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EVALUATION OF EFFICIENCY ASSOCIATED WITH OPTIMAL LOCATION OF AGRICULTURAL COMMUNAL DRYING FACILITIES

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Abstract. *Many facilities location models are applied to the consolidation and establishment of elementary schools and fire stations. Those models are formulated to have target demand and facility characteristics and used for analysis. This paper deals with the location problem of the communal drying facilities used by farmers to produce rice. The harvested rice has a large amount of water and needs to be dried for long storage. Farmers who do not have their own drying facilities use the communal drying facilities. In this paper, for farmers using the communal drying facilities, we formulate and analyze as a facility location problem for optimal placement of this facility. Furthermore, the efficiency of the facilities is investigated by using Data Envelopment Analysis (DEA) for the facilities located. Here, the effectiveness of the proposed method is shown using simple numerical examples. By using this method, it is possible to determine the facility to be shipped by the farmer that minimizes the cost of the facility and the travel cost, taking into account the capacity of the facility. And it is possible to suggest a plan to improve the efficiency of the facility.*
Keywords: Facility location problem, Communal drying facility, DEA, Efficiency

1. **Introduction.** Maintenance plans for public facilities and so on, are treated as facility location problems, formulated as mathematical programming problems, and have been actively analyzed in recent years [1].

Takahagi et al. proposed a method to determine the number and location of future fire stations using population distribution while maintaining current accessibility [2]. Considering the effective use of existing facilities, the facility location based on the p-median model corresponding to the expansion and the abolition of the number of facilities has also been proposed [3,4]. Furthermore, it is extended to an optimal spatial facility location model for periodically changing population distribution, and compact urban formation is discussed [5]. The research using each generation data, it has been shown that the optimal facility location solution for each generation does not match [6].

There are many studies on public facility arrangements that provide public services in this way, but there are few studies that deal with the arrangement of agricultural facilities owned by agricultural cooperatives. So, in this paper, we focus on the facility location problem of the communal drying facilities owned by the agricultural cooperative. We capture the characteristics of farmers using this facility, and formulate the installation

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of a new facility considering the existing facility as a facility location problem. And the effectiveness is described through a simple numerical experiment. In addition, we use Data Envelopment Analysis (DEA) to evaluate the efficiency and analyze the efficiency of the new facility installation.

2. **Formulation of Facility Location Problem.** Here, we will deal with which facilities are used to process the products by multiple demands. One of the methods to analyze such a facility arrangement quantitatively is the facility location problem, and here we refer to the case where the capacity of each facility is limited. A facility location problem is a general term for the problem of selecting the optimum point for placing the facilities in the space.

Here, a farmer who is a producer is regarded as demand, a set of demand locations is I, and a set of candidate locations for arranging facilities is J. When the demand location i had use of the facility j, the decision variable $x_{ij} = 1$, otherwise $x_{ij} = 0$. The shipped the facility j befomes $y_j = 1$ and the facility cost is incurred. If it is not shipped, $y_j = 0$ and there is no cost for the facility.

Since each demand is considered to select the facility with the lowest shipping cost, it is assumed that the decision on the shipping destination depends on the distance to the facility. Therefore, we focus on discrete models and formulate using p-median model [1] as follows. This model aims at minimizing the total distance from the demand to the facility to be shipped. Furthermore, in order to minimize the total of facility cost and the travel cost, the following integer programming problem is defined.

$$\min \sum_{j=1}^{n} f_j \cdot y_j + \sum_{i=1}^{m}\sum_{j=1}^{n} d_{ij} h_i s_i x_{ij} \tag{1}$$

$$\text{s.t.} \sum_{j=1}^{n} x_{ij} = 1 \qquad (\forall i \in I) \tag{2}$$

$$\sum_{i=1}^{m} h_i s_i x_{ij} \le l_j \qquad (\forall j \in J) \tag{3}$$

$$x_{ij} \le y_j \qquad (\forall i, j) \tag{4}$$

$$x_{ij} \in \{0, 1\} \qquad (\forall i \in I,\ \forall j \in J) \tag{5}$$

$$y_j \in \{0, 1\} \qquad (\forall j \in J) \tag{6}$$

where,

f_j: Cost for facility j;
d_{ij}: Distance from demand i to facility j;
h_i: Ratio of production using facilities to total production of demand i;
s_i: Product units of demand i;
l_j: Capacity of facility j;
x_{ij}: Allocation of demand i to facility j;
y_j: Candidate location of facility j.

