Solving a Maximal Covering Model of Emergency Ambulance Location Problem in Urban Areas by Dynamic Programming Technique

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Abstract: This paper considers the maximal covering ambulance location problem for regular traffic situation and heavy traffic congestion situation in urban areas. A two hierarchical objectives model for planning level based on MCLP model is proposed and exact searching algorithm based on Dynamic Programming technique is developed for its solution. The traffic behavior is assumed to be normally distributed. The stochastic traveling speed is derived to be a static variable using inverse cumulative function by a given percentile rank. The model defines regular traveling speed with 0.50 percentile of distribution and speed for heavy traffic congestion situation with 0.05 percentile of distribution. The proposed model solved by proposed searching algorithm is compared with the MCLP model solved by CPLEX and proposed searching algorithm. Computational results using both randomly generated data and real data of Osaka city confirm the efficiency of the proposed approach.

Keywords: Urban Areas, Ambulance Location, Maximal Covering Location Problem, Dynamic Programming, Hierarchical Objectives

1. INTRODUCTION

The emergency medical service (EMS) is an important service in the city. It aims to reduce number of unnecessary death and disability. The main objective of emergency ambulance service in the role of transporting emergency medical technicians (EMT) is to reach the scene within the effective time for treatment. The key idea of emergency ambulance location problem is to determine the "best" base locations for ambulances in order to optimize service level objective (or surrogate objective). All emergency calls in urban areas should be administered (100% covered) with in standard response time. Every patient should be treated by a physician within 15 minutes (US ACS, 1963) and that resuscitation cases should be treated immediately within 4 minutes (De Maio *et al*., 2003).

The context of the problem is to locate a limited number of EMT teams to set of potential ambulance stations in urban areas for maximizing covered population both in regular traffic situation and heavy traffic congestion situation. The focus of this paper is on location decisions made at planning level of emergency ambulance services. More specifically, the aim is to develop and solve exactly a static coverage location model. It is intended to assist local authorities to locate the EMT teams to potential ambulance stations.

The research on location problem for emergency ambulance stations has a long history in MS/OR literature since 1970s. The review of ambulance location models can be found in Brotcorne *et al.* (2003), Goldberg (2004), and Sorensen and Church (2010). The first maximal covering model is proposed by Church and ReVelle (1974) to locate p stations for maximizing population coverage. Schilling *et al*. (1979) extended Church and ReVelle's work (1974) for two types of ambulance. Daskin (1983) incorporated Church and ReVelle's model (1974) with busy probability. The model is assumed that each ambulance has the same probability q, called the *busy fraction*, is estimated by dividing the total calls by the total number of available ambulances. Bianchi and Church (1988) combined Schilling *et al.*'s approach (1979) and Daskin's approach (1983) for two types of ambulances. ReVelle and Hogan (1989) implemented Daskin's approach (1983) to maximize the coverage with a given reliability of service, α. The minimum number of ambulances required to serve each demand node with reliability α is determined. Repede and Bernardo (1994) implemented Daskin's approach (1983) for a decision support system for all time period of the day. Marianove and ReVelle (1996) implemented ReVelle and Hogan's approach (1989) with queuing theory. The model computes the minimum number of ambulances for a region using M/G/s-loss queuing system. Mandell (1998) expanded Schilling *et al.*'s work (1979) for two-tier services. Marianov and Serra (1998) extended Church and ReVelle's model (1974) for ensure the maximum waiting queue. Marianov and Serra (2001) proposed covering model for hierarchical two-level service system. Gendreau *et al.* (2006) implemented the busy fraction methodology of Daskin (1983) into Church and ReVelle's model (1974) for relocation problem. Schmid and Doerner (2010) extended Gendreau *et al.*'s model (1997) for multi-period relocation problem.

The backup coverage (double coverage) models have been proposed in Daskin and Stern (1981), Hogan and ReVelle (1986), Prikul and Schilling (1989), and Prikul and Schilling (1992). Gendreau *et al.* (1997) extended backup coverage models to double standard model. Gendreau *et al.* (2001) extended Gendreau *et al.*'s model (1997) to relocation problem.

Most of ambulance location models assumed the ambulances is travels with the maximum authorized speed. In urban areas and mega-cities, EMS systems encounter the dynamic of road traffic and congestion especially during rush hour under the limitation of resources to serve the uncertainty of scene locations and amount of events. To deal with stochastic traveling speeds, Daskin (1987) presented a model that integrated the probability, P_{ij}, allowing an ambulance to reach specific demand node within standard response time using random travel time while Goldberg and Paz (1991) assumed path travel times are normal distribution. They used regression analysis to estimate average travel time as a function of distance among various types of roads, and compute the P_{ij} values using the mean and the standard deviation of the residuals. Marianov and ReVelle (1996) also assumed travel time is normally distributed and the node is covered within average travel time plus standard deviation. Moreover, Ingolfsson *et al.* (2008) assumed the travel time and the delay of dispatch are normally distributed.

There are currently no ambulance location models considering the optimal sitting location for both regular traffic situation and high traffic congestion situation. The authors' aim is to develop a maximal covering model for both regular traffic situation and high traffic congestion situation, and to design exact searching algorithm using Dynamic Programming technique for its solution. The proposed model is extended the maximal covering location problem (MCLP) of Church and ReVelle (1974) to incorporate with traffic congestion. It has two hierarchical objectives to maximize population coverage for regular traffic situation and considers population coverage for heavy traffic situation. The model assumes travel speed is normally distributed and represents stochastic traveling speed with a static value using inverse cumulative function. The method considered should also be exact, robust, and fast for planning level.

The proposed model is presented in next section, followed by the searching algorithm with Dynamic Programming technique in Section 3. The computational results of generated data and real data are reported in Section 4 and by the conclusion in Section 5.

2. MATHEMATICAL MODEL

2.1 Representing Traffic Congestion

The traffic behavior is assumed to be normally distributed (Donald and Daniel, 1951; Daskin, 1987; Marianov and ReVelle, 1996; Ingolfsson *et al.*, 2008). The stochastic travel speed of ambulance is obtained for two static values by specifics the percentile (β) of the inverse cumulative distribution, one for regular traffic situation and the other for heavy traffic congestion situation. The regular traveling speed (average speed or maximum authorized speed) of the speed distribution is specified at 0.50 of percentile (β = 0.50). Decreasing the percentile represents more congestion in network (low speed). This research specified the speed of the heavy traffic congestion situation at 0.05 percentile rank (β = 0.05).

2.2 The Maximal Covering Location Model (MCLP)

It is useful to recall the maximal covering location problem (MCLP) of Church and ReVelle (1974) formulation for locate p stations to maximize number of population covered. Let I be the set of n demand nodes. Let J be the set of m potential ambulance stations. The problem is defined on a graph $G = (I \cap J, E)$, where E is the set of edges $\{(i,j): i \in I, j \in J\}$, each associated with distance, $d_{i,j}$. The maximum travel time (response time) is denoted by r minutes. The number of stations to be located is denoted by p. Let a_i corresponds to the population of demand node $i \in I$. Let $\mathbb{L}$ is pattern of station located. Let x_j be a binary variable which equal to 1 if and only if station is located at $j \in J$. Church and ReVelle (1974) used maximum authorized speed to measure the covering function. It represented to the speed at 0.50 percentile. Let $y_i^{0.50}$ be a binary variable which equal to 1 if and only if demand node $i \in I$ is covered with the traveling speed of regular traffic situation. A demand node $i \in I$ is considered to be covered by a station $j \in J$ whenever the traveling time from j to i is no more than a specified coverage time r. Denote by $J_i^{0.50}$ is the subset of stations set, J, that cover demand node $i \in I$ with traveling speed of regular situation. The mathematical formulation of MCLP model is:

$$\text{(MCLP)} \quad \text{Maximize} \quad \sum_{i \in I} a_i y_i^{0.50} \tag{1}$$

$$\text{Subject to} \quad \sum_{j \in J_i^{0.50}} x_j \geq y_i^{0.50} \qquad \forall i \in I \tag{2}$$

$$\sum_{j \in J} x_j = p \tag{3}$$

$$x_j = 0,1 \qquad \forall j \in J \tag{4}$$

$$y_i^{0.50} = 0,1 \qquad \forall i \in I \tag{5}$$

For MCLP model, constraint (2) means the demand node is covered only if at least an ambulance station is located in $J_i^{0.50}$, and constraint (3) controls the number of stations to be located. Constraint (4) makes decision to locate the station at site j or not. Constraint (5) presents the demand node i is covered for regular traffic situation by the station location pattern or not.

