FOUNDATIONS OF COMPUTING AND DECISION SCIENCES
Vol. 48 (2023) No. 3
ISSN 0867-6356
DOI: 10.2478/fcds-2023-0014 e-ISSN 2300-3405

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Designing a Mathematical Model to Solve the Uncertain Facility Location Problem Using C Stochastic Programming Method

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Abstract. Locating facilities such as factories or warehouses is an important and strategic decision for any organization. Transportation costs, which often form a significant part of the price of goods offered, are a function of the location of the plans. To determine the optimal location of these designs, various methods have been proposed so far, which are generally definite (non-random). The main aim of the study, while introducing these specific algorithms, is to suggest a stochastic model of the location problem based on the existing models, in which random programming, as well as programming with random constraints are utilized. To do so, utilizing programming with random constraints, the stochastic model is

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transformed into a specific model that can be solved by using the latest algorithms or standard programming methods. Based on the results acquired, this proposed model permits us to attain more realistic solutions considering the random nature of demand. Furthermore, it helps attain this aim by considering other characteristics of the environment and the feedback between them.

Keywords: location problem, mathematical model, meta-heuristic algorithms, service level, stochastic modeling.

1. Introduction

Before the 1960s, the most fundamental assumption in historical economic geography about how industries grow and become more economical was based on the theory of homo economics, in which it is assumed that humans compete for higher gains with foresight and equipped with the information and knowledge required for decision-making [1-3]. This assumption is not perfectly realistic. Meanwhile, the minimum cost theories were focused entirely on the effect of transportation cost, ignoring how demand can also determine the geographical location of industrial activities [4-6]. This led to the tendency of theoretical analysis to focus on accessible markets and the competition to develop and expand these markets [7,8]. According to this theory, industry owners try to maximize revenues by reducing production costs (including transportation costs) and accessing safer and larger markets [9-11].

In the late 1970s, researchers influenced by systemic approaches to problem-solving combined the theories mentioned above into what became known as the location theory. In this approach, economic activities and industries should be located in places that maximize the owners' revenue-cost difference (profit) [12,13].

In general, location is the act of identifying a region's spatial and non-spatial potentials to select a suitable site for a particular use. In recent years, location studies have emerged as one of the key elements in the success and survival of industrial units [7,14]. In the stochastic facility location problem, the goal is to find optimal locations for a series of facilities and allocate demand points to these facilities to minimize cost and overall transport distance when demand points have random locations [15,16].

In the real world, it could be challenging to accurately estimate parameters such as the size of demand for goods or services specific to each facility, the location of facilities, the location of demand points, etc. [17,18]. This problem can be modeled in various ways based on the demand size (which can be assigned a specific distribution based on the amount and location of demand points) and the type of demand [19,20].

After this introduction, in the second section, we review the literature on the stochastic location problem and some of the models proposed for this problem, along with their objective functions and constraints. Considering the gap in the research literature, in the third section, we present an efficient stochastic location model with more realistic constraints and conditions. After presenting the model, we explain the objective function and constraints used in the model and finally describe its properties and features. We then present the results of a case study and end the paper with conclusions and some suggestions regarding the problem.

2. Literature Review

In a study by Schütz et al. [12], they developed a stochastic facility location model to minimize the cost of locating single-product facilities and allocating potential demands to them. In this investigation, a two-stage formulation for this problem was introduced. In the first stage, the facility cost function is approximated. In the second stage, a piecewise linear cost function is formulated for long-run and short-run costs. In the first stage, the objective function is to minimize the probability of occurrence of a series of scenarios by limiting the satisfaction of all demands by facilities. Scenarios in this model are based on parameters such as the location of destinations, the location of existing facilities, the size of demand at each destination, and the capacity of each facility. In the second stage, the objective function is to minimize the cost of production and transportation from facilities to destinations subject to constraints concerning demand satisfaction, allocation of demands to facilities with sufficient capacity, and allocation of demands to available facilities.

