COMPARISON OF OPTIMIZING MODELS FOR AMBULANCE LOCATION PROBLEM FOR EMERGENCY MEDICAL SERVICE

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Determining the optimal location of ambulance stations is an important strategic and operational consideration. We are study two static ambulance location models; the location set covering model (LSCM) and the double standard model (DSM) using open source nonlinear programming solver computed on instances derived from the Kyoto city data and randomly generate of demand.

Key Words : Location Optimization, Emergency Medical Service, Location Set Covering Model, Double Standard Model

1. INTRODUCTION

In case of Japan, the Fire Defense Act was amended in 1963, assigning ambulance service responsibilities to Fire Defense organizations[1)]. The ambulances are located at fire stations and there is a one-tiered EMS system[2)]. EMSs are providing by the local governmental fire defense headquarters, as based on the Local Autonomy law and Firefighting Acts.; no other organization allowed to providing ambulance service.

Emergency response system in urban areas should be located to ensure adequate coverage and rapid response time. Determining the optimal location of ambulance stations is an important strategic and operational consideration. They are so many of ambulance location and relocation models since 1971. Early models are several of objective functions under constraint of given number of ambulances, minimum covering, number of ambulance types, and allocated condition at site; they are no constraints to the location of ambulance stations.

Ambulance location problem was focused since 1970s. The review of ambulance location and relocation models was found in [2), 3), 4), 5), 6)]. The classic ambulance location problem is a tactical planning problem of demand covering in an area.

If costs are identical for all possible locations, then an equivalent problem is to minimize the total number of ambulance station. We used Location Set Covering Model (LSCM)[7)] to answered the lower bound on the number of stations required. LSCM ignore several aspects of real-life problems, the most important probably being that once an ambulance is dispatched, some demand points are no longer covered. We used Double Standard Model (DSM)[8)] to seek the maximize demand covered twice.

2. MODEL REVIEW

Ambulance location models are defined on graphs. The set of demand points is denoted by V and the set of potential ambulance location sites is denoted by W. The shortest travel time t_{ij} from vertex i to vertex j of the graph was known. A demand point $i \in V$ is said to be covered by site $j \in W$ if and only if $t_{ij} \leq r$, where r is a preset coverage standard. Let $W_i = \{ j \in W : t_{ij} \leq r \}$ be the set of location sites covering demand point i.

The location set covering model (LSCM) introduced by Toregas et al. in 1971, the aim is to minimize the number of ambulances needed to cover all demand points. It uses binary variables x_j equal to 1 if and only if an ambulance is located at vertex j:

(LSCM)

Minimize $$\sum_{j \in W} x_j \quad (1)$$

Subject to

$$\sum_{j \in w_i} x_j \geq 1 \quad \forall i \in V \quad (2)$$

$$x_j = (0,1) \ \forall\, j \in W \quad (3)$$

The double standard model (DSM) original proposed by Gendreau et al. in 1997 seeks to maximize the demand covered twice within a time standard of r_1, using p ambulances, at most p_j ambulances at site j, and subject to the double covering constraints, two coverage standards are used r_1 and r_2, with $r_1 < r_2$. All demand must be covered by an ambulance located within r_2 time units, and a proportion α of the demand must lie within r_1 time units of an ambulance, which may possibly coincide with the ambulance that covers demand within r_2 units. Let $W_i^1 = \{j \in W : t_{ij} \leq r_1\}$ and $W_i^2 = \{j \in W : t_{ij} \leq r_2\}$. The integer variable y_j denotes the number of ambulances located at $j \in W$ and the binary variable x_i^k is equal to 1 if and only if the demand at vertex $i \in V$ is covered k times (k = 1 or 2) within r_1 time units. The formulation is then:

(DSM)