The decision variables x_{ij} and y_j are 0-1 variables, and indicate the carry status to each facility and the location of the facility. Constraint Equation (2) shows that each demand is assigned to one facility. This means that there is only one facility that a farmer can carry. That product is carried within the capacity of each facility is constrained by Equation (3). Then, Equation (4) represents that it is possible to assign a demand only where the facility is opened.

3. **Evaluation of Facility by DEA.** Here, we use DEA to evaluate the facilities and evaluate the efficiency of the facilities. This method can analyze the efficiency of multi-input and multi-output systems, and can create efficiency improvement plans for inefficient

facilities. The CCR model, which is the basic model of DEA, is as follows [9].

$$\begin{aligned} \max \quad & \frac{\sum_{a=1}^{A} v_{ja} O_{ja}}{\sum_{b=1}^{B} u_{jb} I_{jb}} \\ \text{s.t.} \quad & \frac{\sum_{a=1}^{A} v_{ka} O_{ka}}{\sum_{b=1}^{B} u_{kb} I_{kb}} \le 1 \qquad (\forall k \in J) \\ & u_{jb} \ge 0 \qquad (\forall b \in B) \\ & u_{ja} \ge 0 \qquad (\forall a \in A) \end{aligned} \tag{A}$$

where,

I_{jb}: Input values of facility j;
O_{ja}: Output values of facility j;
u_{jb}: Weight assigned to the inputs of facility j;
v_{ja}: Weight assigned to the outputs of facility j.

The optimal solution for this optimization problem (A) is obtained by solving the following linear programming problem. At this time, it is called an input oriented model when assuming $\sum_{b=1}^{B} u_{jb} I_{jb} = 1$, and an output oriented model when assuming $\sum_{a=1}^{A} v_{ja} O_{ja} = 1$. Here we deal with input oriented models. This model can show how much efficiency can be improved by changing input values. In this study, we use input values obtained from the solution of the facility location problem (A). Since the amount of collection at each facility has an effect on efficiency, the efficiency can be improved by controlling the input value.

$$\begin{aligned} \min \quad & \sum_{a=1}^{A} v_{ja} O_{ja} \\ \text{s.t.} \quad & \sum_{b=1}^{B} u_{jb} I_{jb} = 1 \\ & \sum_{a=1}^{A} v_{ka} O_{ka} - \sum_{b=1}^{B} u_{kb} I_{kb} \le 0 \qquad (\forall k \in J) \\ & u_{jb} \ge 0 \qquad (\forall b \in B) \\ & u_{ja} \ge 0 \qquad (\forall a \in A) \end{aligned} \tag{B}$$

4. **Computer Simulations.** Here we assume 10 demands and 4 facilities. A numerical experiment is performed using these virtual data arranged as shown in Figure 1 and Table

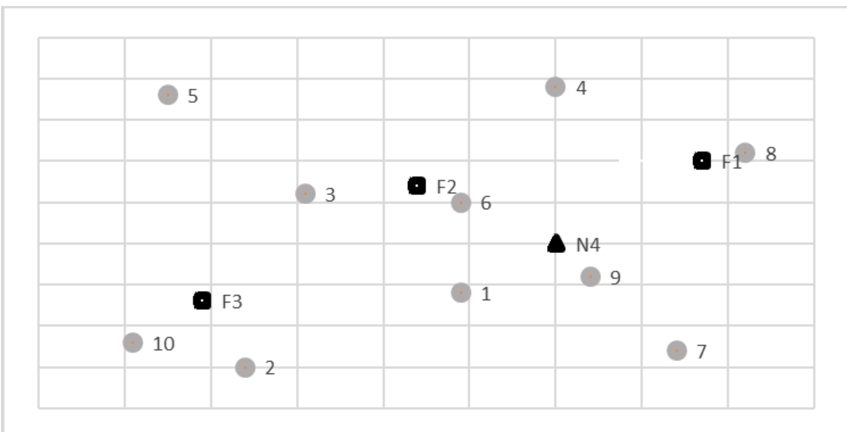

FIGURE 1. Location of 10 demands and 4 facilities

TABLE 1. Virtual values used in this experiment

Facility	Capacity	Cost	Operating days
F1	1330	12798	365
F2	649	9822	200
F3	2225	10900	300
N4	1800	15000	365

Demand	Product	Ratio of production using facilities
1	1685	0.34
2	497	0.52
3	189	0.13
4	1229	0.18
5	406	0.68
6	987	0.17
7	1872	0.37
8	353	0.5
9	926	0.26
10	833	0.78

1. In it, gray circles in the figure represent demand (1 to 10), and black squares represent existing facilities (F1 to F3). The black triangle (N4) indicates the facility that is being considered for installation. The amount of production at each demand, and the capacity and usage rate at each facility are assumed as shown in Table 1.