Li et al. [6] designed a model for the location-allocation problem with predetermined inputs using chance-constrained programming and dependent-chance programming. They used the simplex algorithm to solve this stochastic model. This study used the genetic algorithm and stochastic simulation to create an efficient solution algorithm. In their model, the goal was to minimize the costs of satisfying customer demand in proportion to the distance between the facility and customers while ensuring limited satisfaction of all random demands. Finally, they used a numerical example to demonstrate the performance of the proposed algorithm.

Roudsari and Wong [16] presented a facility location model with stochastic demand points. In this model, each of m existing facilities with coordinates (a_i, b_i) has a probability of being located in a place like $f(a_i, b_i)$. Considering the location of the new facility to be located as (x, y) and the positive weight assigned to the existing facilities as w_i, they formulated their model as follows:

$$\text{minimize } [\max E\{w_i(|x - a_i| - |y - b_i|) = f(a_i, b_i)\}]$$
Subject to:
$$C_{j1}x + C_{j2}x \leq C_{j3}x \tag{1}$$

where C_1, C_2, and C_3 are the constants used to create linear constraints. Also, the marginal probability of the location of each existing facility was formulated as follows:

$$E[f_i(x,y)] = w_i \int_{-\infty}^{+\infty}\{|x - a_i| \int_{-\infty}^{+\infty} f(a_i, b_i)db_i\}da_i + w_i \int_{-\infty}^{+\infty}\{|y - b_i| \int_{-\infty}^{+\infty} f(a_i, b_i)da_i\}db_i = w_i \int_{-\infty}^{+\infty}|x - a_i| f_{1(a_i)}da_i + w_i \int_{-\infty}^{+\infty}|x - b_i| f_{2(a_i)}db_i = E[f_i(x)] + E[f_i(y)] \tag{2}$$

In the end, they proved the good performance of their model by conducting a simulation with a numerical example.

Viswanath and Ward [7] proposed a stochastic facility location allocation model with random demand points. In this model, locations of demand points and facilities are considered random at certain intervals. They formulated a model for minimizing the total cost, including the costs due to the distance between facilities and demand points.

In a study carried out by Golabi et al. [13], they presented a facility location model with stochastic demand points and immobile facilities. In this model, it is assumed that customers prefer the closest facility available. The objective of this model was to minimize the total cost of transportation and waiting costs. The model also had a constraint for the number of facilities that should be available and the longest waiting time for each facility. To solve this problem, they used three meta-heuristic methods, namely, a greedy-dropping procedure, a branch-and-bound algorithm, and Tabu Search. The results of numerical tests showed that the greedy-dropping procedure does not perform as great as the branch-and-bound algorithm, and the Tabu search and its solutions could be up to 20% sub-optimal in some cases.

Mousavi and Niaki [15] proposed a capacitated location-allocation model for cases where demands are located at random points and are uncertain. In this study, demands were considered to be fuzzy, locations were assumed to have a normal distribution, and the distance between facilities and customers was assumed to have a Euclidean distribution. Two sets of Euclidean and Euclidean squared terms were considered for measuring the expected distance between facilities and customers. To solve this problem, they used intelligent meta-heuristic methods, including the simplex algorithm, fuzzy simulation, and modified genetic algorithm. They also used a numerical example to demonstrate the performance of the algorithm.

Gabor and van Ommeren [1] proposed a model for facility location with stochastic demand and inventory. This model assumes that the demands are independent and follow a Poisson process. They also introduced a confidence factor to the formulation in order to avoid zero inventory levels (α-1) was considered as the acceptance area). The main objective of this model is to locate facilities such that inventory levels meet the allocated demand at the confidence level (α-1) with minimum restocking cost:

$$\lambda_{ij} = \begin{cases} \text{If facility located at i is available} & \lambda_{ij} \\ \text{Otherwise} & 0 \end{cases} \tag{3}$$