2.3 The Maximal Covering Location Model Considering Heavy Traffic Congestion (MCLP-*htc*)

The problem is planning stage for determine the optimal ambulance station location pattern in urban areas considering heavy traffic congestion. The maximal covering location problem considering heavy traffic congestion (MCLP-*htc*) model has two hierarchical objective functions are maximize the population covered for regular traffic situation and then maximize the population covered for heavy traffic congestion situation as shown in Figure 1.

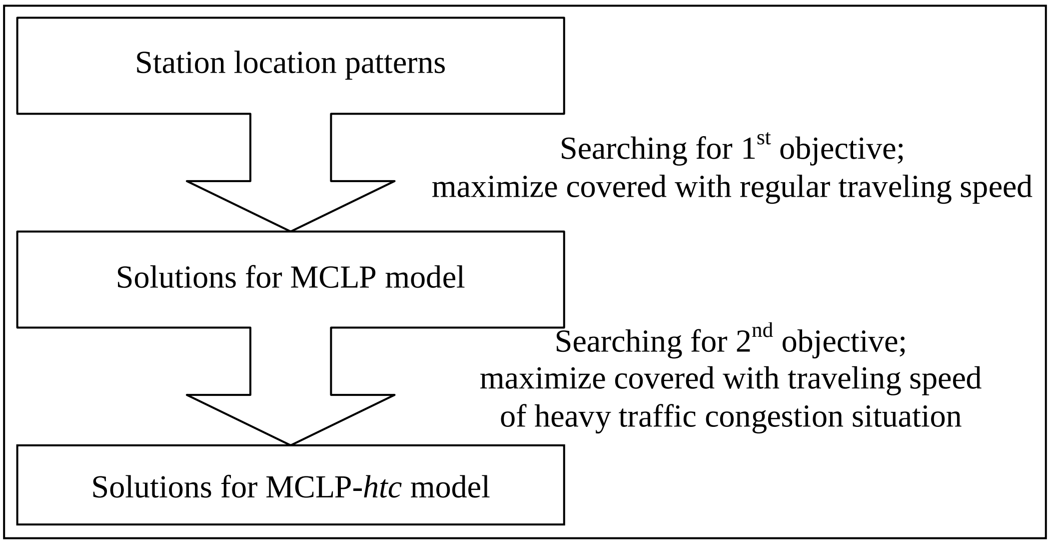

Figure 1. Conceptual of the MCLP-*htc* model

Denote Z^1 to the population covered with of regular traveling speed and denote Z^2 to the population covered with traveling speed of heavy traffic congestion situation. The first objective represented by Equation (6). It is related to Equation (1).

$$\text{Maximize} \qquad Z^1(\mathbb{L}, p) = \sum_{i \in I} a_i y_i^{0.50} \tag{6}$$

And then follows by the second objective, represented by Equation (7).

$$\text{Maximize} \qquad Z^2(\mathbb{L}, p) = \sum_{i \in I} a_i y_i^{0.05} \tag{7}$$

The constraints of MCLP-*htc* model are:

$$\text{Subject to} \quad \sum_{j \in J_i^{0.50}} x_j \geq y_i^{0.50} \qquad \forall i \in I \tag{8}$$

$$\sum_{j \in J_i^{0.05}} x_j \geq y_i^{0.05} \qquad \forall i \in I \tag{9}$$

$$\sum_{j \in J} x_j = p \tag{10}$$

$$p < m \tag{11}$$

$$y_i^{0.50} \geq y_i^{0.05} \qquad \forall i \in I \tag{12}$$

$$x_j \quad = 0,1 \qquad \forall j \in J \qquad (13)$$
$$y_i^{0.50}, y_i^{0.05} \quad = 0,1 \qquad \forall i \in I \qquad (14)$$

where I = {1,2,…,n} is set of demand nodes indexed by i
J = {1,2,…,m} is set of potential stations indexed by j
a_i = population at node i
p = number of stations to be located
β = specific percentile rank for inverse cumulative distribution function
d_{ij} = shortest distance from node i to station j
r = standard response time (maximum travel time)
s^β = speed of ambulance at β percentile rank of travel speed distribution
$J_i^\beta = \{j \in J \mid d_{ij} \leq (r \times s^\beta)\}$
$x_j = \begin{cases} 1 \text{ if station } j \text{ is located} \\ 0 \text{ otherwise} \end{cases}$
$y_i^\beta = \begin{cases} 1 \text{ if } \sum_{j \in J_i^\beta} x_j > 0 \\ 0 \text{ otherwise} \end{cases}$

For MCLP-*htc* model, constraints (8), (10), and (13) followed constraints (2) – (4) of MCLP model. Constraint (11) controls the number of stations to be located, p, is less than the total number of potential station locations, m. The demand node cannot be covered at 0.05 percentile if it is not covered at 0.50 percentile by constrain (12). Constraint (14) presents the demand node i is covered for regular traffic situation ($y_i^{0.50}$) and for heavy traffic congestion situation ($y_i^{0.05}$) by the station location pattern or not.

3. SEARCHING ALGORITHM

The Dynamic Programming (DP) technique (Richard, 1957; Wagner, 1995; Coremen *et al.*, 2009) is suitable method for solving the exact solution and the multiple objectives problem. According to the MCLP model and the MCLP-*htc* model, the problem has broken to be 4 simpler sub-problems are:

1) Dose pattern $\mathbb{L}$ is located p stations? If true, stores $\mathbb{L}$ into the possible solution list. This sub-problem represents Equation (3) and Equation (11); denoted to F1.
2) Which demand node is covered by pattern $\mathbb{L}$ in possible solution list with specific β percentile? This sub-problem represents function y_i^β=1 if and only if $\sum_{j \in J_i^\beta} x_j > 0$; denoted to F2.
3) Dose pattern $\mathbb{L}$ in possible solution list provide maximum demand coverage at the regular travel speed? If not, removes it from possible solution list. This sub-problem represents Equation (1) and Equation (6); denoted to F3.
4) Dose pattern $\mathbb{L}$ in possible solution list provide maximum demand coverage for the speed of high traffic congestion? If not, removes it from possible solution list. This sub-problem represents Equation (7); denoted to F4.

Exact searching algorithm for solving the MCLP model and the MCLP-*htc* model were developed and their flowcharts are presented in Figure 2. The pseudocodes of searching algorithm for MCLP model and MCLP-*htc* model are presented in Figure 3 and Figure 4.

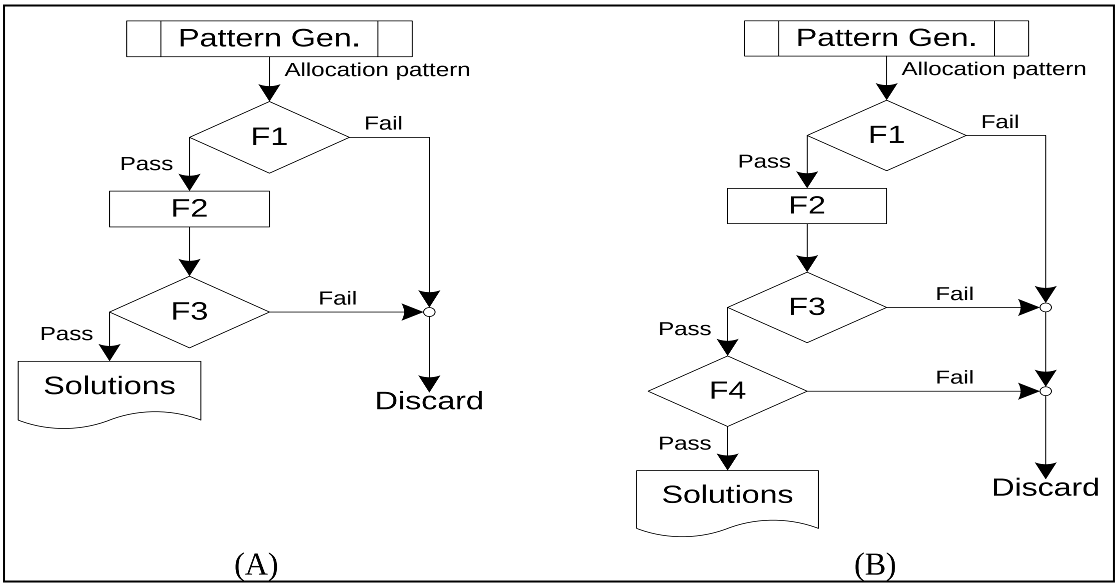

Figure 2. Flowchart of searching algorithm for MCLP model (A) and MCLP-*htc* model (B)

```
SearchMCLP(PossibleSolution) {
  Cov50 = population covered by PossibleSolution with speed
          at 0.50 percentile
  if (Cov50 >= Max50 ) {
    if (Cov50 > Max50 ) {
      clear SolutionList
      Max50 = Cov50
    }
    add PossibleSolution into SolutionList
  }
}
```

