 0.77 | 83.07 | 148.22 |
| 2  | Tuhard        | 14.00 | 91.5 | 144.7 | 46.05 | 0.30 | 27.82 | 43.99 |
| 3  | Nosok         | 73.55 | 78.7 | 198.9 | 13.37 | 5.50 | 433.01 | 1,094.35 |
| 4  | Khatanga      | 5.82 | 414.9 | 259.6 | 332.86 | 0.02 | 7.25 | 4.54 |
| 5  | Dudinka       | 33.56 | 138.3 | 140.4 | 70.25 | 0.48 | 66.06 | 67.06 |
| 6  | Potapovo      | 0.00 | 146.3 | 112.5 | 96.79 | 0.00 | 0.00 | 0.00 |
| 7  | Total         |     |     |       |       | 7.07 | 617.21 | 1,358.16 |

X2/Y2 = 87.34, 192.19

Z2 = 6,212.08

Table 7. Calculation of the optimal location of the slaughter point by the method of successive approximations (1st iteration)

| №  | Farm location | Number of reindeer, th heads (Pi) | Coordinates, km | 1st iteration |
|----|---------------|---------------------------------|-----------------|---------------|
|    |               | xi | yi | Ri(o) | Pi/Ri(o) | xi*Pi/Ri(o) | yi*Pi/Ri(o) |
| 1  | Karaul        | 2.915 | 108.5 | 193.6 | 18.12 | 0.16 | 17.45 | 31.14 |
| 2  | Tuhard        | 2.738 | 91.5 | 144.7 | 43.38 | 0.06 | 5.78 | 9.13 |
| 3  | Nosok         | 14.384 | 78.7 | 198.9 | 16.57 | 0.87 | 68.34 | 172.71 |
| 4  | Khatanga      | 1.138 | 414.9 | 259.6 | 331.47 | 0.00 | 1.42 | 0.89 |
| 5  | Dudinka       | 6.563 | 138.3 | 140.4 | 66.99 | 0.10 | 13.55 | 13.75 |
| 6  | Potapovo      | 0.0001 | 146.3 | 112.5 | 93.51 | 0.00 | 0.00 | 0.00 |
|    | Total         |     |     |       |       | 1.19 | 106.54 | 227.63 |

X1/Y1 = 89.25, 190.69

Z1 = 1,226.74
Table 8. Calculation of the optimal location of the bottom-hole point by the method of successive approximations (2nd iteration)

| №  | Farm location | Number of reindeer, th. heads (Pi) | Coordinates, km | 2nd iteration |
|----|---------------|-----------------------------------|-----------------|---------------|
|    |               | xi      | yi      | Ri(1)       | Pi/Ri(1)  | xi*Pi/Ri(1) | yi*Pi/Ri(1) |
| 1  | Karaul        | 2.915   | 108.5   | 193.6       | 19.47     | 0.15        | 16.25       | 28.99        |
| 2  | Tuhard        | 2.738   | 91.5    | 144.7       | 46.05     | 0.06        | 5.44        | 8.60         |
| 3  | Nosok         | 14.384  | 78.7    | 198.9       | 13.37     | 1.08        | 84.69       | 214.03       |
| 4  | Khatanga      | 1.138   | 414.9   | 259.6       | 332.86    | 0.00        | 1.42        | 0.89         |
| 5  | Dudinka       | 6.563   | 138.3   | 140.4       | 70.25     | 0.09        | 12.92       | 13.12        |
| 6  | Potapovo      | 0.0001  | 146.3   | 112.5       | 96.79     | 0.00        | 0.00        | 0.00         |
|    | Total         |         |         |             |           | 1.38        | 120.71      | 265.63       |

|     | X2/Y2         | 87.34   | 192.19  |

| Z2  | 1,214.96     |

At this stage, we finally determine the location of the bottom-hole point (Figure 1, in this example X = 87.34, Y = 192.19) within the limits of the accuracy of the calculations (up to 0.5 km). The economic efficiency of the decision on the value of the objective function of the problem (Z = 1,214.96) was further determined. Economic efficiency in terms of the objective function to determine the optimal location of the bottom-hole point is very different depending on the applied criterion: the more conditions, the lower the economic efficiency.

Figure 1. The layout of the point of deer slaughter relative to reindeer enterprises by the method of successive approximations.
4. Conclusion

The most rational location of deer slaughter point relative to the reindeer enterprises was determined by the method of successive approximations. The coordinates obtained do not coincide with the coordinates of the existing point of deer slaughter in Dudinka. Different criteria were used with varying the dynamics of the objective function. The result of the calculations was determined by the highest economic efficiency indicator, that is, a location that minimizes the distance that deer walk to the point of slaughter.

When conducting practical calculations using this technique, one should always compare the results obtained by economic-mathematical and traditional methods in order to bring the mathematical optimum to the real one. The method of calculation used in this paper can be applied directly to other territories, given their territorial affiliation to reindeer herding farms.

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