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Facility location via fuzzy modeling and simulation

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ABSTRACT

This paper presents a continuous facility location model with fuzzy methodology. The developments concern mainly to some drawbacks in the initial model which takes it far from being used in practice. A fuzzy modeling method is proposed to estimate the required functions in the initial model. Structure identification in the proposed fuzzy modeling method is carried out using subtractive clustering, and parameter identification is conducted via some heuristics as well as an optimization problem. Furthermore, a simulation method along with some heuristic relations is used for implementation and evaluation of the modified model. Efficiency of the proposed method to fuzzy modeling as well as the proposed simulation method is presented by a numerical example.

1. Introduction

In the domain of supply chain management there are two complementary issues for most production systems: facility layout and facility location. Facility layout problems deal with the position of manufacturing machines, stores, and manpower inside a firm. It has attracted the attention of many researchers because it can considerably reduce the material handling costs and yet increase flexibility of the manufacturing system. Facility layout is usually regarded as an optimization problem to determine the most efficient layout based on some prespecified criteria [1,12].

Facility location, on the other hand, concerns the choice of the location of one or multiple facilities, in a given geographical space and subject to some constraints, to optimally fulfill predetermined objectives. It is a strategic decision making compared to facility layout which is more operational. Facility location might be part of a more comprehensive problem named Production–Distribution System Design (PDSD). In general, a PDSD problem involves the determination of the best configuration, regarding location and size of the facilities and distribution centers, their technology content, commodity offerings, and transportation decisions, for achieving a firm's long term goals [11]. It is a strategic issue for both industrial firms and governmental agencies, in that an efficient PDSD can result in reducing transportation costs, enforcing operational efficiency and logistic performance, and improving the quality of the services.

Facility location problems are usually categorized based on some characteristics such as: number of facilities (single/multiple), objective function (single/multiple), solution space (discrete/network/continuous), number of commodities (single/multiple), capacity limitation (yes/no), shape of facility (point/extensive), and demand (discrete/continuous). However, it should be noted that these characteristics are not restricted to the above mentioned ones [7,8,14,19,20].

The main decision variables in facility location problems are coordination (geographical location) of each facility. Besides, number of facilities, capacity of each facility, and its respective service region might be decision variables of the model as well. In problems with discrete solution space, the facilities can conceptually be placed only at a limited number of eligible points on the plane or in a network. On the other hand, in a continuous solution space the points to be located can generally be placed anywhere on the plane or in a network [18,20].

Typically, continuous location problems tend to be nonlinear optimization problems, while discrete location problems involve zero–one variables that result in integer programming optimization problems. Moreover, considering the number of facilities and the capacity of each facility as the decision variables makes the model more complicated, from both the problem formulation and the problem solving perspectives. As a result, the most complex facility location problems are those that consider the number of facilities as well as their coordination and capacities as decision variables in a continuous solution space with multiple objectives and multiple commodities.

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Although the field of facility location is active from the research point of view, when it comes to applications, there appears to be a significant deficit, at least as compared to other similar fields [20]. One reason for this gap could be that many applications cannot be solved by the plain version of a location problem, but further constraints (e.g. forbidden regions) must be introduced in order to construct a reasonable model [7]. To this end, many concepts, tools and techniques of artificial intelligence such as fuzzy logic can be used to improve the implementation of numerous models in operations research [10,11,18,20].

The literature shows that the majority of the works in the area of facility location have used fuzzy theory to fuzzify the parameters of the model or have dealt with the facility location problem as a fuzzy multiple attribute decision making problem [2,3,10,16,24]. Wen and Kang [25], for example, consider fuzzy demands to construct some optimization models for facility location. Unlike these models, a novel utilization of fuzzy theory in facility location is proposed in this paper, in which we deal with estimation of some required nonlinear functions through fuzzy modeling. Although the proposed method is used to develop an existing model proposed by Dasci and Verter [6], it can be extended to formulate any facility location model in which a mathematical function, especially a nonlinear one, is needed for demand density, transportation cost, operational cost, fixed cost, and so on.

The remaining of this paper is organized as follows: Section 2 concisely states the initial model and its drawbacks. Section 3 introduces the required materials for fuzzy modeling and the proposed method. In Section 4, development of the initial model through fuzzy modeling and simulation is discussed in details. Section 5 indicates implementation of the proposed method via a numerical example. Finally, conclusions of the paper and future works are presented in Section 6.