In other words, λ_{ij} satisfies the demand of points j. With these assumptions, they formulated their stochastic facility location model as follows:

$$\min \sum_{i\in f}(f_i + c_i V_i)y_i + \sum_{i\in f}\sum_{j\in D}\lambda_i\, c_{ij}x_{ij} \tag{4}$$

Subject to:

$$x_{ij} \le y_i, \qquad i \in f, j \in D \tag{5}$$

$$\sum_{i\in f} x_{ij} = 1, \qquad j \in D \tag{6}$$

The objective function of this model is to minimize the fixed and variable costs associated with the size of demand allocated. The first constraint is related to the satisfaction of demand by facilities, which has been defined as a binary variable. The second constraint requires all demands to be satisfied, and the third constraint ensures the satisfaction of demand to the

level specified by the decision-maker. They rewrote the stochastic location model with a Poisson distribution assigned to constraint 3 and solved the problem in a case study.

Fadda et al. [3] comprehensively focused on service facility location problems. This review stated that decision-making techniques, including those of taxonomy type, can provide good results in this area. Mohammadi et al. [10] presented a robust approach for facility location in crises. In this approach, not only the location but also the routing of relief efforts are optimized. These researchers showed that capacity planning for relief facilities could lead to up to 30% cost reduction. Pahlevan et al. [11] developed a mathematical model of facility location and distribution in an aluminum supply chain. They used several meta-heuristic methods, including the red deer algorithm, to solve this mathematical model. Karagöz et al. [8] developed a model for the location of recycling centers using the ARAS method and fuzzy numbers. The results of a case study in Istanbul confirmed the good performance of this facility location model.

3. Material and Methods

The stochastic facility location problem involves locating a set of facilities to satisfy stochastic demands (demand destinations or customers) typically with the objective of total cost minimization. Facilities have certain service level requirements that are modeled by constraints.

3.1. Objective function

In this study, the objective function is regarded as cost minimization. To be precise, the aim of the objective function is to minimize the total system cost, consisting of the fixed cost of facilities and the variable cost of satisfying the allocated demands based on their distance from the facilities to which they are allocated.

3.2. Model constraints

- Demand satisfaction by facilities
- A constraint to ensure the satisfaction of demands (to accelerate the process of finding integer solutions)
- The probability of satisfying the demand given its random nature

In the following matrices, (x_i, y_i) is the location of facility i, (a_j, b_j) is the location of customer j, and Z is the possible states for the satisfaction of each demand by each facility:

$$(X,Y)=\begin{pmatrix} x_1 & y_1 \\ x_2 & y_2 \\ \cdots & \cdots \\ x_m & y_m \end{pmatrix},(a,b)=\begin{pmatrix} a_1 & b_1 \\ a_2 & b_2 \\ \cdots & \cdots \\ a_n & b_n \end{pmatrix},Z=\begin{pmatrix} z_{11} & z_{12} & \cdots & z_{1m} \\ z_{21} & z_{22} & \cdots & z_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ z_{n1} & z_{n2} & \cdots & z_{nm} \end{pmatrix} \quad (7)$$

Before formulating the model, first, its indices, parameters, and variables need to be defined.

3.3. Indices

i: index of facilities $i = 1,\ldots, m$
j: index of customers (demand points) $j = 1,\ldots, n$

3.4. Parameters

f_i: The fixed cost of facility *i*
y_i: The number of candidate locations for facility *i*
x_{ij}: A Binary variable for the allocation of customer *j* to facility *i*
β: A constant used in distance-related cost constraint

3.5. Variables

c_{ij}: The cost of supplying one unit of demand of customer *j* from facility *i*
d_j: The demand of customer *j*
Q_j: The capacity of facility *i*
a_i: The probability that the stochastic demand is met by facility *i*
(x_i, y_i): A decision variable indicating the location of facility *i*
(a_j, b_j): A decision variable indicating the location of customer *j*
z_{ij}: The amount facility i provides to customer j after receiving a stochastic demand

3.6. Modeling of the stochastic facility location problem

$$\text{Minimize } Z = \sum_{i=1}^{m} f_i\, y_i + \sum_{i=1}^{m}\sum_{j=1}^{m} c_{ij}\, x_{ij} \tag{8}$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = 1 \qquad i = 1, \ldots, m \tag{9}$$

$$\sum_{i=1}^{m} x_{ij} \le y_i \qquad j = 1, \ldots, n \tag{10}$$

$$\text{prob}\left(\sum_{j=1}^{n} d_j \,.\, x_{ij} \le Q_i y_i\right) \ge a_i \qquad i = 1, \ldots, m \tag{11}$$

$$z_{ij} \ge 0 \qquad i = 1, \ldots, m \quad j = 1, \ldots, n \tag{12}$$

$$\sum_{i=1}^{m} z_{ij} \le Q_i \qquad j = 1, \ldots, n \tag{13}$$

$$\sum_{j=1}^{n} z_{ij} = d_i \qquad i = 1, \ldots, m \tag{14}$$

$$c_{ij} = \beta\sqrt{\left(x_i - a_j\right)^2 - \left(y_i - b_j\right)^2} \qquad i = 1, \ldots, m \quad j = 1, \ldots, n \tag{15}$$

$x_{ij} = 0,1, z_{ij} \geq 0 \quad , \quad j = 1, \dots, n \quad i = 1, \dots, m$

3.7. Description of constraints and objective function of the stochastic facility location model

The objective function is to minimize system costs, including fixed facility costs and variable costs, to satisfy the demand points allocated to each facility.

Provided in the following is a brief description of the constraints used in the model.

Constraint 1 ensures that a facility meets every demand. Constraint 2 states that the total demand of each customer should be smaller than the allocated resources. Constraint 3 guarantees that the probability of satisfying a demand is greater than a predetermined threshold (the decision-maker determines this; in this model, this threshold is assumed to be 90%, 80%, and 85%). Constraint 4 ensures that the quantities provided to customer j are supplied from facility i. Constraint 5 states that the quantities provided to customer j from facility i are equal to or smaller than the capacity of that facility. Constraint 6 requires the satisfaction of all demands, and Constraint 7 sets the cost associated with each demand in proportion to its distance from the facility.

3.8. Types of demand distribution in the stochastic facility location model

As mentioned, the distributions typically used in stochastic facility location models are normal and Poisson. In the following, we examine the normal distribution and its effect on the objective function and constraints.

3.9. Demands with normal distribution

Suppose that the total demand allocated to a facility, assuming a normal distribution, has the following mean and variance:

$$\sum_{i=1}^{n} \mu_j X_{ij}, \qquad \sum_{j=1}^{n} \sigma_j^2 X_{ij} \tag{16}$$

With this assumption, the stochastic constraint can be rewritten as follows:

$$\frac{Q_i - \sum_{i=1}^{n} \mu_j X_{ij}}{\sqrt{\sum_{j=1}^{n} \sigma_j^2 X_{ij}}} \geq z_{a_i} \qquad i = 1, \dots, m \tag{17}$$

In this function, z_{ai} denotes the critical values of the standard normal distribution with probability $prob\ (z \leq z_{ai})$. The proposed model can also be solved with stochastic programming and meta-heuristic methods.

4. Results and Discussion

The proposed model was applied to a numerical example related to the iron and steel industry. In this example, 5 facilities located in industrial estates must satisfy the demand of 15 customers from different parts of Asia. The demand has an average of 100 and a variance of 10. The rest of the problem information is provided below (Table 1).