Minimize $$\sum_{i \in V} d_i x_i^2 \quad (4)$$

Subject to

$$\sum_{j \in W_i^2} y_j \geq 1 \qquad \forall i \in V \quad (5)$$

$$\sum_{i \in V} d_i x_i^1 \geq \alpha \sum_{i \in V} d_i \quad (6)$$

$$\sum_{j \in W_i^1} y_j \geq x_i^1 + x_i^2 \qquad \forall i \in V \quad (7)$$

$$x_i^2 \leq x_i^1 \qquad \forall i \in V \quad (8)$$

$$\sum_{j \in W} y_j = p \quad (9)$$

$$y_j \leq p_j \qquad \forall\, j \in W \quad (10)$$

$$x_i^1, x_i^2 = (0,1) \qquad \forall i \in V \quad (11)$$

$$y_j = \text{integer} \qquad \forall\, j \in W \quad (12)$$

3. EXPERIMENTATION AND RESULT

We use open source nonlinear programming solver[9] add-in on Open Office™ 3.3[10] provide by Sun Microsystems™, Inc. using Evolution Algorithms (EA). The experimentation runs on AMD Athlon™64 X2 Dual Core 4800+ and 3 GB of RAM operated by Microsoft® Windows XP™ 32bits (Service Pack 3). Evolution Algorithms technique[11] is similar to genetic programming, but the structure of the program is fixed and its numerical parameters are allowed to evolve. Evolution Algorithms model[12] is natural processes, such as selection, recombination, mutation, migration, locality and neighborhood. **Fig.1** shows the structure of a simple evolutionary algorithm.

(1) Experimental data

Experimental data is derived from urban area of Kyoto city. We assigned customer vertexes in to square area of size 300 meters width and 300 meters length, they are 1392 customer vertexes by selected only residential area and business area is shown in **Fig.2**. Based on real data, Kyoto city has 41 sites of fire department facilities[13] located in real geography position shown on **Fig.3**. We estimate distance from each possible ambulance locations to center of customer vertexes by using the Direction function provided by Google™ Earth® [14].

(2) Experimental conditions

Ambulances pass through traffic with special permission but not allowed to increase the risk of accident. Thereat, average of ambulance travel speed in urban area as same as limited about 60 km/h. We using seven different values of average ambulance travel speed as 30, 35, 40, 45, 50, 55 and 60 km/h, specify standard travel time r_1 as 5 minutes because 50% of persons who called an ambulance could get help within five minute[4] and specify standard travel time r_2 as 10 minutes same as standard response time in urban area defined by the US EMS Act of 1973[14], and let space for ambulance stand at each station is 1.

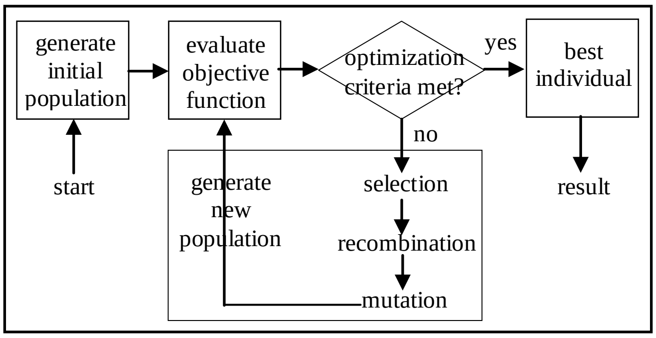

Fig.1 Structure of a single population evolutionary algorithm (original source: www.geatbx.com/docu/algindex-01.html)