2. Problem statement

Continuous models are successfully used in spatial economics and logistics, but there are probably a few papers that use continuous models for facility design [6]. Models of this type assume that customers are spread over a given market area and prescribe the optimal service region for each facility to be established [6]. Dasci and Verter [6] present a PDSD model in which the concentration is on facility location with the following main features:

(1) the model consists of two multi-element layers: manufacturing facilities and end customers,
(2) the number of manufacturing facilities is a decision variable,
(3) the model is a single-product PDSD problem,
(4) customers' demand is deterministic and is specified by a density function,
(5) there is no limitation for manufacturing facilities' capacity,
(6) all customers' demand must be satisfied.

The objective is to minimize the sum of total annual costs including fixed, operational, and transportation costs. They present a modeling framework based on the use of continuous functions to represent spatial distributions of cost and costumer demand. Herein, the Dasci and Verter's model [6] is briefly addressed.

Assume that a firm wants to open some manufacturing facilities in a demand area, where each facility serves a single service region. In such a case, decision variables are: *the number of facilities*, *the location of facilities*, and *the service region of each facility*. Facilities can be located anywhere in the demand area. Let's M denotes the market area for which the following variables and parameters are defined:

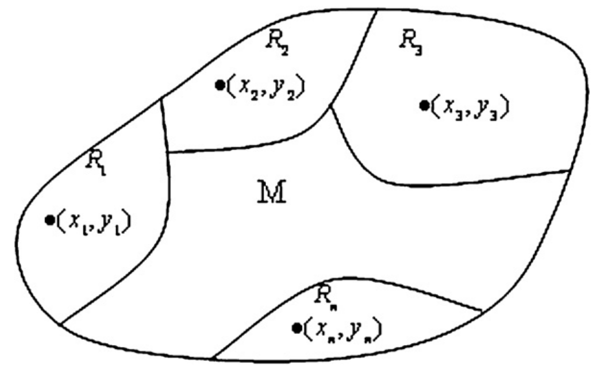

Fig. 1. A sample solution of the initial model.

Decision variables:
n: number of facilities
(x_i, y_i): location coordination of the ith facility
R_i: service region to be served by facility i, which is located at $(x_i, y_i) \in R_i$
A_i: area of the service region i (km^2)
Parameters:
$D(x, y)$: demand density at $(x, y) \in M$ (item/km^2 year)
$F(x, y)$: fixed cost of opening a facility at $(x, y) \in M$ (\$/year)
$f(x, y, w)$: operational cost of opening a facility of size w at $(x, y) \in M$ (\$/year)
$g(x, y, R_i)$: total transportation cost given facility location $(x, y) \in M$ and service region R_i (\$/year)

It is assumed that the whole demand is to be satisfied, thus service region must cover the demand area. Furthermore, each service region is served by a single facility. Generally, service regions can have irregular, rather than just geometrical, shapes. Fig. 1 depicts a hypothetical sample solution.

The objective is to minimize total annual costs including annual fixed, operational, and transportation costs. It is assumed that all parameters vary slowly within a service region. Also, the operational cost is assumed to be a linear function as:

$$f(x, y, w) = O(x, y) \cdot w \tag{1}$$

where $O(x, y)$ is the production cost in the facility located in (x, y) for each unit of the product and w is the total annual production. As a result, the total annual operational cost is defined as:

$$\sum_i f(x_i, y_i, w) = \sum_i f\left(x_i, y_i, \int_{R_i} D(x, y)dx\,dy\right) \tag{2}$$

Since

$$A_i = \int_{R_i} dx\,dy \tag{3}$$

and

$$\int_{R_i} D(x, y)dx\,dy \approx D(x_i, y_i) \cdot A_i \tag{4}$$

Eq. (2) is transformed to:

$$\sum_i f(x_i, y_i, w) \approx \sum_i f(x_i, y_i, D(x_i, y_i) \cdot A_i) \approx \sum_i O(x_i, y_i) \cdot D(x_i, y_i) \cdot A_i \tag{5}$$

By assuming that the transportation costs are usually charged on a per item km basis, the following variables can be defined: