

A Multi-Objective Approach for Emergency Facility Planning

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Abstract: Many types of emergency facilities location models have been developed to find optimal spatial patterns with respect to multiple location criteria that include cost, timeliness, coverage and etc. In this paper, we developed a multi-objective DEA and GP combined model that first uses DEA to evaluate the relative efficiency of each alternative location, and then combines that formulation in a multi-objective framework. A hypothetical example is presented to illustrate the applicability of the proposed model. The analysis verified that the proposed DEA and GP combined model is an effective tool for generating a set of more realistic and flexible optimal solution in solving emergency facility location problems and provides a promising rich approach to multi-objective facility location problems.

Keywords: multi-objective; data envelopment analysis; goal programming; location

1. Introduction

Emergency services such as police, fire departments and ambulance systems are crucial in saving lives and reducing injury and must provide a high level of quality service to ensure public safety. The number and location of emergency facilities have a strong influence on the quality of emergency services. Thus, determination of where to locate emergency facilities and how many emergency facilities to have in a given area is perhaps the most important decision faced by any Chief Emergency Administrator.

Emergency facility location problems have multiple objectives which often conflict with each other. Timeliness is one of the most important objectives that reflect the quality of emergency service systems (Goldberg JB, 2004). In addition to it, the objectives such as cost minimization, maximization of coverage equity, efficiency of emergency facilities resources, service level to the uncovered zones, etc must be considered in the selection procedure of an emergency facility location. Therefore, emergency facility location selection can be viewed as a multiple-criteria decision-making (MCDM) problem (Current J et al, 1999; Drezner T. et al, 2006).

In this paper, a multi-objective facility location model for emergency services by the application of two operations research methodologies, data envelopment analysis (DEA) and the multi-objective goal programming (GP) is proposed. Based on the DEA methodology as originally proposed by Charnes, Cooper, and Rhodes (1978), Shroff et al (1998) described their problem of locating long-term care facilities in the Northern Virginia region as one of "locational benchmarking" and used DEA as a locational benchmarking tool to measure the relative efficiencies of potential geographical regions to support the siting decision for a long term health care facility. Thomas et al (2002) developed a multiple decision-making-unit (DMU) version of the DEA model

called the multi-alternative DEA model. This multi-alternative DEA model simultaneously solves the DEA model in one linear programming for picking the most efficient p obnoxious-facility locations based on the DEA score.

In order to simultaneously both patterns of locations for facilities and the associated relative efficiencies of those facilities at each potential location, Ronald and Samuel (2006) develop the simultaneous DEA model (SDEA) that can simultaneously find the efficiencies of all potential locations.

In the above-mentioned papers, when DEA is used alone to evaluate the relative spatial efficiency of location decisions, the potential location with the highest relative efficiency is selected for implementation. Unfortunately, the selection of location alternatives via the DEA-only solution method has not taken into consideration the other facets of the problem (Badri M, 1999). Thus, when the decision makers are faced with a multiple location problem, extending the traditional DEA method to selecting multiple locations with the highest combined efficiency-score among all the facilities at a time can result in an infeasible selection since possible limiting or constraining resources are not directly considered in the selection process. To extend the DEA approach to cover the above limitation, this paper suggests a combined DEA and goal-programming methodology. The purpose of this paper is to demonstrate how a combined DEA and GP model can be used to aid in optimal spatial and efficient facility location/allocation patterns.

The paper is further organized as follows. In Section 2, we develop and present formulations combining the multi-objective goal programming facility location problem with the DEA problem. Section 3 includes an illustration of the proposed model to demonstrate the effectiveness of the solution approaches used. Finally, concluding remarks are presented in the last section.

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2. Combined DEA and Goal Programming Model

In this section, two methodologies are combined for the emergency facility location selection. DEA is first presented as a stand-alone methodology and then a combined DEA and GP model is presented as an extension to consider additional criteria in decision making process.

We utilized the ratio DEA model, proposed by Charnes et al. (1978), shown as Model (3), in evaluating the relative efficiency scores h_j of the branch offices j .

