Two-Generation Ant Colony System for Vehicle Routing Problem with Time Windows

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***Abstract*—Ant Colony Optimization based algorithm for vehicle routing problem with time windows (VRPTW) is presented. To solve it, a two-generation (father and children) ant colony algorithm is proposed. The aim of the first children generation is construction of the sub-tours, whereas in the second father generation the sub-tours are composed of feasible solutions. The computational results show that the tow-generation ant colony algorithm is effective in solving multi-objective VRPTW.**

Keywords- vehicle routing problem; ant colony system multi-objective optimization

I. INTRODUCTION

Customer service the output of logistics system determines the success of a company especially in the second changeable global E-market environment. Distribution is integral to marketing and sales performance because it provides timely and economical product availability as a connection. During the last few years, customers have enforced the use of time windows in all respects of distribution, motivated by the Just-in-time principles and the awareness of the competitiveness arising from adopting such principles, for example minimum inventory, reduced cycle times, Just-in-time production, etc.[1]. Typically VRPTW is classed into two VRP with hard time windows in which each customer must start within an associated time windows and VRP with soft time windows where time windows can be violated at a cost. In fact, company usually do not maintain the customers' dissatisfaction as low as zero, but keep the satisfaction degree to a proper percent less than 100%. Because perfect service performance must be accompanied by high running cost including fleet purchase, running payment, time window violate punishment etc. Providing effective tools to the sales-marketing department of a company, which allow for time window adjustment that can reduce vehicle fleet size during sales negotiation, is of paramount importance [2]. So in this paper, we proposed an algorithm to derive such kind of result allowing time windows violations to 5-10% for the aim of fleet size reduction.

VRPTW as an extension of traditional capacitated Vehicle Routing Problem has been widely studied. Recently metaheuristics include simulated annealing, tabu search, evolutionary algorithms have been already applied to VRPTW. But there are only a few researches are done by Ant Colony Optimization. The first ant system for vehicle routing problem was designed by Bullnheimer[3]. Then, Chen, Chia-Ho[4],[5], Liu, Zhi-Shuo[6], Mazzeo[7] used different improved ant colony algorithm for vehicle routing problem. Liu, Zhi-Shuo[8] proposed An Adaptive Hybrid Ant Colony Algorithm (AHACA) based on the two-phase construction procedure of feasible solution which was established to solve the Vehicle Routing Problem with Hard Time Window (VRPHTW) and studied the evenness of the solutions [9]. Last but not least, Baran, Benjamin[10] presented two ant colonies to minimize first the number of vehicles and then the total traveled distance for VRPTW. However, there is few research considers the reduction of vehicle fleet size with a small number of time violation. Therefore, our key research contribution is the presentation of a two-generation ant colony system for the multi-objective VRPTW, which provides better results than the previous work.

The rest of paper is organized as follows: Section 2 develops the proposed algorithm. In 3 the computational result is shown. Finally, conclusions are drawn in section 4.

II. TWO-GENERATION ANT COLONY SYSTEM FOR VRPTW

The VRPTW problem can be described as follows: a unique center depot owns a fleet of Q capacity. L customers asked for quantity g_i of goods must be served by an available vehicle, where $g_i < Q$. For each customer i, let S_i denote the vehicle arrive time, if $S_i \in [ET_i, LT_i]$ (ET_i is the earliest arrive time and LT_i is the latest arrive time) the customer is satisfied, else punishment must be taken. Since the vehicle capacity and travel distance are limited, in case of either violation the truck must return to the depot. Solution of VRPTW is a minimum cost (vehicle activation, route cost and time violation cost) collection of tours where each customer is visited only once.

The problem is a typically multi-objective NP-hard problem. Because the criteria are often in conflict, it appears plausible that minimization of the total travel distance does not inevitably lead to a reduction in the number of vehicle. There exist a similar conflict between the minimization of the number of vehicles and the minimization of the total schedule time

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[11]. In order to overcome this problem above, we propose a two-generation metaheuristics that split the criteria in different phases. Firstly, the children ants are sent to compose sub routes with no permission of time violation in order to guarantee customer satisfaction, so the time is first consideration and find the minimum travel distance. Then the sub routes are combined into Father-routes. According to Liu, Zhi-Shuo [6] the combination routes are feasible in most cases, but the experiment proves it not, usually there are some customers can not be added. In this paper saving algorithm for travel distance is introduced for the insertion of unvisited customers and allows the time violation of the last customers for the reduction of vehicle number. Fig. 1 describes the overall tow-generation ant colony algorithm.