Figure 3. Pseudocode of searching algorithm for MCLP model

```
SearchMCLPhtc(PossibleSolution) {
  Cov50 = population covered by PossibleSolution with speed
          at 0.50 percentile
  Cov05 = population covered by PossibleSolution with speed
          at 0.05 percentile
  if (Cov50 >= Max50 ) {
    if (Cov50 > Max50 ) {
      clear SolutionList
      Max50 = Cov50
      Max05 = Cov05
      add PossibleSolution into SolutionList
    }
    else {
      if (Cov05 >= Max05 ) {
        if (Cov05 > Max05 ) {
          clear SolutionList
          Max05 = Cov05
        }
        add PossibleSolution into SolutionList
      }
    }
  }
}
```

Figure 4. Pseudocode of searching algorithm for MCLP-*htc* model

4. COMPUTATIONAL RESULTS

The problems were analyzed on Intel® Core™ i7 965, 3.2 GHz, 6 GB of RAM operated by Microsoft® Windows XP™ Professional x64 with Service Pack 2. The proposed searching algorithms were coded in Java and run on JRE 7 update 11. Exact solution for the MCLP model is solved by constraint programming (CP), CPLEX 12.4 preview version (IBM, 2013) and proposed searching algorithm. Exact solution for the MCLP-*htc* model is solved by proposed searching algorithm. The standard response time is 15 minutes. The number of stations to be located is 1 to the m minus 2. The table and figure acronyms are as follows:

p	Number of stations to be located
CP	Results by Constraint Programming in CPLEX optimizer
DP	Results by proposed Dynamic Programming searching algorithm
MCLP	Results of MCLP model
MCLP-*htc*	Results of MCLP-*htc* model by Dynamic Programming searching algorithm

4.1 Evaluated in Hypothetical Networks

Two hypothetical networks are created. The **60-Nodes** hypothetical network is made on the Cartesian coordinate system. The coordination of 60 demand nodes and 15 potential ambulance stations are randomly generated between 1 and 59. The distance between each pair of demand node and potential ambulance station is calculated in the Euclidean system. The population each demand node is randomly generated between 1 and 59. The total population is 1,787. Figure 5(A) shows the coordination of **60-Nodes** hypothetical network with black color represents the demand nodes and red color represents the potential ambulance stations. The regular speed is given as 50 units per hour and standard deviation of travel speed distribution is given as 12.5 units per hour (a quarter of average speed).

The second hypothetical network based on data of Osaka city, Japan, named **OsakaNet**. The 1,614 demand nodes were assigned using mesh size 300 x 300 meters. The 26 fire stations (OMFD, 2013) were assigned to potential ambulance stations. The mesh of demand nodes and the location of potential ambulance stations are mapped in Google®™ Earth™ as shown in Figure 5(B). The distance $d_{i,j}$ between each demand node and potential ambulance station in the road network using all streets accessible by car, are given in meters by Google®™ Distance Matrix Service (Google, 2013). The population each demand node randomly generated between 0 and 1000. The total population is 822,799.

Recently in Japan, The vehicle information communication systems (VICS) (Odawara, 2006) are available for providing traffic information on travel time, level of congestion, crashes and car parks. The travel speed distribution on weekday of Osaka areas is retrieved from VICS's data between October 4^{th} 2010 and November 5^{th} 2010. Figure 6 shows the min-max chart of travel speed distribution.

Defined two scenarios of ambulance traveling speed for the **OsakaNet** hypothetical network. The first scenario assumed the regular traveling speed of ambulance is the maximum authorized travel speed at 50 km/h. The second scenario assumed the regular traveling speed of ambulance is the average traveling speed of the road network. The number of standard deviation (S.D.) for both scenarios is used the S.D. number of the road network. The average traveling speed and S.D. of travel speed distribution is derived from VICS's data of Osaka road network between 0700hrs and 0800hrs on weekdays between October 4^{th} and November 5^{th} 2010, there are 24.3178 km/h and 10.6798 km/h. The summary of hypothetical networks for the evaluations is shown in Table 1.

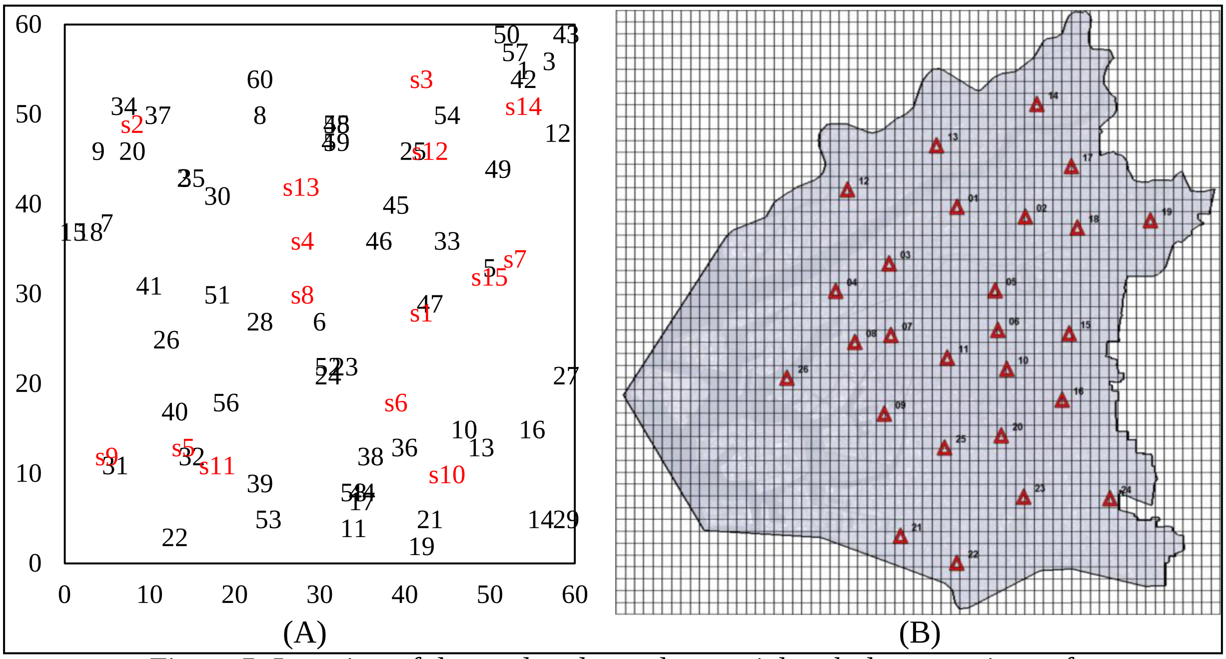

Figure 5. Location of demand nodes and potential ambulance stations of **60-Nodes** hypothetical network (A) and **OsakaNet** hypothetical network (B).

