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A New Model and Tabu Search Approach for Planning the Emergency Service Stations

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Summary. The location planning of emergency service stations is crucial, especially in the populated cities with heavy traffic conditions such as Istanbul. In this paper, we propose a Backup Double Covering Model (BDCM), a variant of the well-known Maximal Covering Location Problem, that requires two types of services to plan the emergency service stations. The objective of the model is to maximize the total population serviced using two distinct emergency service stations in different time limits where the total number of stations is limited. We propose a Tabu Search (TS) approach to solve the problem. We conduct an extensive experimental study on randomly generated data set with different parameters to demonstrate the effectiveness of the proposed algorithm. Finally, we apply our TS approach for planning the emergency service stations in Istanbul.

1 Introduction

The location planning of emergency medical service (EMS) stations is crucial, since an effective planning of these stations directly affects human life protection. In the last 30 years, a lot of research effort has been spent in the literature to plan the locations of both fire brigade and EMS stations. [1] and [7] provide a good review of these studies. In this paper, we propose a Backup Double Covering Model (BDCM), a variant of the well-known Maximal Covering Location Problem, that requires two types of services. The proposed Backup Double Covering Model (BDCM) is conceptually similar to Maximal Covering Location Model in [3], Double Coverage Model in [5], and Backup Coverage Model in [8]. Metaheuristic approaches have been successfully employed for solving such models, e.g. [5] proposed a Tabu Search (TS) algorithm to plan the EMS stations in Montreal and [4]compared the performance of Ant Colony Optimization to that of TS in Austria. In this paper, we propose a TS approach and test its performance on both randomly generated data and data gathered for Istanbul.

2 Backup Double Coverage Model

For location planning of EMS stations, we propose BDCM where two types of service requests are fulfilled. Our aim in having a double covering model is to provide a backup station in case no ambulance is available in the closer station. In the proposed model, the objective is to maximize the total population serviced within t_1 and t_2 minutes ($t_1 < t_2$) using two distinct emergency service stations where the total number of stations is limited. If a region is covered by any emergency service stations, we assume that the whole population in this region is covered. BDCM originally proposed by [2] is as follows: M: set of demand regions, N: set of location sites, K: Maximum number of EMS stations to be opened and P_j: Population of region j.

$$a_{ij} = \begin{cases} 1, \text{if station in location } i \text{ can reach region } j \text{ in } t_1 \text{ time units} \\ 0, \text{otherwise} \end{cases}$$

$$b_{ij} = \begin{cases} 1, \text{if station in location } i \text{ can reach region } j \text{ in } t_2 \text{ time units} \\ 0, \text{otherwise} \end{cases}$$

Decision variables:

$$x_i = \begin{cases} 1, \text{if a station is opened in location } i \\ 0, \text{otherwise} \end{cases}$$

$$y_j = \begin{cases} 1, \text{region } j \text{ is double covered} \\ 0, \text{otherwise} \end{cases}$$

$$\max \sum_{j \in M} P_j y_j \tag{1}$$

subject to

$$\sum_{i \in N} x_i \leq K, \tag{2}$$

$$\sum_{i \in N} a_{ij} x_i - y_j \geq 0, \ \forall j \in M \tag{3}$$

$$\sum_{i \in N} b_{ij} x_i - 2y_j \geq 0, \ \forall j \in M \tag{4}$$

$$x_i \in \{0,1\}, \ \forall i \in N, y_j \in \{0,1\}, \ \forall j \in M \tag{5}$$

The objective of the model is to maximize the population which is double covered with a backup station. Constraint 2 imposes the total number of stations that can be opened. Constraints 3 ensure that any demand point must be covered in t_1 minutes in order to be covered multiple times. Constraints 4 ensure that y_j takes the value 1 if location j is double covered by two distinct stations. Constraints 5 show that all the decision variables are binary.

3 Tabu Search Approach

TS is a local search technique that was originally developed by [6]. Using an initial feasible solution TS investigates the neighbors of the existing solution in each iteration in an attempt to improve the best solution obtained so far by trying to escape local optima. Thus, new candidate solutions are generated by using different neighborhood search methods. In order to avoid the repetition of the same solutions, TS forbids a given number of moves by keeping these moves in a tabu list. The moves in the tabu list are not accepted unless they provide solutions better than a pre-determined aspiration level.

In our TS approach, three initialization methods are utilized for comparison. A random method, where we randomly select K stations among potential locations; a steepest-ascent method, where essentially pairs of stations are opened that gives the maximum additional double coverage per station; and a Linear Programming (LP) relaxation method, where the relaxation of the model is solved and integer x_i's in addition to maximum fractional x_i are fixed at 1 and the resulting model is solved until the maximum number of stations are opened.

