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Adaptive temperature control of simulated annealing for solving capacitated vehicle routing problem

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Abstract. In this paper proposed variant of simulated annealing algorithm (SA) for solving Capacitated Vehicle Routing Problem (CVRP). The main difference between our approach and the classical SA is that, our approach dynamically changes the temperature during the search process. The adaptive temperature control is used that changes temperature based on the number of consecutive improving moves. The Capacitated Vehicle Routing Problem (CVRP) is a well known problem and it has been one of the most studied combinatorial optimization problems during the last decades. Simulation results are reported on twenty large-scale benchmark instances. Results show that the proposed approach to be very competitive with the best-known methods.

Keywords: Capacitated vehicle routing problem, simulated annealing, combinatorial optimization.

1. Introduction

The Vehicle Routing Problem (VRP) is a well known NP-Hard problem and one of the main combinatorial optimization problems that many algorithms are applied to solve it.
The capacitated vehicle routing problem (CVRP) is a variant of vehicle routing problem (VRP). The objective of this problem is to minimize the total cost of the number of vehicles and the travel distance of vehicles to serve a set of customers with known demands. The design of route, each customer should be visited once and by once vehicle only. However, the optimal solutions when the problem scale is large cannot be found in reasonable time by mathematical methods or classical search algorithms.

Basically, Heuristic approaches are divided into two types. The first type is a classical heuristic approaches which can obtain feasible solution quickly, but this feasible solution may have a large disparity compared with the best solution.

The second type is Meta-heuristic approaches which can obtain a near optimal solution in reasonable time. Accordingly, the main purpose of this paper is to modified version of the simulated annealing algorithm for solving CVRP. Different meta-heuristic approaches are applied to solve the CVRP during the last decades such as Genetic algorithm (GA), Tabu search (TS) and Simulated annealing (SA) **[1]** because it can obtain a near optimal solution or even a global optimal solution in reasonable time. The rest of this paper is organized as follows: Section 2 gives introduces the main ideas behind our approach; in Section 3, computational results are compared to the solutions of the previous studies. Finally, conclusion is included in the last section.

2. The proposed approach for CVRP

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Simulated annealing (SA) were suggested by Metropolis et al. in 1953 [2] and Kirkpatrick et al. [3] were the first applied SA to solve the combinatorial optimization problems.
The idea of SA can be described briefly as follows. This method is starts from an initial feasible solution which was generated by savings algorithm. The main different point between the SA algorithm and Hill Climbing is the decision when to replace the original candidate solution with the newly candidate solution which is generated randomly. Specifically as follow: if the newly candidate solution better than the original candidate solution always replace it. But if the newly candidate solution worse, may still replace according to a special probability. For more information about simulated annealing can be found in Aarts and Lenstra [4].

In this paper, we propose a modified version of the simulated annealing algorithm for CVRP. The main difference between our approach and the classical SA is that, our approach dynamically changes the temperature during the search process. The adaptive temperature control is used that changes temperature based on the number of consecutive improving moves. While in conventional simulated annealing, the initial temperature is set to a high number which will allow a higher chance of transition to a worse solution and cause to escape from local optima. However, as the search continues, the temperature continuously declines resulting in a reduced chance of uphill transition. Such an approach could be useful if the local minima are near the start point, but may not lead to a near optimal solution if some local minima are encountered at a relatively low temperature toward the end of the search.
Here the adaptive simulated annealing method that takes into consideration the characteristics of the search trajectory are proposed. Based on the profile of the search path, we use an adaptive cooling schedule that adjusts the temperature dynamically. Such adjustments could be enhancing the possibility of reheating. We used a function that keeps the temperature is above a minimum level. The heating process gradually takes place if there is any upward move, but the cooling is sudden with the first downhill move. The following temperature control function is used [8] and [10].

$$\theta_i=\theta_{min}+\lambda \ln (1+r_i)$$

Where θ_{min} is the minimum value that the temperature can take, λ ln is a coefficient that a control the rate of temperature rise, and r_i is the number of consecutive upward moves at iteration i. The initial value of r_i is zero ($\theta_i=\theta_{min}$). The purpose of the minimum temperature, θ_{min} is twofold.
During the search, if the new solution better than the previous solution, the replace is made and the counter r_i increases by 1. If the new solution has an equal the previous solution, r_i remains unchanged; otherwise r_i is equal to zero.

In this method, The coding representation is the permutation of *n* numbers in the set {1, 2,.., n}, where the i^{th} number in the permutation denotes the customer is the i^{th} customer to be visited. For more information about the coding representation can be found in Lin S-W [1] and [9].

3. Computational Results

The proposed algorithm was programmed using C ++ and the simulations were performed on the Pentium 2.1 machine with 512 RAM. The initial temperature parameter may not be the case since the temperature changes dynamically during the search process. The adaptive temperature control is used that changes temperature based on the number of consecutive improving moves. In order to verify the effectiveness of the proposed algorithm, a computational experiment has been conducted to compare the performance of the proposed algorithm with some results of the meta-heuristic approaches designed for solving CVRP. We executed the algorithm on the twenty large-scale benchmark instances [11]. The results for this dataset are reported for ten independent runs, and in each run the algorithm was executed for 200 iterations. The results are presented in Table 1. The Table contains the comparison between our results and some results of the meta-heuristic approaches designed for solving CVRP. As shown in the Table 1; the results show that the proposed approach to be very competitive with the best-known methods.

Table 1: Comparisons between the proposed algorithm and other approaches

Problem Instance	GTS [5]	HMH [6]	EA [7]	Our best solution
Kelly01	5736.15	5795.61	5646.63	5795.52
Kelly02	8553.03	8501.67	8447.92	8502.45
Kelly03	11402.75	11364.69	11036.22	11464.45

Kelly04	14910.62	14136.32	13624.52	13536.34
Kelly05	6697.53	6512.27	6460.98	6550.81
Kelly06	8963.32	8553.19	8412.80	8420.60
Kelly07	10547.44	10422.65	10195.59	102113.23
Kelly08	12036.24	11986.73	11828.78	11986.91
Kelly09	593.35	586.68	591.54	587.32
Kelly10	751.66	748.89	751.41	750.61
Kelly11	936.04	924.70	933.04	933.00
Kelly12	1147.14	1125.71	1133.79	1126.78
Kelly13	868.80	867.29	875.16	867.10
Kelly14	1096.18	1098.86	1086.24	1085.01
Kelly15	1369.44	1356.65	1367.37	1356.81
Kelly16	1652.32	1642.90	1650.94	1642.90
Kelly17	711.07	712.26	710.42	710.45
Kelly18	1016.83	1017.91	1014.8	1015.2
Kelly19	1400.96	1384.93	1376.49	1377.00
Kelly20	1915.83	1855.91	1846.55	1846.40

4. Conclusion

In this paper, we proposed an adaptive temperature control of simulated annealing for solving capacitated vehicle routing problem. The main difference between our approach and the classical SA is that, our approach dynamically changes the temperature during the search process. The adaptive temperature control is used that changes temperature based on the number of consecutive improving moves. To verify the performance of this proposed method, we were applied of well known CVRP selected from the literature. The proposed approach can be applied to vehicle routing problems of various types with loading capacity constraints. Hopefully, the proposed algorithm can be used to solve the vehicle routing problems with different limitation conditions in the future.

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