In these circumstances, it is shown in Figure 2 the results of optimal facility location. In this paper, we calculated using IBM ILOG CPLEX Optimization Studio 12.8.0.0. Here, the left figure is the result of solving the optimal facility placement problem with existing facilities. The numerical value written above the facility number indicates the ratio of the collection amount to the capacity of the facility. The right figure is the result of the optimal location problem when considering a new facility. The solution obtained is indicated by arrows in the figure from demand to facilities.

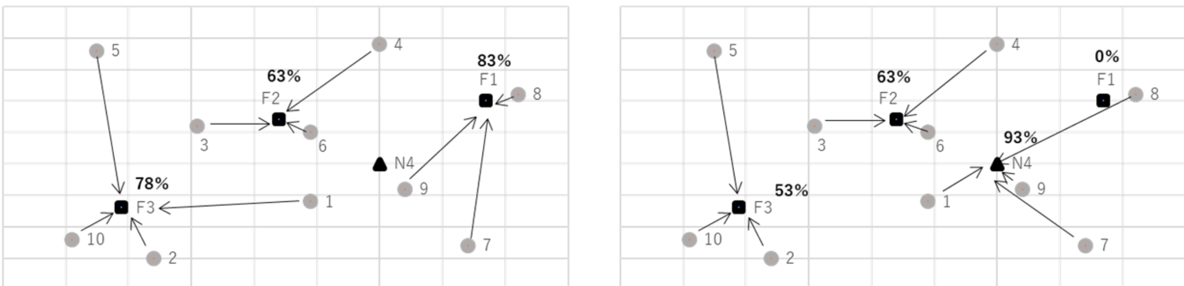

FIGURE 2. Location of 10 demands and 4 facilities

From these figures, it can be seen that the facility F1 becomes unnecessary when installing a new facility N4. Demand 1 with relatively large volume of production becomes selecting N4, which is a closer facility. Demand 1, 7, 9 is by changing the facility N4, the moving distance becomes shorter. However, since the nearest facility F1 is not opened, the demand 8 will carry the next closest N4. In particular, since the production volume at demand 1 is the second largest among all demand points, its travel cost has a large effect on the objective function. Table 1 shows that the cost of facility N4 is 1.17 times higher than that of facility F1. However, this model was judged that the travel cost of demand 1 was more important than the cost of the facility, and F1 was not installed.

Next, in the results on the right side of Figure 2, numerical experiments are performed on an input-oriented model in which the number of input factors is 3 and the number of output factors is 2. Concretely, the input values are capacity, cost and number of operating days, and the output values are the total amount of collection and the collection ratio to the capacity. The result is shown in Table 2.

Table 2. The values obtained from DEA

MAIN	Objective function value	Optimal value				
		u1	u2	u3	v1	v2
F2	1	0	0.000102	0	5.59E-05	1.532957
F3	0.968454743	0	9.17E-05	0	0.000818	0
N4	1	0	6.67E-05	0	0.000594	0

From the viewpoint of efficiency, facilities 2 and 4 are efficient but facility 3 is inefficient. From Figure 2, it seems that the efficiency of the facility 3 is affected as a result of changing the place where the demand 1 carries. The establishment of new facilities is also necessary to consider the future changes in the amount of production.

5. **Conclusions.** In this paper, we focused on the communal drying facilities owned by JA, and formulated the placement of new facilities considering the existing facilities as the facility placement problem. The numerical experiments in this report show that the establishment of a new facility is desirable to close the existing facility. Also, with the placement of new facilities, it is possible to clarify the different demands of the facilities used. Furthermore, it is found that the facilities used are efficient by evaluating the efficiency using DEA. Although numerical experiments using virtual data are shown here, we believe that more effective knowledge can be obtained by conducting computer experiments using actual data. In addition, based on the environment surrounding agriculture in the future, it is necessary to conduct research on the establishment of facilities that take into account the prediction of rice production.

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