The greater the relative efficiency h_j , the greater the preference for the specific j th location. Extending the use of the DEA methodology to consider resource limitations and other goals, we propose a GP model, which incorporates the DEA relative efficiencies as one of its goals as in Eq.(1)

$$\sum_{j=1}^n Y_j h_j + d_n^- - d_n^+ = \sum_{j=1}^n Y_j \quad (1)$$

In addition to the DEA relative efficiencies, multiple as well as conflicting goals are present in the emergency facility location problem. Two common goals used in many emergency-location related studies are (a) to minimize the fixed cost including the total setup and operating cost, (b) to minimize the time from the fire station to any incident site (Ceyhun Araz et al,2007). In our approach we adopt the model built by Badri M et al (1998). These are explained below:

Goal 2: Minimize the total setup and operating cost

One common objective used in many emergency- location related studies is to minimize the fixed cost associated with locating the new facility (Tsouros and Sartzemi, 1994).

$$\sum_{j=1}^n Y_j f_j + d_f^- - d_f^+ = F \quad (2)$$

In Eq. (2), F is the total fixed cost targeted, n is the number of potential sites, and f_j is the fixed cost associated of opening a facility at candidate location j .

Goal3: Minimize maximum time traveled from station to accident site

Eq. (3) presents the constraint associated with minimizing the maximum time traveled from fire stations to demand areas.

$$\sum_{i=1}^m \sum_{j=1}^n X_{ij} t_{ij}^{\max} + t^{\max-} - t^{\max+} = T_{\max}^* \quad (3)$$

where the right-hand side is set to $T_{\max}^*$, $T_{\max}^*$ is the optimal solution when the maximum time is the objective function to be minimized. $t_{ij}^{\max}$ is the maximum time between station j to area i .

Goal 4: Minimize total time traveled from station to accident sites

As mentioned, many researches used the length of time which elapses between the call to the emergency facility and the arrival of appliances and men to the site to reflect the loss from any emergency incident. Furthermore, every additional emergency facility, if probably located, will reduce the overall time between call and arrival.

$$\sum_{i=1}^m \sum_{j=1}^n a_i X_{ij} t_{ij}^{av} + t^{\text{total}-} - t^{\text{total}+} = T_{\text{total}}^* \quad (4)$$

where the right-hand side is set to T_{total}^* , T_{total}^* is the optimal solution when the total time is the objective function to be minimized. t_{ij}^{av} is the average distance between station j to area i , and m is the number of areas to be served and a_i is the demand in area i

Goal 5: Attain targeted number of fire stations required

The goal for attaining the targeted number of emergency facilities, given by Eq. (5), represents the desired expansion rate reflecting forecasted demand for emergency services.

$$\sum_{j=1}^n Y_j + d_l^- - d_l^+ = L \quad (5)$$

where L is the targeted number of emergency facilities required.

Hence, given the above constraints and considering the priorities assigned to the achievement of goals, the emergency facilities location problem was reduced to the problem of minimizing the sum of goal deviational variables subject to the goal constraints giving due considerations to the priority factors. Of course, the priorities given to each goal will attempt to reflect the decision making criteria of decision-makers. Therefore, the proposed combined DEA and GP model can be formulated as following:

$$\begin{aligned} \min Z = & P_1(d_f^- + d_f^+) + P_2(t^{\max-} + t^{\max+}) \\ & + P_3(t^{\text{total}-} + t^{\text{total}+}) + P_4(d_n^- + d_n^+) + \\ & P_5(d_l^- + d_l^+) \end{aligned}$$

3. Example

In this section, we give an illustrative example to show how the proposed models can be used to optimize the facility locations for emergency services. We also compare the solution obtained by the combined DEA and GP model with the solution to the DEA-only location problem, thereby assessing the advantages of the combined model (if any).

We grid the demand area into square zones using the center of each zone as an aggregated demand point. In this example, a total of 15 demand zones from which emergency services are generated were established. Furthermore, ten eligible sites in which emergency facilities could be placed are identified.

Guided by Chun-Hsiung Lan et al (2007), the list of

costs includes the number of on-duty personnel. The on-duty cost, the total vehicle displacement and the vehicle maintenance fee. The benefits were defined: the number of fire cases, the number of rescue cases, the number of public service cases. The ratio DEA model was utilized in evaluating the relative efficiency scores of the branch offices.

Given the DEA relative efficiencies, a combined DEA and GP model is formulated. The resulting solutions are presented in table 1 and 2.