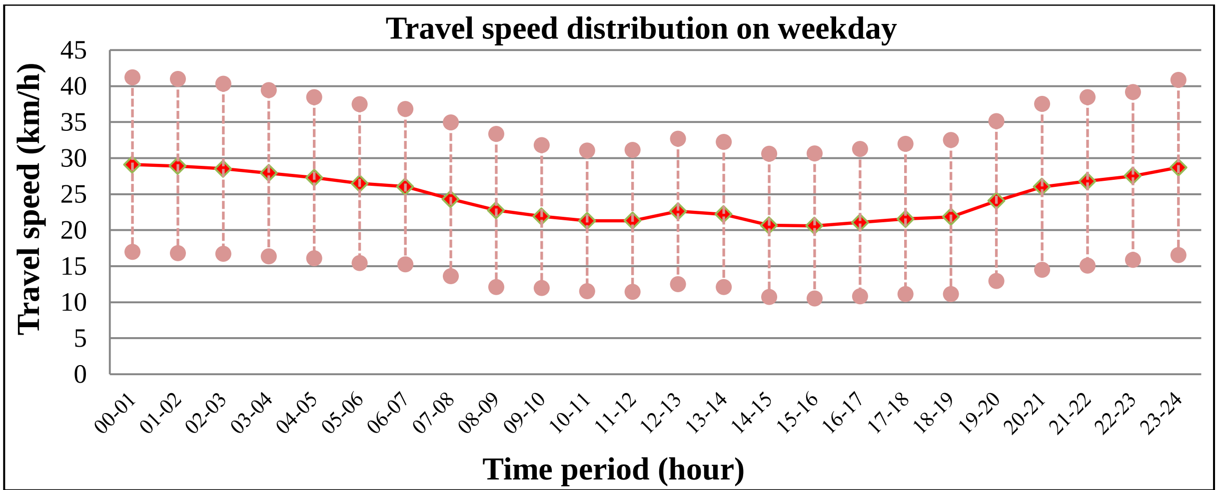

Figure 6. Travel speed distribution on weekday between Oct 4th and Nov 5th 2010 of Osaka city.

Table 1. Summary of hypothetical networks

	60-Nodes	1st scenario, **OsakaNet**	2st scenario, **OsakaNet**
Demand nodes	60	1,614	1,614
Potential stations	15	26	26
Population	random(1,59)	random(0,1000)	random(0,1000)
Distance	Euclidean	Google distance service	Google distance service
Regular speed	50 units/h	50 km/h	24.3178 km/h
S.D.	12.5 units/h	10.6798 km/h	10.6798 km/h
Response time	15 minutes	15 minutes	15 minutes

For **60-Nodes** hypothetical network, the computational results are reported in Table 2. The first station location patterns are reported in Table 3.

Table 2. Computational results for **60-Nodes** hypothetical network

p	Number of solution			Computing time (second)			Demand covered		
	MCLP		MCLP	MCLP		MCLP	MCLP		MCLP
	CP	DP	*-htc*	CP	DP	*-htc*	CP	DP	*-htc*
1	1	1	1	0.296	<0.001	<0.001	350	350	350
2	1	1	1	0.437	<0.001	<0.001	635	635	635
3	1	1	1	1.061	0.016	<0.001	910	910	910
4	1	1	1	0.749	<0.001	<0.001	1140	1140	1140
5	1	1	1	0.936	0.015	<0.001	1334	1334	1334
6	1	1	1	0.265	0.016	0.016	1460	1460	1460
7	1	1	1	0.265	0.016	0.015	1570	1570	1570
8	1	1	1	0.187	0.015	0.016	1598	1598	1598
9	1	4	1	0.125	0.016	0.016	1606	1606	1606
10	1	28	1	0.109	0.015	0.015	1606	1606	1606
11	1	61	1	0.062	0.016	<0.001	1606	1606	1606
12	1	62	1	0.031	<0.001	<0.001	1606	1606	1606
13	1	33	3	0.016	<0.001	<0.001	1606	1606	1606

Table 3. The first station location pattern for **60-Nodes** hypothetical network

p	Result for MCLP		Result for MCLP-htc
	by CP	by DP	
1	12	12	12
2	10 12	10 12	10 12
3	1 3 10	1 3 10	1 3 10
4	1 3 10 11	1 3 10 11	1 3 10 11
5	1 10 11 13 14	1 10 11 13 14	1 10 11 13 14
6	1 2 10 11 13 14	1 2 10 11 13 14	1 2 10 11 13 14
7	1 2 8 10 11 13 14	1 2 8 10 11 13 14	1 2 8 10 11 13 14
8	1 2 5 8 10 11 13 14	1 2 5 8 10 11 13 14	1 2 5 8 10 11 13 14
9	1 2 3 5 8 10 11 13 14	1 2 3 5 8 10 11 13 14	2 5 8 10 11 12 13 14 15
10	1 2 3 5 7 8 10 11 13 14	1 2 3 4 5 6 10 11 13 14	1 2 5 8 10 11 12 13 14 15
11	1 2 3 4 5 7 8 10 11 13 14	1 2 3 4 5 6 7 10 11 13 14	1 2 5 6 8 10 11 12 13 14 15
12	1 2 3 4 5 7 8 9 10 11 13 14	1 2 3 4 5 6 7 8 10 11 13 14	1 2 5 6 8 9 10 11 12 13 14 15
13	1 2 3 4 5 6 7 8 9 10 11 13 14	1 2 3 4 5 6 7 8 9 10 11 13 14	1 2 3 5 6 8 9 10 11 12 13 14 15

For **OsakaNet** hypothetical network, the computational results for first scenario and second scenario are reported in Table 4 and Table 5. The first station location patterns for first scenario and second scenario are reported in Table 6 and Table 7.

The results are shown in Table 2, Table 4, and Table 5 confirm that proposed searching algorithm is acceptable for planning level. It reaches objective function as same as standard commercial solver, CPLEX. The MCLP-*htc* model maintains level of demand covered as same as the MCLP model and it reduces the number of optimal location patterns with the second objective as shown in Table 4 and Table 5.

Table 4. Computational results for the first scenario of **OsakaNet** hypothetical network

p	Number of solution			Computing time (second)			Demand covered		
	MCLP		MCLP	MCLP		MCLP	MCLP		MCLP
	CP	DP	*-htc*	CP	DP	*-htc*	CPLEX	DP	*-htc*
1	1	1	1	41.106	0.015	0.016	671905	671905	671905
2	1	1	1	197.606	0.032	0.031	809012	809012	809012
3	1	13	1	47.846	0.234	0.234	822795	822795	822795
4	1	55	1	18.127	1.250	1.187	822799	822799	822799
5	1	1429	1	18.049	5.922	6.016	822799	822799	822799
6	1	14543	1	15.116	22.953	23.797	822799	822799	822799
7	1	85643	2	12.464	69.797	77.719	822799	822799	822799
8	1	341407	19	8.346	168.734	209.984	822799	822799	822799
9	1	1000841	296	10.374	364.375	471.891	822799	822799	822799
10	1	2267857	2119	9.984	650.781	930.297	822799	822799	822799
11	1	4102432	9446	9.064	1023.125	1526.843	822799	822799	822799
12	1	6054685	29583	7.722	1337.797	2113.266	822799	822799	822799
13	1	7399689	69277	8.518	1505.985	2480.860	822799	822799	822799
14	1	7563195	125828	8.206	1394.969	2825.281	822799	822799	822799
15	1	6504149	181336	8.455	1219.281	2657.219	822799	822799	822799
16	1	4719214	210276	7.270	878.906	1952.906	822799	822799	822799
17	1	2888171	197703	7.238	560.828	947.531	822799	822799	822799
18	1	1485898	151074	6.630	298.156	536.094	822799	822799	822799
19	1	638287	93586	6.583	124.750	235.828	822799	822799	822799
20	1	226433	46632	6.505	47.047	86.906	822799	822799	822799
21	1	65251	18427	1.482	13.547	26.344	822799	822799	822799
22	1	14903	5644	1.732	3.250	5.953	822799	822799	822799
23	1	2598	1292	1.388	0.438	1.109	822799	822799	822799
24	1	325	208	1.685	0.047	0.172	822799	822799	822799