Table 1. Case problem information

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
f_1	800000	a_2	0.85	d_2	109	d_{10}	91
f_2	800000	a_4	0.9	d_3	102	d_{11}	104
f_3	800000	Q_1	280	d_4	100	d_{12}	107
f_4	1000000	Q_2	350	d_5	109	d_{13}	93
f_5	1000000	Q_3	330	d_6	104	d_{14}	107
a_1	0.9	Q_4	325	d_7	108	d_{15}	109
a_3	0.9	Q_5	300	d_8	92		
a_5	0.85	d_1	95	d_9	90		

After solving the model with the above values, the results showed a 12.04% cost reduction, which is significant considering the industry's high expenses. After reviewing the solution, however, we found that it requires all demands to be met by a single facility, which, although it seems reasonable, is not practical since one facility may not be able to satisfy all demands at all times. Therefore, a more reliable cost reduction can be achieved by satisfying the demand of customers based on their distance from facilities. The results are as follows (Table 2):

Table 2. Results obtained for the case problem

Parameter	Obtained Value	Parameter	Obtained Value
z_{015}	95	z_{073}	108
z_{024}	6	z_{084}	92
z_{025}	103	z_{094}	38
z_{035}	102	z_{091}	90
z_{042}	100	z_{103}	91
z_{052}	109	z_{111}	104
z_{062}	71	z_{123}	107
z_{064}	33	z_{133}	46
z_{141}	107	z_{154}	109

The other z values are zero. As can be seen, the results indicate the good performance of the model.

4.1. Sensitivity analysis

This section is dedicated to presenting the numerical results obtained for the sensitivity analysis of the model. Regarding sensitivity analysis of the presented model, the aim was to analyze the impact of the demand parameter on the objective function value. To meet that aim, demand was changed by multiple rates between -50% and + 50%. To compare their sensitivity, this was carried out for both the stochastic and the deterministic models. The results of this sensitivity analysis are provided in Table 3.

Table 3. Results of sensitivity analysis with respect to demand

Demand change	Certain model	Stochastic model
-0.5	2461.00	2347.00
-0.4	2461.00	2347.00
-0.3	2461.00	2375.56
-0.2	2461.00	2375.56
-0.1	2609.39	2375.56
0	2609.39	2457.58
0.1	2609.39	2498.25
0.2	2609.39	2498.25
0.3	2609.39	2645.13
0.4	2609.39	2645.13
0.5	2609.39	2645.13

The results show that in both deterministic and stochastic models, the objective function value increases with the increase in demand. This increase is sharper for demand changes of -20% to +20% but has a much smaller gradient for demand changes beyond 20%. These results highlight the critical importance of considering demand variations when conducting facility location, as a mere 20% change in demand can greatly increase the total cost of the system.

Moreover, comparing the deterministic and stochastic models, it can be concluded that the stochastic model forces lower costs on the decision-maker. Furthermore, this model provides the decision-maker with a more realistic image of the situation in comparison with the deterministic model. These results are indicative of the good performance of the proposed mathematical model.

5. Conclusion

One of the most important challenges in the location of municipal service projects in our country is the traditional view of managers toward the location of these facilities. Our managers tend to make such location decisions based solely on experience instead of using scientific methods and analyses. It could be very difficult and sometimes impossible to

estimate the basic parameters needed for such analyses in real-world situations. Therefore, it is highly recommended to use some means of dealing with uncertainty to overcome the challenges of working with dynamic conditions. In the facility location field, the stochastic location approaches can be very effective in responding to the needs of real-world problems.

Stochastic facility location models allow us to reach more realistic solutions by considering the random nature of demand. They also help us to achieve this goal by considering other such characteristics of the environment and the feedback between them.

After examining the previous stochastic facility location models and their objective functions and constraints and observing the gaps in the research literature, in this paper, we proposed a stochastic facility location model with more realistic conditions. In this model, many limitations associated with real-world situations in relation to the satisfaction of demands allocated to facilities are considered. In the end, the performance of this model was investigated and confirmed by applying it to a real case example.

Future studies in the field of stochastic facility location are recommended to consider time windows for stochastic demands to reach better and more realistic models to minimize the costs associated with demand satisfaction.

Conflict of interest: there is no conflict of interest.
Acknowledgments: not applicable.
Funding: the article did not use any funding.

References

[1] Gabor A.F., van Ommeren J.C., An approximation algorithm for a facility location problem with stochastic demands and inventories, *Operations research letters*, **34**, 3, 2006, 257-263.