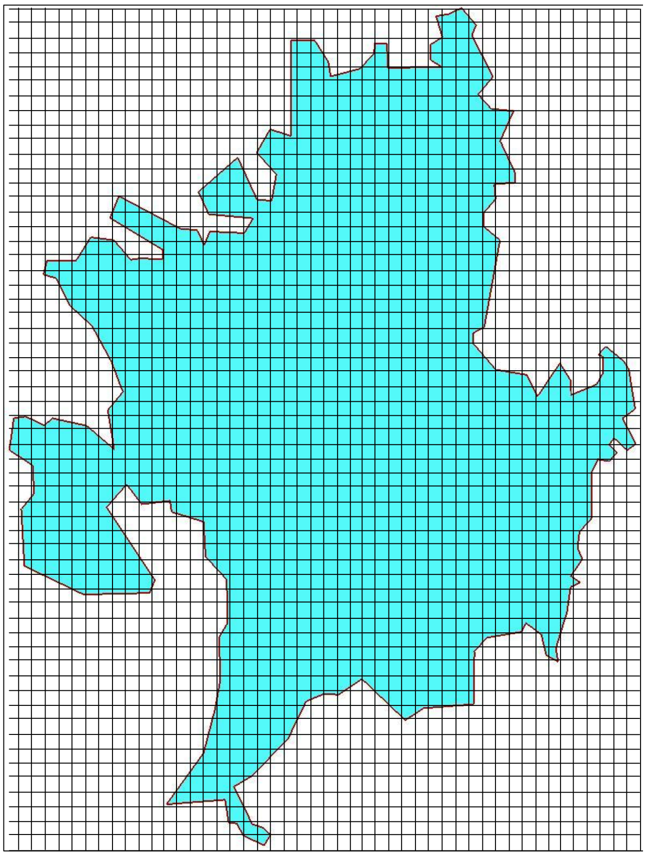

Fig.2 Assigned customer vertexes

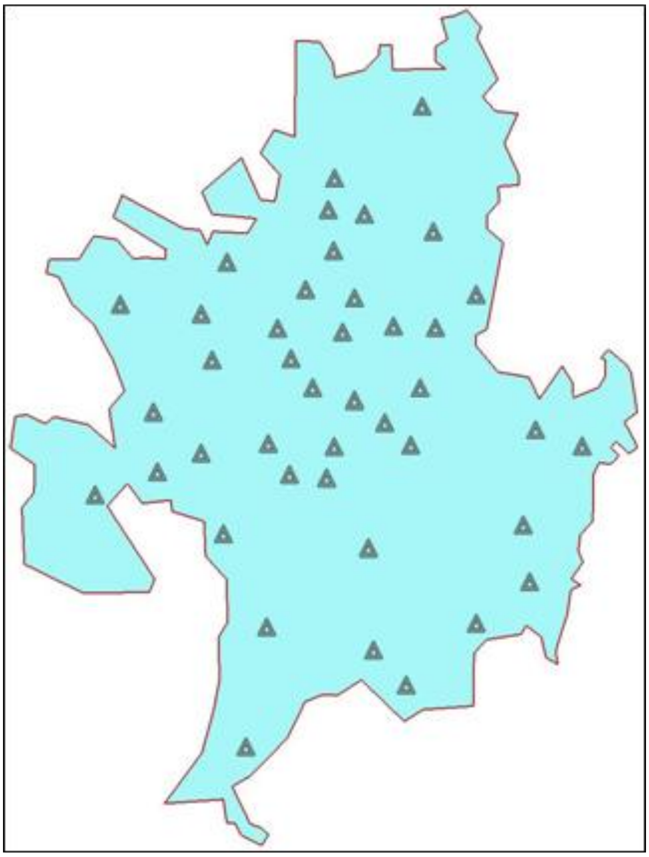

Fig.3 Location of fire department facilities

First, we use the LSCM to seek lower bound of the number of ambulance stations for each average travel speed within r_2 limited travel time. Next, we assigned the maximum number of ambulance stations for each average travel speed to the DSM with result of the LSCM. We avoiding constrain (6) and continue seeking solutions of objective function (4), we will get the level of coverage in r_1 both of two models.

(3) Experimental result

Computation results of 1392 customer vertexes and 41 potential ambulance stations via open source nonlinear programming add-in solver using Evolution Algorithms. Output of the LSCM is shown in **Table 1** and output of the LSCM is shown in **Table 2**. The table heading are as follows:

s	Average ambulance travel speed;
1..41	ID of potential ambulance stations;
ns	Number of ambulance stations;
%c_r1	Percentage of demand covered within r_1;
%c_r2	Percentage of demand covered within r_2;
c_1	Demand covered at least once time;
c_2	Demand covered at least twice time;
at	Average travel time to sense (minutes)

Each experimentation conditions had taken a lot of computing time; the LSCM used at least 3 hours and near to 8 hours of longest time, the DSM took more than 8 hours for minimum and up to 24 hours. Output shown in **Table 1** in column of facilities location, the digit 1 means the solution assigned ambulance to stand at that potential site.

