Resource-Constrained Scheduling Optimization for Public Bicycles using Multi-Variety Ant Colony Algorithm

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Abstract — Public bicycle system has the problems of borrowing and returning in practical motion, the main reason being the inter-station bicycle scheduling is unreasonable and not timely. The paper proposes a resource-constrained scheduling optimization algorithm for public bicycles based on multi-variety ant colony algorithm. Firstly: i) we study scheduling optimization problems of public bicycles, ii) and give scheduling optimization model under resource-constrained condition, iii) we consider scheduling vehicle capacity constraint and station supply constraint. Secondly: i) we improve the scheduling optimization model for public bicycles by making use of ant colony algorithm, such that ii) all ant colonies carry out search and decision independently based on serial schedule generation mechanism to improve optimal performance, and iii) we deal with the interaction of pheromone that exists between all ant colonies to realize acceleration search. Finally, we verify the effectiveness of the proposed method by scheduling optimization experiment of public bicycles system in the area of Binjiang of Hangzhou City.

Keywords: public bicycle; ant colony algorithm; multi-variety; resource-constrained; pheromone

I. INTRODUCTION

“Public bicycle system” (public bicycle system, PBS) originates from Europe, implementation purpose is to solve the problem of “last 1km” from public transportation station to places of residence. From the end of 1990s, many countries in Europe and America introduce free bicycle lease service; in international large cities of Lyons, Paris, London, New York, Amsterdam, etc., free bicycle lease service develops quickly; implementation effect shows PBS has positive function to ease traffic pressure and promote energy conservation and emission reduction.

Domestic PBS implementation is in starting stage; research in public bike planning just begins; Yao Yao, Guo Minhui and Li Lihui have respectively introduced PBS planning in Hangzhou, Shanghai and Wuhan; put forward respectively stationing principle, bicycles distribution scale and layout planning scheme for bicycle system service point according to condition of all cities. After PBS implementation in recent years, urgent generality problems occur in PBS of several domestic cities, which mainly are the problems of “difficult borrowing and difficult returning”. Main reasons include: ① unreasonable site selection of PBS station; ② unreasonable bicycle distribution of PBS station; ③ unreasonable and not timely scheduling for bicycle between stations. Reasonable and timely scheduling for bicycle numbers between stations of PBS can improve effectively turnover rate of bicycles and service level of PBS. Travel route of “scheduling vehicle” between stations of bicycle is a typical travelling salesman problem. Difficulty of solving shortest travel return route increases obviously with the increase of stations number.

Therefore, the Paper puts forward a kind resource-constrained scheduling optimization algorithm for public bicycle based on multi-variety ant colony algorithm. Optimize scheduling optimization model for public bicycle by making use of ant colony algorithm. At last, verify the effectiveness of proposed method by experiment.

II. MATHEMATICAL DESCRIPTION OF MODEL

Inter-station bicycle scheduling is a special sales man problem in PBS, shown as Fig. 1. Scheduling vehicle shall start from 1 fixed starting point and collect spare bicycles or provide and supply certain amount of bicycles when passing each station; at last, it returns back to starting point and completes a bicycle scheduling. It is assumed in the research that bicycle scheduling is routine operation; namely, carry out scheduling operation according to practical experience.

Figure 1. Public bicycle system

According to particularity of scheduling optimization, mathematical description to establish model by making use of given diagram form is:

\[ G = (V, A) \] (1)
Where, $V$ is set of bicycle stations; $A$ is frontier set that is constituted by all stations. Supposed that $D = (d_{ij})$ is distance matrix that is constituted by distance between station $i$ and station $j$; supposed that $B = (b_{ij})$ is bicycle amount that shall be scheduled by all stations of bicycles; $b_i > 0$ represents $b_i$ spare bicycles in station $i$; otherwise, it represents $b_i$ bicycles needed to be supplied; station of $b_i = 0$ does not need scheduling; clear and remove these stations during scheduling optimization. Sum of spare bicycles in station $i$ is $ib_i$. Value $ib_i$ of all stations is obtained by present actual bicycles number subtracting ideal distribution number calculated by history data.

In Fig. G, it is required that 1 Hamilton loop $T$ with shortest length shall be confirmed; namely, start from a station (starting point), only one-time shortest distance $L$ by passing all stations. For set $V = \{v_1, v_2, \ldots, v_n\}$ with $n$ stations, Hamilton loop access order is:

$$T = \{t_1, t_2, \ldots, t_n\}$$  (2)

Where, $t_i \in V$ ($i = 1, 2, \ldots, n$) and record as $t_{n+1} = t_1$.

The task of scheduling vehicle is to collect spare bicycles and supply needed bicycles by passing all bicycles stations. For starting point, if there are spare bicycles in starting points, they can be put in scheduling vehicle; if starting point lack bicycles, the second station shall have spare bicycles. Afterwards, each station shall have special constraint condition: ① capacity constraint for scheduling vehicle; the constraint of maximal loading bicycle number Bicycle Max shall be considered during collection of bicycles, namely, after collecting spare bicycles of next station, the total number of bicycles on scheduling vehicle shall less than or equal to supply number of next station. Otherwise, bicycle on scheduling vehicle will be inadequate. ② Supply constraint for next station point; consider whether the number of bicycles on scheduling vehicle shall be larger than or equal to demand of next station point; otherwise, the number of bicycles on scheduling vehicle shall be inadequate. If the 2 constraint conditions are not satisfied, the station cannot be selected as next station. Record the number of bicycles on scheduling vehicle by $ba_i$ during scheduling process. Therefore, $ba_i$ shall meet:

$$\text{BikeMax} \geq ba_i \geq 0 (i = 1, 2, \ldots, n)$$  (3)