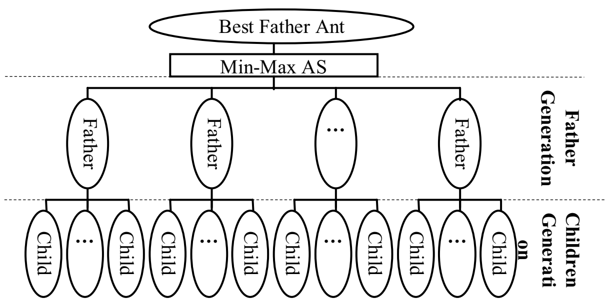

Figure 1. Architecture of Tow-generation Ant Colony System

A. Sub route of child ant

In order to improve the diversification of sub route the child ants start form the customer point evenly by MOD function for the remainder. The core code is as follows:

```
For i=1 to MaxAnts
  Ant(i).StratingCity=i MOD MaxCities
  If Ant(i).SatrtingCity=0 then
    Ant(i).SatrtingCity= MaxCities
  End if
Next i
```

When child ant at city i select city to then next city, if for any $T_i \in [ET_i, LT_i]$, $T_j \notin [ET_i, LT_i]$ then define $Citytabu_{ij}$ as Boolean equals false. Introduce another parameter in the probability formulation $Windowsize_i$.

$$Windowsize_i = LT_i - ET_i \qquad i = 1,2,\cdots l \qquad (1)$$

The probability for child ant k to append arc(i,j) to its partial solution is then given by:

$$p_{ij}^k = \begin{cases} \dfrac{\tau(i,j)^\alpha \eta(i,j)^\beta Citytabu(i,j)^\tau [1/Windowzize(i,j)]^\theta}{\sum_{j \in J_k} \tau(i,j)^\alpha \eta(i,j)^\beta Citytabu(i,j)^\tau [1/Windowzize(i,j)]^\theta} & if \quad j \in J_k \\ 0 & else \end{cases} \qquad (2)$$

For child ant from depot and not the route construction procedures are different, the pseudo code is below:

Procedure sub route construction:
For each child ant
  If starts from depot then
    While child ant load no more than truck capacity OR exist city fit then time window
      Select next city via (2)
      While arrive time not between select city's earliest and latest time
        Select next city via (2)
        If arrive time is between select city's earliest and latest time then
          Exit Do
        End if
      End While
      Pheromone matrix update
    End While
  Else
    TravelE equals child ant starts city's ET_i, TravelL equals child ant starts city's LT_i
    While TravelE is more than the nearest travel time form city to depot
      Select next city backwards to depot
      Minus TravelE by travel time from city i to select city
    End while
    Go back to depot
    According to the partial route go forward and examine the time window
    Go on the same way as the depot start ant above
  End if
Next child ant

B. Feasible route of father ant

Reference [6] does not introduce the algorithm to compose the feasible solutions, however in this paper an adding algorithm is presented. First look for then longest sub route and introduce it into the solution. Then calculate the city intersection with other sub routes, find the route with smallest intersection number, add it into the solution. Do until the add cities is less than two. Fig. 2 describes the algorithm structure. After the sub route introduction, there are usually city that not visit. So we introduce them into the route allowing some extent of time window violation. The algorithm considers both the saving distance and time break. Fig. 3 denotes the insert procedure.

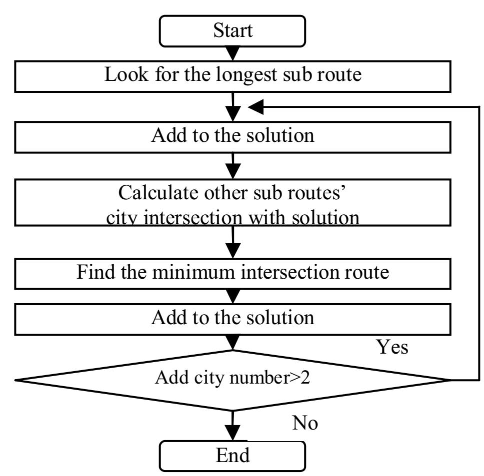

Figure 2. Sub route compose structure

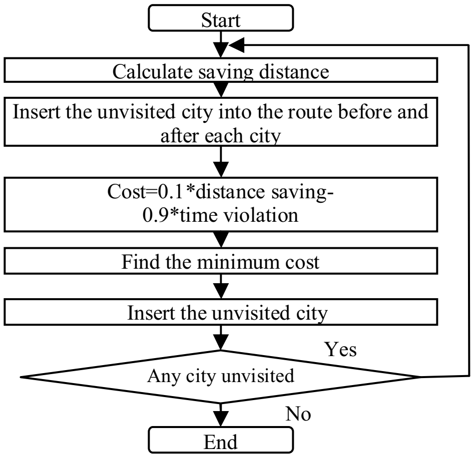

Figure 3. Last unvisited city insertion

Finally pass the feasible solution to the father ants and use Stuetzle, Thomas [12] Max-Min ant system updating the pheromone of the best and the worst route.