Table 5. Computational results for the second scenario for **OsakaNet** hypothetical network

p	Number of solution			Computing time (second)			Demand covered		
	MCLP		MCLP	MCLP		MCLP	MCLP		MCLP
	CP	DP	*-htc*	CP	DP	*-htc*	CPLEX	DP	*-htc*
1	1	1	1	21.809	<0.001	<0.001	240803	240803	240803
2	1	1	1	70.684	0.016	0.032	416115	416115	416115
3	1	1	1	117.297	0.172	0.203	572503	572503	572503
4	1	1	1	530.341	1.187	1.172	651850	651850	651850
5	1	1	1	485.850	6.031	5.765	709681	709681	709681
6	1	1	1	101.089	22.938	22.031	743682	743682	743682
7	1	1	1	78.593	68.015	65.859	766716	766716	766716
8	1	1	1	16.786	176.884	166.141	781639	781639	781639
9	1	1	1	10.452	384.468	352.406	784604	784604	784604
10	1	1	1	7.176	736.266	633.687	785928	785938	785938
11	1	5	1	4.259	1142.484	959.219	786232	786232	786232
12	1	91	1	3.838	1454.828	1158.938	786232	786232	786232
13	1	654	1	4.087	1701.218	1674.859	786232	786232	786232
14	1	2689	1	4.134	1286.860	1256.656	786232	786232	786232
15	1	7338	1	4.134	1147.218	981.156	786232	786232	786232
16	1	14345	1	3.557	822.625	897.500	786232	786232	786232
17	1	20966	1	2.824	502.516	657.188	786232	786232	786232
18	1	23453	1	2.231	260.578	306.390	786232	786232	786232
19	1	20294	1	2.168	114.453	135.375	786232	786232	786232
20	1	13596	1	1.607	41.406	51.282	786232	786232	786232
21	1	6996	1	1.170	12.110	14.844	786232	786232	786232
22	1	2715	1	0.936	2.844	2.891	786232	786232	786232
23	1	769	1	0.889	0.547	0.594	786232	786232	786232
24	1	150	1	0.811	0.063	0.063	786232	786232	786232

Table 6. The first station location pattern for the first scenario of **OsakaNet** hypothetical network

p	Results for MCLP by CP	Results for MCLP by DP	Results for MCLP-*htc*
1	10	10	10
2	1 25	1 25	1 25
3	4 19 21	3 17 21	3 18 21
4	4 15 19 22	3 15 17 21	3 17 21 24
5	2 8 15 19 22	1 3 15 17 21	4 12 18 21 24
6	2 8 9 15 19 22	1 2 3 5 15 21	4 8 12 18 21 24
7	2 8 9 14 15 19 22	1 2 3 4 5 15 21	4 8 12 14 18 21 24
8	2 4 8 9 14 15 19 22	1 2 3 4 5 6 15 21	4 8 9 12 14 18 21 24
9	1 2 4 8 9 14 15 19 22	1 2 3 4 5 6 7 15 21	1 4 8 9 12 14 18 21 24
10	1 2 4 7 8 9 14 15 19 22	1 2 3 4 5 6 7 8 15 21	1 2 4 8 9 12 14 18 21 24
11	1 2 4 7 8 9 14 15 18 19 22	1 2 3 4 5 6 7 8 9 15 21	1 2 3 4 8 9 12 14 18 21 24
12	1 2 3 4 7 8 9 14 15 18 19 22	1 2 3 4 5 6 7 8 9 10 15 21	1 2 3 4 5 8 9 12 14 18 21 24
13	1 2 3 4 7 8 9 10 14 15 18 19 22	1 2 3 4 5 6 7 8 9 10 11 15 21	1 2 3 4 5 6 8 9 12 14 18 21 24
14	1 2 3 4 5 7 8 9 10 14 15 18 19 22	1 2 3 4 5 6 7 8 9 10 11 12 15 21	1 2 3 4 5 6 7 8 9 12 14 18 21 24
15	1 2 3 4 5 7 8 9 10 14 15 18 19 22 23	1 2 3 4 5 6 7 8 9 10 11 12 13 15 21	1 2 3 4 5 6 7 8 9 10 12 14 18 21 24
16	1 2 3 4 5 7 8 9 10 12 14 15 18 19 22 23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 21	1 2 3 4 5 6 7 8 9 10 11 12 14 18 21 24
17	1 2 3 4 5 7 8 9 10 12 14 15 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 18 21 24
18	1 2 3 4 5 7 8 9 10 12 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 18 21 24
19	1 2 3 4 5 7 8 9 10 11 12 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 21 24
20	1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 21 24
21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 24
22	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 24
23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 24
24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 22 23 24 25 26	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Table 7. The first station location pattern for the second scenario of **OsakaNet** hypothetical network

p	Results for MCLP by CP	Results for MCLP by DP	Results for MCLP-*htc*
1	20	20	20
2	3 20	3 20	3 20
3	4 18 23	4 18 23	4 18 23
4	4 16 17 21	4 16 17 21	4 16 17 21
5	4 13 18 24 25	4 13 18 24 25	4 13 18 24 25
6	4 11 13 18 21 24	4 11 13 18 21 24	4 11 13 18 21 24
7	4 11 12 14 18 21 24	4 11 12 14 18 21 24	4 11 12 14 18 21 24
8	4 8 10 12 14 19 21 24	4 8 10 12 14 19 21 24	4 8 10 12 14 19 21 24
9	4 5 8 12 14 19 21 24 25	4 5 8 12 14 19 21 24 25	4 5 8 12 14 19 21 24 25
10	4 5 8 12 13 14 19 21 24 25	4 8 10 12 13 14 19 21 24 25	4 8 10 12 13 14 19 21 24 25
11	4 8 9 10 12 13 14 19 21 24 25	4 7 8 10 12 13 14 19 21 24 25	4 8 9 10 12 13 14 19 21 24 25
12	2 4 8 9 12 13 14 15 19 21 24 25	1 4 7 8 10 12 13 14 19 21 24 25	4 5 8 9 12 13 14 16 19 21 24 25
13	2 4 8 9 12 13 14 15 19 21 22 24 25	1 2 4 7 8 10 12 13 14 19 21 24 25	4 5 8 9 12 13 14 16 18 19 21 24 25
14	1 2 4 8 9 12 13 14 15 19 21 22 24 25	1 2 3 4 7 8 10 12 13 14 19 21 24 25	4 5 8 9 12 13 14 16 18 19 21 23 24 25
15	1 2 4 7 8 9 12 13 14 15 19 21 22 24 25	1 2 3 4 5 7 8 10 12 13 14 19 21 24 25	4 5 8 9 10 12 13 14 16 18 19 21 23 24 25
16	1 2 4 7 8 9 12 13 14 15 18 19 21 22 24 25	1 2 3 4 5 6 7 8 10 12 13 14 19 21 24 25	4 5 8 9 10 12 13 14 15 16 18 19 21 23 24 25
17	1 2 3 4 7 8 9 12 13 14 15 18 19 21 22 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 19 21 24	4 5 8 9 10 12 13 14 15 16 18 19 21 22 23 24 25
18	1 2 3 4 7 8 9 10 12 13 14 15 18 19 21 22 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 19 21 24	4 5 8 9 10 12 13 14 15 16 18 19 20 21 22 23 24 25
19	1 2 3 4 5 7 8 9 10 12 13 14 15 18 19 21 22 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 19 21 24	4 5 8 9 10 12 13 14 15 16 17 18 19 20 21 22 23 24 25
20	1 2 3 4 5 7 8 9 10 12 13 14 15 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 21 24	2 4 5 8 9 10 12 13 14 15 16 17 18 19 20 21 22 23 24 25
21	1 2 3 4 5 7 8 9 10 12 13 14 15 16 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 24	2 4 5 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
22	1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 24	2 3 4 5 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 24	2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

4.2 Application in Osaka city's network

There are 898 demand nodes defined by Statistic Bureau, Ministry of Internal Affairs and Communication, Japan (MIAC, 2013a) using mesh size of 500 x 500 meters. The population each demand nodes is on November 2011 (MIAC, 2013b). There were 2,550,359 inhabitants in total. There are 26 fire stations given to the location of potential emergency ambulance stations (OMFD, 2013). The location of demand nodes and the location of fire stations are mapped in Google®™ Earth™ as shown in Figure 7. The distance $d_{i,j}$ between each demand node and potential ambulance station in the road network using all streets accessible by car, are given in meters by Google®™ Distance Matrix Service (Google, 2013).