(4) Discussion

Output of the LSCM in case 30 km/h of average ambulance travel time has shown the solver cannot seek near-optimal solution for covered all demand vertexes within 10 minutes (some vertexes are far from fire department facilities more than 10 minutes of travel time to sense).

Both of two models are concern 100 % covered within r_2 time standard. With same number of ambulance stations but different objective function, the difference on four output values make easy to comparing the level of service between two models. Focused four output values are:

%c_r1:c_1	Percentage of covered at least once time within r_1,
%c_r1:c_2	Percentage of covered at least twice time within r_1,
%c_r2:c_2	Percentage of covered at least twice time within r_2, and
at	Average travel time to sense (minutes).

With positive and negative of the difference values is easy to describe what models give better level of service

Table 1 Computation result of the location set covering model (r_1 = 5 minutes, r_2 = 10 minutes)

	facilities location																																									% c_r1		% c_r2		
s	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	ns	c1	c2	c1	c2	at
60	1							1																							1					1		1				5	0.6565	0.0518	1.0000	0.8329	4.1429
55	1							1																							1					1		1				5	0.5702	0.0276	1.0000	0.7203	4.5195
50				1			1													1									1		1					1		1				7	0.6040	0.1838	1.0000	0.8347	4.3397
45				1						1					1			1										1			1			1	1			1				9	0.6396	0.1063	1.0000	0.8510	4.3107
40		1								1							1			1					1	1		1						1		1		1		1		11	0.6483	0.0625	1.0000	0.8797	4.2059
35		1						1		1								1								1	1	1						1	1			1			1	11	0.5753	0.0312	1.0000	0.7831	4.6347
30	No solution																																									Not available					

Table 2 Computation result of the double standard model (r_1 = 5 minutes, r_2 = 10 minutes)

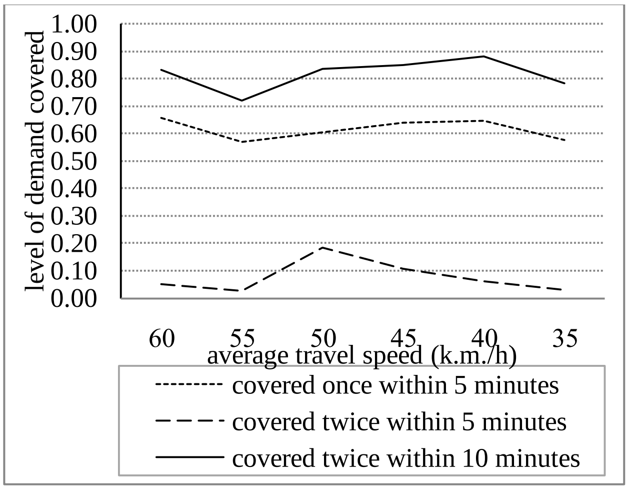

Fig.4 Trend of demand covered using the LSCM

Fig.5 Trend of demand covered using the DSM

Fig.6 Trend of average travel time to sense

Fig.7 Comparison of covered at least once time within r_1

Fig.8 Comparison of covered at least twice time within r_1

Fig.9 Comparison of covered at least twice time within r_2

4. CONCLUSION AND FURTURE WORK

We using evolution algorithm provide by open source nonlinear programming solver add-in on Open Office™ 3.3; followed the LSCM to seek lower bound of the number of ambulance stations to cover all demand and followed the DSM to solves heuristically a static coverage location for ambulance stations using output of the LSCM as *p* values based on Kyoto city's map. The experiment used randomly vertex's demand value between 0 and 1, using seven different average travel speeds= [30, 35, 40, 45, 50, 55, 60] km/h, set r_1 to 5 minutes, and set r_2 to 10 minutes.

Ambulance service in Kyoto city with current 41 fire department facilities locations cannot deliver 100% covering within 10 minutes if average travel speed of ambulance is less than 35 km/h.

The next step is to study multi period model and dynamic model of ambulance location model to understand effect of time variant variable to level of service for ambulance services. We will drill deeply in evaluation algorithm; take experimentation with population distribution data of the Kyoto city and looking for better performance tools.

The result would be included in final submission and would be presented at the conference.

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