[2] Ryu J., Park S., A branch-and-price algorithm for the robust single-source capacitated facility location problem under demand uncertainty, *EURO Journal on Transportation and Logistics*, **11**, 2022, 100069.

[3] Fadda E., Manerba D., Cabodi G., Camurati P.E., Tadei R., Comparative analysis of models and performance indicators for optimal service facility location, *Transportation Research Part E: Logistics and Transportation Review*, **145**, 2021, 102174.

[4] Ni W., Shu J., Song M., Xu D., Zhang K., A branch-and-price algorithm for facility location with general facility cost functions, *INFORMS Journal on Computing*, **33**, 1, 2021, 86-104.

[5] Sonuç E., Binary crow search algorithm for the uncapacitated facility location problem. *Neural Computing and Applications*, **33**, 21, 2021,14669-14685.

[6] Li H., Zhang B., Ge X., Modeling emergency logistics location-allocation problem with uncertain parameters, *Systems*, **10**, 2, 2022, 51.

[7] Viswanath K., Ward J., Stochastic location-assignment on an interval with sequential arrivals, *Networks and Spatial Economics*, **10**, 3, 2010, 389-410.

[8] Karagöz S., Deveci M., Simic V., Aydin N., Interval type-2 Fuzzy ARAS method for recycling facility location problems, *Applied Soft Computing*, **102**, 2021, 107107.

[9] Cooper L., The stochastic transportation-location problem, *Computers & Mathematics with Applications*, **4***,* 3, 1978, 265-275.

[10] Mohammadi S., Darestani S.A., Vahdani B., Alinezhad A., A robust neutrosophic fuzzy-based approach to integrate reliable facility location and routing decisions for disaster relief under fairness and aftershocks concerns, *Computers & Industrial Engineering*, **148**, 2020, 106734.

[11] Pahlevan S.M., Hosseini S.M.S., Goli A., Sustainable supply chain network design using products' life cycle in the aluminum industry, *Environmental Science and Pollution Research*, 2021, 1-25.

[12] Schütz P., Stougie L., Tomasgard A., Stochastic facility location with general long-run costs and convex short-run costs, *Computers & Operations Research*, **35***,* 9, 2008, 2988-3000.

[13] Golabi M., Idoumghar L., Arkat J., A bi-objective single-server congested edge-based facility location problem under disruption. *In 2022 IEEE Congress on Evolutionary Computation (CEC*) (pp. 01-08). IEEE. 2022.

[14] Bhowmick S., Inamdar T., Varadarajan K., Fault-tolerant covering problems in metric spaces, *Algorithmica*, **83**, 2, 2021, 413-446.

[15] Mousavi S.M., Niaki S.T.A., Capacitated location allocation problem with stochastic location and fuzzy demand: A hybrid algorithm, *Applied Mathematical Modelling*, **37***,* 7, 2013, 5109-5119.

[16] Roudsari A. H., Wong K.Y., A bi-objective stochastic single facility location model for a supermarket, *International Journal of Services and Operations Management*, **17***,* 3, 2014, 257-279.

[17] Fraj E., Matute J., Melero I., Environmental strategies and organizational competitiveness in the hotel industry: the role of learning and innovation as determinants of environmental success, *Tourism management*, **46**, 2015, 30-42.

[18] Nga T.T.T., Pham K.D., The effect of business strategy on R&D expenditure and firm performance–evidence from Taiwan, *Management Systems in Production Engineering*, **30***,* 1, 2022, 80-90.

[19] Xu J., Shang Y., Yu W., Liu F., Intellectual capital, technological innovation and firm performance: evidence from China's manufacturing sector, *Sustainability*, **11***,* 19, 2019, 5328.

[20] Alam A., Uddin M., Yazdifar H., Shafique S., Lartey T., R&D investment, firm performance and moderating role of system and safeguard: evidence from emerging markets, *Journal of Business Research*, **106**, 2020, 94-105.

Received 16.07.2022, Accepted 14.05.2023