Table 1 Comparison of the DEA-GP model solution and DEA-only solution (decision variables)

Location Alternative	The combined model selection solution	DEA-only selection decision
F1	Yes	No(0.5817)
F2	No	No(0.6257)
F3	No	No(0.5745)
F4	Yes	Yes(1)
F5	Yes	No(0.7811)
F6	No	Yes(0.9288)
F7	No	No(0.5991)
F8	No	No(0.7393)
F9	No	Yes(1)
F10	Yes	Yes(0.8291)

Table 2 Comparison of the DEA-GP model solution and DEA-only solution (deviation form goals)

Resource	Targeted goals	DEA-GP model deviation	DEA-only model deviation
Fixed cost	1980	0	-460
Total distance	56935	19827	29883
Maximum distance	492	38	203
Desired expansion rate	4	0	0
DEA relative efficiency	4	-0.8081	-0.2421

A comparison of the DEA-only, and the combined DEA-GP solutions reveals the potential superiority of the combined model. If we run the DEA-only model to select the four highest DEA relative efficiency locations by setting the associated Y_i 's to be 1 (i.e. F4, F6, F9, F10 respectively), we can see that this selection decision will exceed the budgeted fixed cost (i.e., by 460) and most importantly increase the maximum time (i.e., by 203) and the total time (i.e., by 29883) compared to the AHP-GP result of only 19827 and 38 respectively. In other words, the DEA-only solution of selecting the four highest relative efficiencies constitutes an infeasible solution since insufficient resources exist to support that selection. Moreover, the maximum time and the total time (the total loss from the emergency accidents) will increase greatly although the negative deviation associated with the DEA relative efficiency is (-0.2421) com-

pared to the AHP-GP result of (-0.8081). Thus, the solution provided by the combined DEA-GP model is realistic and feasible since it takes into consideration resource limitation and the total and maximum travel time, which are the dominant factors for the emergency facility location.

4. Conclusion

In this paper a DEA and GP combined multi-objective model for locating emergency facilities is presented. This is accomplished by first using DEA to evaluate the relative efficiency of each alternative location, and then combining that formulation in a multi-objective goal programming framework. A numerical example presented in this paper illustrated the applicability of the proposed model. A comparison of the DEA-only and the combined DEA and GP solutions reveals the potential superiority of the combined solution when making the emergency facility location decisions.

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References

- [1] Badri M. Combining the analytic hierarchy process and goal programming for global facility location-allocation problem. *Int. J. Production Economics* 1999,62,P237-248
- [2] Ceyhan Araz, Hasan Selim, Irem Ozkarahan A fuzzy multi-objective covering- based vehicle location model for emergency services. *Computers & Operations Research* 2007, 34 ,P705-726
- [3] Charnes A, Cooper WW, Rhodes E.. Measuring efficiency of decision making units. *European Journal of Operational Research* 1978,2, P29-44.
- [4] Current J, Min H, Schilling D. Multi- objective analysis of facility location decisions. *European Journal of Operational Research* 1999,49,P295-307.
- [5] Drezner, T.; Drezner, Z.; Salhi, S. . A multi-objective heuristic approach for the casualty collection points location problem. *Journal of the Operational Research Society* 2006,57,P727-734
- [6] Goldberg JB. Operations research models for the deployment of emergency services vehicles. *EMS Management Journal* 2004,1(1),P20-39.
- [7] Lili Yang , Bryan F. Jones , Shuang-Hua Yang . A fuzzy multi-objective programming for optimization of fire station locations through genetic algorithms. *European Journal of Operational Research* 2007,181,P903 - 915
- [8] Ronald K. Klimberg, Samuel J. Ratlick. Modeling data envelopment analysis efficient location/allocation decisions. *Computers & Operations Research*, Article in press. doi: 10.1016/j.cor.2006.03.010
- [9] Shroff HE, Gullledge TR, Haynes KE Siting efficiency of long-term health care facilities. *Socio-Economic Planning Sciences* 1998,32(1), P25-43.
- [10] Thomas P, Chan Y, Lehmkuhl L, NixonW . Obnoxious-facility location and data envelopment analysis: a combined distance-based formulation. *European Journal of Operation Research* 2002,141(3),P495-514