III. COMPUTATIONAL RESULTS

To test the algorithm in section3, a computer with Pentium IV, 2.4 GHz CPU, 512M RAM , Windows 2000 is used, the code is programmed by Visual Basic 6.0. For comparative tests, we use the instance form [8]. The parameters set for the algorithm: truck capacity=8, average travel speed=60, number of father ants=20, number of children ants=30, iteration=100, vehicle activation=1000, τ_{max}=10, τ_{min}=0.01, τ_0=0.1, α=2, β=2, ρ=0.1, γ=1, θ=1. See the evolution graph in fig. 4 below.

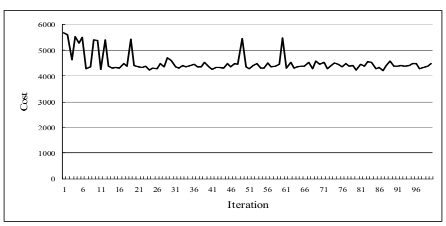

Figure 4. Evolution Graph

Fluctuation happens when Father Ants try to add a vehicle because vehicle activation is much more expensive than travel cost. Run then program for 50 times and finally we get the best route in which 1 stands for the depot and 2-21 denotes 20 customers. The average and root mean square of the experiment 50 random solutions is shown in table 1, table 2 for the arrive time of each customer and the routing graph is show in Fig. 5.

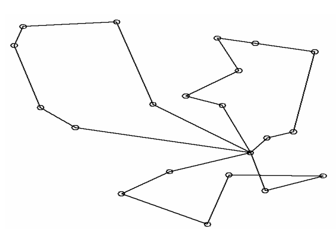

Figure 5. Best route Graph

TABLE I. ANALYSIS OF 50 SOLUTIONS

Parameters	Result
Average break number	1.44
Service level	92.8%
Total cost average	4174.9
Root mean square of cost	38.3766856
Average truck number	3
Root mean square of truck number	0
Best route	1-> 6-> 15-> 3-> 13-> 10-> 11-> 8-> 2-> 1 1-> 21-> 12-> 18-> 19-> 5-> 4-> 1 1-> 9-> 20-> 16-> 17-> 14-> 7-> 1
Break time	5.02019701391756E-02
Break number	1
Break city	16

TABLE II. TIMETABLE OF BEST SOLUTION

City	Arrive	Earl-iest	Lat-est	City	Arrive	Earl-iest	Lat-est
6	0.286	0	5	15	0.572	0	10.5
3	1.857	1	8	13	2.471	1	8
10	2.864	1	5	11	3.424	0.5	4
8	4.090	0.5	7	2	4.487	0.5	5.5
21	0.870	0.5	8.5	12	1.467	1	5
18	2.459	0.5	6.5	19	3.271	0	5.5
5	4.222	0.5	4.5	4	4.850	0	5.5
9	1.247	0.5	3	20	2.604	1	7.5
16	3.550	1.5	3.5	17	3.863	2	10
14	4.882	1	5	7	5.354	1	7.5

Compare our solution with [8] the best of which the best routeis1-19-1-6-15-3-13-10-11-8-2-1-9-20-16-17-14-7-1-2112-18-4-5-1 with travel cost 1091 and 4 trucks, the result in this research which is in consider of the truck purchasing cost and less than 10% of time violation gets much more even route. Because the sub route steps in [8] is 2,9,7,6; however our is 9,7,7. The minimum travel cost is 1174, 83 more than 1091, but the vehicles in use is 1 less than [8], moreover just with a little break of the time window.

IV. CONCLUSION

In this paper we presented a new solution method for the vehicle routing problem with time windows. A tow generation structure of ant colony system is designed to construct sub tours forward and backward in child generation and compose feasible route in the father generation via Min-Max ant system. The algorithm deal with the time window constrains, vehicle activation cost and travel distance saving step by step. Finally the experiment result proves the effectiveness of the metaheuristics with sacrifice of average 7.2% unsatisfied customer for the saving of 1 running truck which also get much more even solution.

Although the proposed method works well in the 20 city instance, there is still much work in solving VRPTW. We will attempt to solve large scale problem in the future.

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