The outline of the TS algorithm is as follows. First an initial solution is obtained using one of the methods described above. Then we find the station pair whose closing and opening provides the largest objective function value. We decided to use two separate tabu lists, one of which for the station opened and the other for the closed one. If they are not in the tabu list, we do the exchange and update objective function value if necessary. If at least one move is in tabu list, the moves are executed if the aspiration criteria is satisfied. Otherwise, we repeat the above steps. To avoid cycling, we replace the station to be closed with the station resulting in the least decrease in the current objective function if the current objective function value remains same during the last k_1 iterations. If the best-so-far objective function value does not improve during the last k_2 iterations, we perform random diversification by randomly closing and opening a station. The diversification mechanism improves the solution quality significantly. This procedure is repeated for k_3 iterations.

4 Experimental Study

After making experiments on randomly generated data, we decided to use $k_1 = 5$, $k_2 = 15$ and $k_3 = 5000$. The tabu list size is chosen as 7 and aspiration level of 100% of the best solution is used.

A set of problem instances with different number of potential stations and demand points are generated to test the efficiency of the proposed TS. The algorithms are coded in C++ and executed on 1.7 GHz Intel Celeron with 512 MB RAM. Our data set includes problems with different number of potential stations and demand points are generated 200, 300, 400, and 500 demand regions. The demand regions are distributed uniformly within a square area. The total number of potential sites is set equal to 100%, 75%, and 50% of the number of demand points. For each demand point-location site configuration we have generated 5 problem instances. Thus a total of 60 problem instances were generated. The average speed of the ambulances is assumed to be 40 km/h and Euclidean metric is assumed as the distance measure. Using these data a_{ij} and b_{ij} values are obtained. The populations of the demand regions were generated from an exponential distribution with mean 1000. The values of t_1 and t_2 are set equal to 5 minutes and 8 minutes, respectively, as determined by the Directorate of Instant Relief and Rescue (DIRR).

The results are compared with respect to different initialization mechanisms as well as against solutions obtained by OPL Studio 5.5 with CPLEX 11.0 (will be referred as CPLEX). First, we investigate the performance of the initialization heuristics benchmarked against the solution obtained using CPLEX. While the random heuristic gives a gap of 54.89% on the average, steepest-ascent and LP-relaxation heuristics' performances are similar: 6.95% and 7.18%, respectively. The gap is calculated as (CPLEX solution/Initialization heuristic solution)-1.

Next we investigate the performance of TS approach. In Table 1, we report the average results of all 60 problem instances. In these experiments, CPLEX time limit is set to 600 seconds for problems with less than 300 potential locations and 1200 seconds for others. TS1, TS2, and TS3, respectively, refer to the TS with the random, steepest-ascent, and LP-relaxation initialization approaches, respectively. As seen in Table 1, all three TS approaches provide good results in comparison with

Table 1. Results for random instances

		CPLEX	TS1		TS2		TS3	
Regions	Potential locations	Time (s)	% Gap	Time (s)	% Gap	Time (s)	% Gap	Time (s)
200	200	31	0.35	90	0.26	93	0.20	141
200	150	9	0.10	71	0.00	75	0.04	123
200	100	6	0.05	45	0.00	49	0.05	84
300	300	558	0.20	298	0.17	299	0.03	392
300	225	18	0.04	232	0.23	227	0.21	308
300	150	11	0.69	157	0.82	152	0.51	223
400	400	1200	0.33	646	0.14	584	0.33	874
400	300	257	0.35	509	0.66	469	0.12	710
400	200	54	0.35	306	0.25	325	0.34	499
500	500	1200	0.00	1182	0.09	1254	0.12	1618
500	375	872	0.65	1136	0.50	1001	0.44	1416
500	250	162	0.69	686	0.47	597	0.45	960
Average		365	0.32	447	0.30	427	0.24	612

the solutions found by CPLEX whose average computation time is 365 seconds.

5 Planning The Locations of EMS Stations in Istanbul

Since Istanbul is a large and populated city, we agreed on a quarter-wise analysis with the DIRR. This corresponds to a total of 710 quarters, 243 in the Asian side and 467 in European side. We forecasted the population for each quarter based on the data provided by Turkish Statistical Institute (TÜIK). Reachability data (a_{ij}, b_{ij}) for the quarters were collected by the help of the experienced ambulance drivers of the DIRR. We assume that each quarter is a potential station site. Furthermore, the response across European and Asian sides is not allowed. The number of stations is determined as 35 by the DIRR. CPLEX solved this problem in 50 seconds. This rather short solution time is possibly due to the fact that Istanbul data have certain characteristics different than the random data. The computational results for Istanbul are shown in Table 2.

6 Conclusion

In this study, we present a mathematical model to plan the locations of EMS stations. Since this problem is intractable for large-scale cases, we propose a TS solution approach. We test the performance of the

Table 2. Results for Istanbul

	CPLEX	TS1	TS2	TS 3
% Coverage	74.75	73.77	74.63	74.60
Time (s)	50	182	166	193
% Gap	-	1.30	0.16	0.20

TS with different initialization methods on randomly generated data as well as the data we collected for Istanbul. The results show that our TS approach with either initialization method provide good results compared to the solutions obtained using CPLEX. Further research on this topic may focus on the multi-objective modelling of the problem by considering the investment and operating costs of the stations and ambulances. Another interesting extension would be the multi-period version of the problem, where there is a maximum number of additional stations that can be opened at every period.

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