Two scenarios of travel speed are followed the experimentation for the **OsakaNet**. The computational results for first scenario and second scenario are reported in Table 8 and Table 9. The proportion of population covered within 8 minutes and 4 minutes for first scenario are shown in Figure 8 and Figure 9; for second scenario are shown in Figure 10 and Figure 11. The first station location patterns for first scenario and second scenario are reported in Table 10 and Table 11. Samples in Figure 12 present graphics of the station location pattern with 10 stations and areas of covered demand nodes. The symbols are as follows:

- location of ambulance station
- covered within 4 minutes
- covered within 8 minutes
- covered within 15 minutes
- uncoverd node

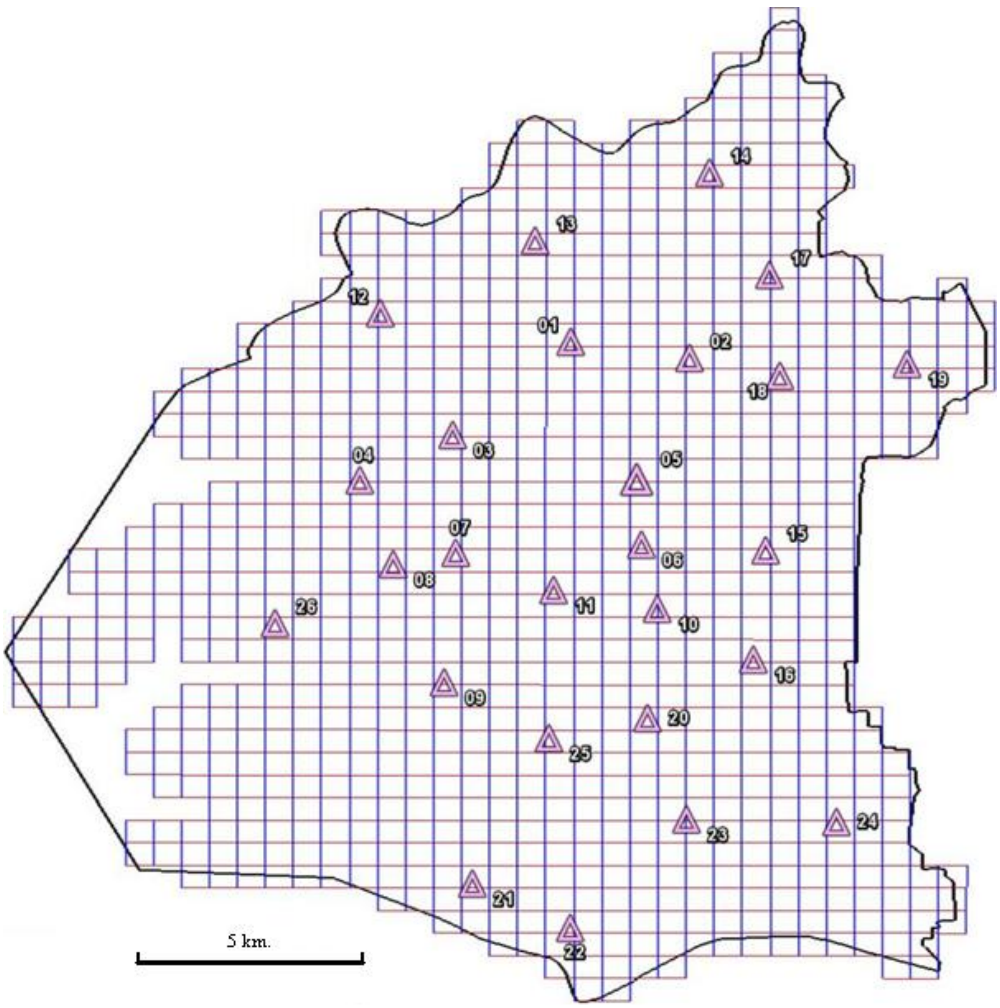

Figure 7. Map of Osaka city with location of fire stations and mesh of demand nodes.

Table 8. Computational results for the first scenario of Osaka city's network

p	Number of solution			Computing time (second)			Population covered		
	MCLP		MCLP	MCLP		MCLP	MCLP		MCLP
	CP	DP	*-htc*	CP	DP	*-htc*	CPLEX	DP	*-htc*
1	1	1	1	18.471	0.016	<0.001	2424578	2424578	2424578
2	1	1	1	59.031	0.016	0.016	2547413	2547413	2547413
3	1	39	1	7.613	0.125	0.078	2550359	2550359	2550359
4	1	925	1	6.084	0.609	0.594	2550359	2550359	2550359
5	1	9699	1	5.491	3.094	3.094	2550359	2550359	2550359
6	1	60514	1	4.898	12.141	13.453	2550359	2550359	2550359
7	1	257395	1	4.711	36.094	45.531	2550359	2550359	2550359
8	1	808267	26	4.290	92.907	138.953	2550359	2550359	2550359
9	1	1971037	289	4.306	199.906	326.578	2550359	2550359	2550359
10	1	3960015	1896	0.749	369.397	631.938	2550359	2550359	2550359
11	1	6210781	8391	0.702	572.828	1015.594	2550359	2550359	2550359
12	1	8339806	26918	0.780	757.375	1477.578	2550359	2550359	2550359
13	1	9444671	65379	0.889	856.235	1708.910	2550359	2550359	2550359
14	1	9080721	123629	0.874	1017.828	1650.375	2550359	2550359	2550359
15	1	7438093	185329	0.842	750.719	1391.281	2550359	2550359	2550359
16	1	5193996	222728	0.936	455.156	1022.297	2550359	2550359	2550359
17	1	3085788	215853	0.842	288.578	649.640	2550359	2550359	2550359
18	1	1552246	168895	0.874	137.922	350.437	2550359	2550359	2550359
19	1	655837	106341	0.842	62.062	155.500	2550359	2550359	2550359
20	1	229957	53430	0.733	21.078	55.922	2550359	2550359	2550359
21	1	65756	21113	0.733	6.266	16.640	2550359	2550359	2550359
22	1	14949	6411	0.889	1.266	4.297	2550359	2550359	2550359
23	1	2600	1442	0.764	0.282	0.672	2550359	2550359	2550359
24	1	325	226	0.842	0.047	0.079	2550359	2550359	2550359

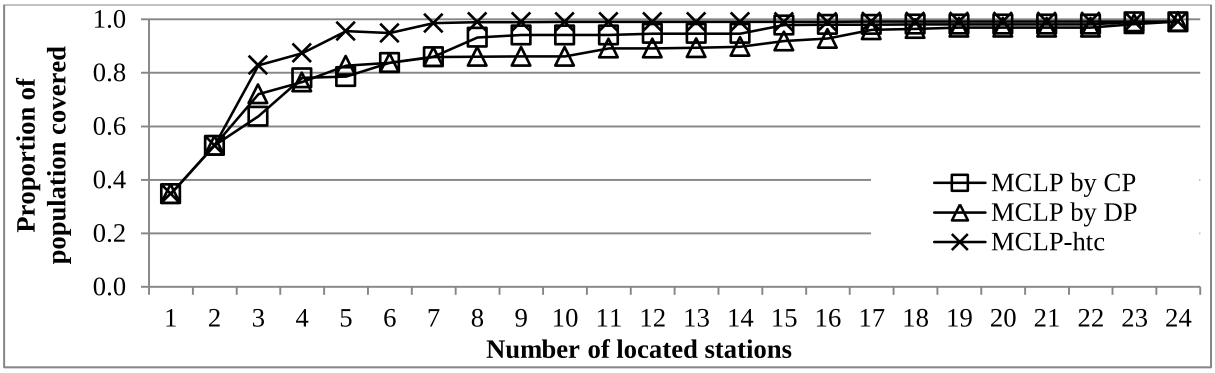

Figure 8. Proportion of population covered for the first scenario of Osaka city's network within 8 minutes

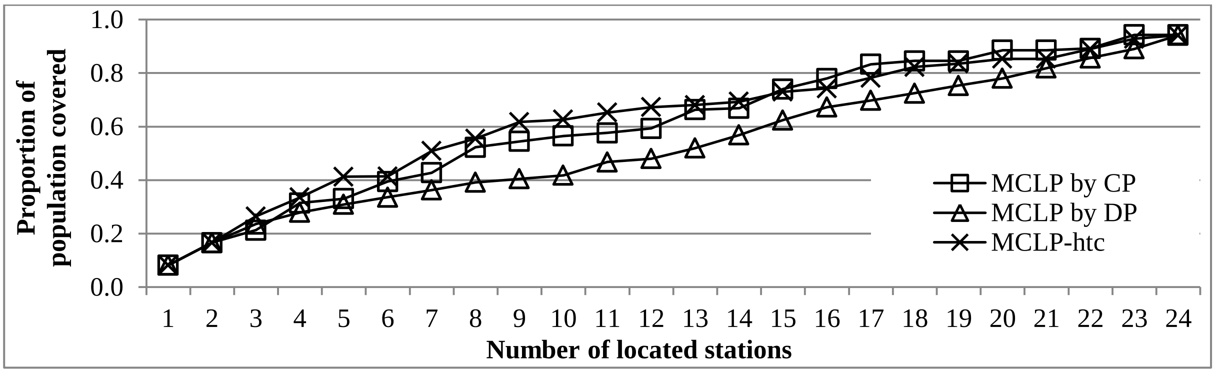

Figure 9. Proportion of population covered for the first scenario of Osaka city's network within 4 minutes

Table 9. Computational results for the second scenario for Osaka city's network

p	Number of solution			Computing time (second)			Population covered		
	MCLP		MCLP	MCLP		MCLP	MCLP		MCLP
	CP	DP	*-htc*	CP	DP	*-htc*	CPLEX	DP	*-htc*
1	1	1	1	9.188	0.016	0.016	893379	893379	893379
2	1	1	1	32.152	0.015	0.015	1558698	1558698	1558698
3	1	1	1	49.062	0.110	0.109	2027638	2027638	2027638
4	1	1	1	59.889	0.703	0.703	2311180	2311180	2311180
5	1	1	1	71.324	3.297	3.359	2398040	2398040	2398040
6	1	1	1	61.886	12.172	12.156	2459396	2459396	2459396
7	1	1	1	31.855	37.843	38.625	2506231	2506231	2506231
8	1	1	1	8.081	94.375	97.750	2518239	2518239	2518239
9	1	8	1	3.198	202.563	209.688	2519036	2519036	2519036
10	1	174	1	3.136	367.187	390.266	2519036	2519036	2519036
11	1	1447	1	3.026	551.047	640.453	2519036	2519036	2519036
12	1	6823	1	3.026	740.953	846.062	2519036	2519036	2519036
13	1	21339	1	2.574	832.094	987.094	2519036	2519036	2519036
14	1	48084	1	2.714	810.359	1031.563	2519036	2519036	2519036
15	1	81959	1	2.262	674.657	550.031	2519036	2519036	2519036
16	1	108806	1	1.888	483.297	410.422	2519036	2519036	2519036
17	1	114398	1	1.919	297.032	205.219	2519036	2519036	2519036
18	1	96018	1	1.716	153.640	107.000	2519036	2519036	2519036
19	1	64415	1	1.638	66.797	48.438	2519036	2519036	2519036
20	1	34371	1	1.170	24.250	18.047	2519036	2519036	2519036
21	1	14418	1	0.811	7.250	5.719	2519036	2519036	2519036
22	1	4658	1	0.749	1.735	1.984	2519036	2519036	2519036
23	1	1120	1	0.577	0.297	0.297	2519036	2519036	2519036
24	1	189	1	0.749	0.047	0.031	2519036	2519036	2519036

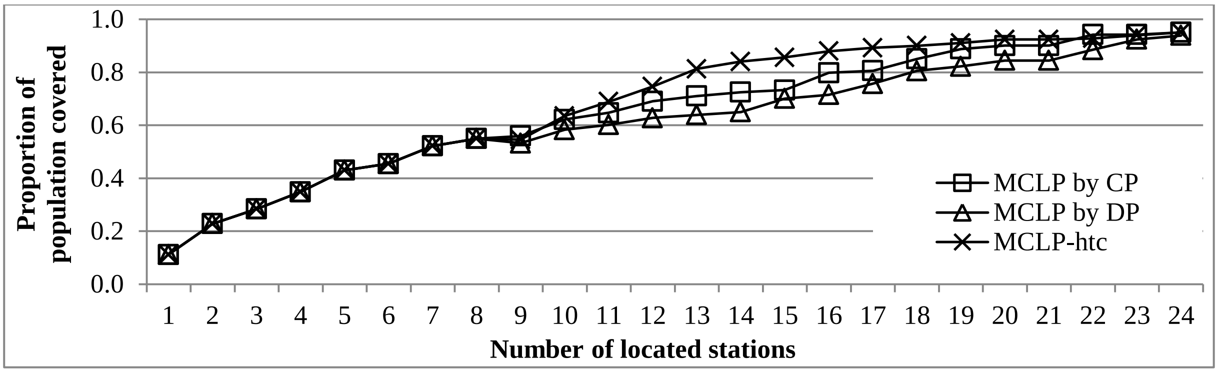

Figure 10. Proportion of population covered for the second scenario of Osaka city's network within 8 minutes

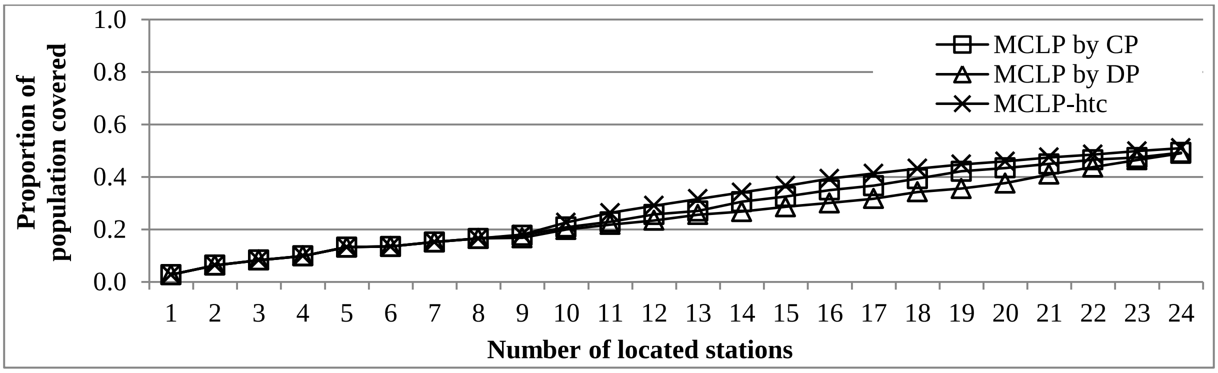

Figure 11. Proportion of population covered for the second scenario of Osaka city's network within 4 minutes

Table 10. The first station location pattern for the first scenario of Osaka city's network

p	Results for MCLP by CP	Results for MCLP by DP	Results for MCLP-*htc*
1	6	6	6
2	8 15	8 15	8 15
3	8 19 22	3 17 21	4 17 23
4	2 8 19 22	1 3 17 21	3 17 21 23
5	2 8 9 19 22	1 2 3 5 21	3 14 18 21 24
6	2 8 9 14 19 22	1 2 3 4 5 21	3 8 14 19 21 24
7	2 4 8 9 14 19 22	1 2 3 4 5 6 21	3 8 14 15 19 21 24
8	2 4 8 9 14 15 19 22	1 2 3 4 5 6 7 21	1 3 8 14 15 19 21 24
9	1 2 4 8 9 14 15 19 22	1 2 3 4 5 6 7 8 10	1 2 3 8 14 15 19 21 24
10	1 2 4 7 8 9 14 15 19 22	1 2 3 4 5 6 7 8 9 10	1 2 3 4 8 14 15 19 21 24
11	1 2 4 7 8 9 14 15 18 19 22	1 2 3 4 5 6 7 8 9 10 11	1 2 3 4 5 8 14 15 19 21 24
12	1 2 3 4 7 8 9 14 15 18 19 22	1 2 3 4 5 6 7 8 9 10 11 12	1 2 3 4 5 6 8 14 15 19 21 24
13	1 2 3 4 7 8 9 10 14 15 18 19 22	1 2 3 4 5 6 7 8 9 10 11 12 13	1 2 3 4 5 6 7 8 14 15 19 21 24
14	1 2 3 4 5 7 8 9 10 14 15 18 19 22	1 2 3 4 5 6 7 8 9 10 11 12 13 14	1 2 3 4 5 6 7 8 9 14 15 19 21 24
15	1 2 3 4 5 7 8 9 10 14 15 18 19 22 23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	1 2 3 4 5 6 7 8 9 10 14 15 19 21 24
16	1 2 3 4 5 7 8 9 10 12 14 15 18 19 22 23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16	1 2 3 4 5 6 7 8 9 10 11 14 15 19 21 24
17	1 2 3 4 5 7 8 9 10 12 14 15 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17	1 2 3 4 5 6 7 8 9 10 11 12 14 15 19 21 24
18	1 2 3 4 5 7 8 9 10 12 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 19 21 24
19	1 2 3 4 5 7 8 9 10 11 12 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 19 21 24
20	1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 21 24
21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 24
22	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 22 23 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 24
23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 24
24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 22 23 24 25 26	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Table 11. The first station location pattern for the second scenario of Osaka city's network

p	Results for MCLP by CP	Results for MCLP by DP	Results for MCLP-*htc*
1	20	20	20
2	18 20	18 20	18 20
3	3 18 23	3 18 23	3 18 23
4	8 13 18 23	8 13 18 23	8 13 18 23
5	3 14 18 24 25	3 14 18 24 25	3 14 18 24 25
6	11 12 14 18 21 24	11 12 14 18 21 24	11 12 14 18 21 24
7	4 11 13 14 18 21 24	4 11 13 14 18 21 24	4 11 13 14 18 21 24
8	1 8 11 12 14 18 21 24	1 8 11 12 14 18 21 24	1 8 11 12 14 18 21 24
9	1 4 9 12 14 15 19 21 24	1 4 5 9 12 14 19 21 24	4 6 9 12 13 14 19 21 24
10	1 2 4 9 12 14 15 19 21 24	1 2 4 5 9 12 14 19 21 24	1 4 7 12 14 18 19 21 24 25
11	1 2 4 8 9 12 14 15 19 21 24	1 2 3 4 5 9 12 14 19 21 24	2 4 7 12 13 14 18 19 21 24 25
12	1 2 4 8 9 12 14 15 19 21 22 24	1 2 3 4 5 6 9 12 14 19 21 24	2 4 7 12 13 14 18 19 20 21 24 25
13	1 2 4 7 8 9 12 14 15 19 21 22 24	1 2 3 4 5 6 7 9 12 14 19 21 24	2 4 7 12 13 14 15 18 19 20 21 24 25
14	1 2 4 7 8 9 12 14 15 18 19 21 22 24	1 2 3 4 5 6 7 8 9 12 14 19 21 24	2 4 7 12 13 14 15 18 19 20 21 23 24 25
15	1 2 3 4 7 8 9 12 14 15 18 19 21 22 24	1 2 3 4 5 6 7 8 9 10 12 14 19 21 24	2 4 7 10 12 13 14 15 18 19 20 21 23 24 25
16	1 2 3 4 7 8 9 10 12 14 15 18 19 21 22 24	1 2 3 4 5 6 7 8 9 10 11 12 14 19 21 24	2 4 7 10 12 13 14 15 18 19 20 21 22 23 24 25
17	1 2 3 4 5 7 8 9 10 12 14 15 18 19 21 22 24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 19 21 24	2 3 4 7 10 12 13 14 15 18 19 20 21 22 23 24 25
18	1 2 3 4 5 7 8 9 10 12 14 15 18 19 21 22 23 24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 19 21 24	2 3 4 7 10 12 13 14 15 17 18 19 20 21 22 23 24 25
19	1 2 3 4 5 7 8 9 10 12 14 15 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 19 21 24	2 3 4 5 7 10 12 13 14 15 17 18 19 20 21 22 23 24 25
20	1 2 3 4 5 7 8 9 10 12 14 15 16 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 21 24	2 3 4 5 7 9 10 12 13 14 15 17 18 19 20 21 22 23 24 25
21	1 2 3 4 5 7 8 9 10 11 12 14 15 16 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 24	2 3 4 5 7 9 10 11 12 13 14 15 17 18 19 20 21 22 23 24 25
22	1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 24	1 2 3 4 5 7 9 10 11 12 13 14 15 17 18 19 20 21 22 23 24 25
23	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 24	1 2 3 4 5 7 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
24	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 21 22 23 24 25	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	1 2 3 4 5 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

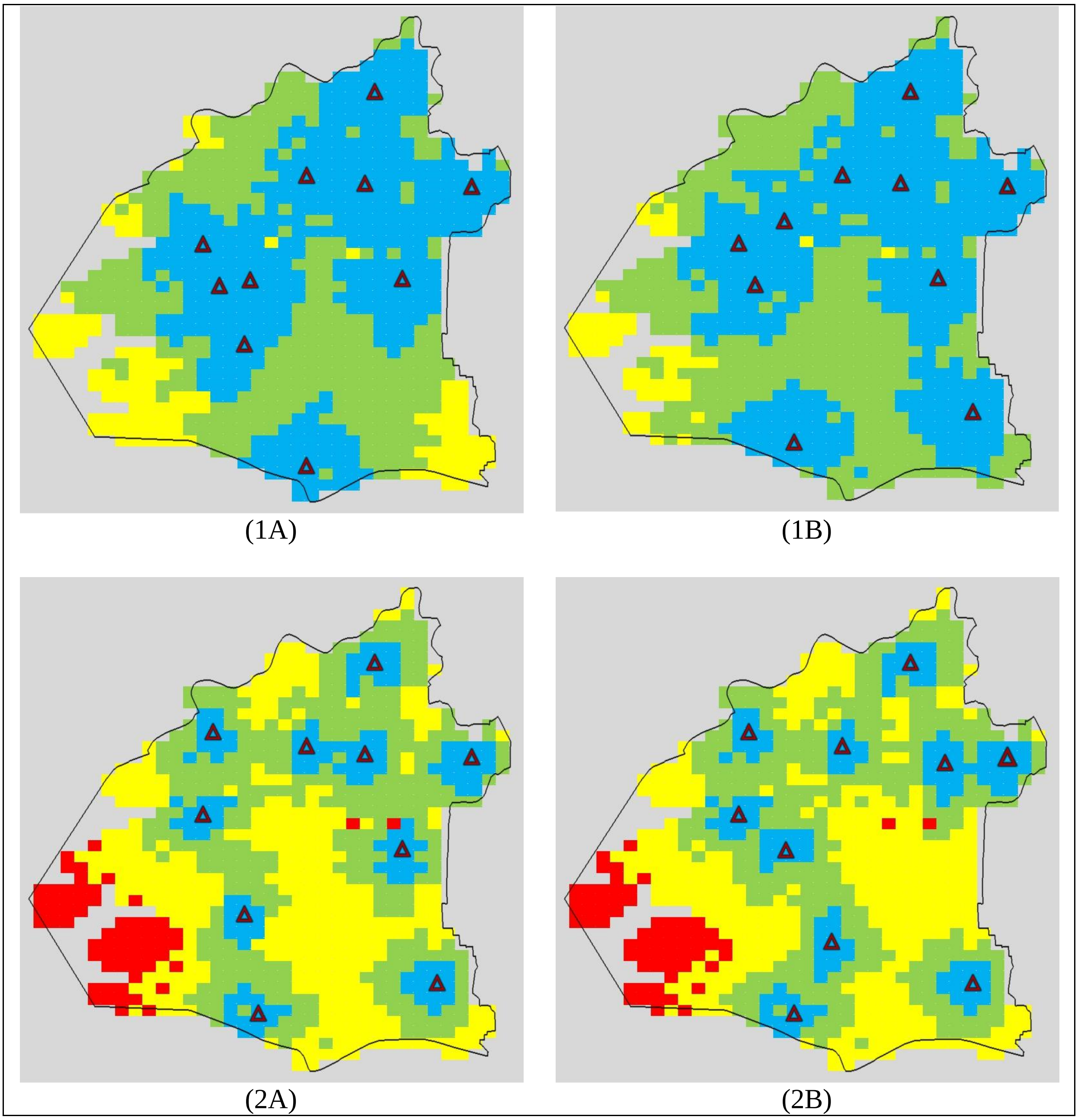

Figure 12. Graphic of covered demand node and station location pattern with 10 stations
(1A) for MCLP model by CPLEX optimizer of 1st scenario
(1B) for MCLP-*htc* model by DP searching algorithm of 1st scenario
(2A) for MCLP model by CPLEX optimizer of 2nd scenario
(2B) for MCLP-*htc* model by DP searching algorithm of 2nd scenario

An outcome of application of the MCLP-*htc* model in Osaka city's network is increasing level of population covered within short response time (8 minutes and 4 minutes) as shown in Figure 8 – 12.

5. CONCLUSION

A new model with two hierarchical objectives and exact searching algorithm based on Dynamic Programming technique for maximal covering ambulance location considering heavy traffic congestion have been developed. Comparing with the MCLP model, the MCLP-*htc* model maintains maximal covering for standard response time (15 minutes) and increases level of population covered within short response time (8 minutes and 4 minutes) by the first solution. The proposed exact searching algorithm is acceptable for planning level.

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