Mathematic model of inter-station scheduling optimization problems of bicycle system is:

$$\min L = \sum_{i,j} d_{ij} \chi_{ij}$$  (4)

Resource constraint condition is:

$$ba_i = \begin{cases} b_i, b_i > 0 \\ 0, b_i < 0 \end{cases}$$  \hspace{1cm} (5)

$$ba_i = ba_{i-1} + b_i \geq 0$$  \hspace{1cm} (6)

$$ba_i = ba_{i-1} + b_i \leq \text{BikeMax}$$  \hspace{1cm} (7)

Where, $i = 2, 3, \ldots, n$

### III. MULTI-VARIETY ANT COLONY ALGORITHM

#### A. Standard ant Colony Algorithm

Ant colony algorithm is simulation that ant colony forages by pheromone and is widely used to optimization problem of various combinations. Generally speaking, ant colony algorithm generates a complete and feasible project scheduling plan by adopting schedule generation system and by expanding local scheduling plan gradually. Receive best solution by repeated research. See Fig. 2 for schematic diagram of simulation of ant foraging.

![Image of ant colony algorithm](image)

In ant colony algorithm, ant searches from the first task and searches all tasks; finish search in the $j$th task. During $gth$ search, after ant $k$ selects task $i$, feasible candidate tasks set is recorded as $D_i^k$; the set includes all schedules that are not arranged. At the same time, schedule of all urgent tasks have been arranged. Therefore, $D_i^k$ not only excludes all selected tasks, but also excludes all tasks that cannot be arranged behind task $i$ logically. Probability of ant $k$ to select task $j$ from $D_i^k$ is:

$$P_i^j(g) = \frac{\tau_i(g)^\alpha \eta_i^j}{\sum_{j \in D_i^k} \tau_i(g)^\alpha \eta_i^j}, j \in D_i^k$$  \hspace{1cm} (8)

Where, $\tau_i$ is pheromone; $\eta_i$ is heuristic information; $\alpha$ and $\beta$ are parameter to control 2 kinds of information weight. Heuristic information generally represents perceptual intuition that can be used in search decision. In RCPSP,
heuristic information is generally constructed by precedence rule. The most common is latest finish time (late finish, LF); record latest finish time of task as \( L_j \); therefore, heuristic information can be represented as:
\[
\eta_j = \max_{h \in H} L_h - L_j + 1 \tag{9}
\]

Updating of pheromone is emphasis of ant colony algorithm, which includes volatilization and accumulation of pheromone; volatilization and accumulation of pheromone generally can adopt the following mechanism:
\[
\tau_{ij}(g + 1) = (1 - \rho)\tau_{ij}(g) + \Delta\tau_{ij}(g) \tag{10}
\]
\[
\Delta\tau_{ij}(g) = \rho / f \tag{11}
\]

Where, \( \rho \) is volatilization rate of pheromone; \( f \) is objective function value after completion of a complete search by ant. When ant \( k \) searches from the first task to the task \( Jh \), it constitutes a complete task line. A feasible project schedule plan can be gotten by arranging starting time of all tasks in order of the task line, on the premise of meeting resource constraint, according to early principle.

B. Search Decision

During the process of search decision, represent the kth ant in the \( l \)th colony by \((l,k)\); the probability of ant \((l,k)\) to select task \( j \) after selecting closely task \( i \) is:
\[
p_{ij}(g) = \begin{cases} 
\sum_{h \in C} \pi_{ij}^h(g), j \in D_i^h \\
0, j \notin D_i^h 
\end{cases} \tag{12}
\]

Where, \( \pi_{ij}^h(g) \) represents tendency degree that ant \((l,k)\) continues to select task \( j \) after selecting task \( i \):
\[
\pi_{ij}^h(g) = \prod_r \left[ (\pi_{ij}^r(g) + \varepsilon)^{\alpha(l,r)} \right] \eta_{ij}^{\beta(l)} \tag{13}
\]

Where, parameter \( \alpha(l,r) \) decides influence of pheromone between colony \( l \) and colony \( r \). If value of \( \alpha(l,r) \) is positive, therefore, pheromone of colony \( r \) has positive promotion effect for search decision in colony \( l \); if \( \alpha(l,r) \) is negative, pheromone of colony \( r \) has negative suppression effect; the larger the absolute value of \( \alpha(l,r) \) is, the stronger the positive effect or negative effect of pheromone. If \( \alpha(l,r) = 0 \), there is no interaction between colony \( l \) and colony \( r \). \( \varepsilon \) is a decimal to prevent strength of pheromone is 0. \( \beta(l) \) presents weight of heuristic information in search decision of ant colony \( l \).

Supposed that objective function of the first ant colony is minimal total distance of bicycle; adopt universe latest completion time precedence rule. Supposed that objective function of the second ant colony is weighting task minimal delay; design the following precedence principle based on task delay:
\[
W_j = w_j(L_j - d_j) \tag{14}
\]

Heuristic information of the second ant colony is:
\[
\eta_j = \max_{h \in H} W_h - W_j + \varepsilon \tag{15}
\]

C. Updating Mechanism of Pheromone

Pheromone of ant colony \( l \) can adopt the following updating mechanism:
\[
\tau_{ij}^l(g + 1) = \tau_{ij}^l(g) + \Delta\tau_{ij}^l(g) \tag{16}
\]

Where, \( \Delta\tau_{ij}^l(g) \) represents pheromone that released by ant \((l,k)\) on virtual route \((i,j)\); its strength depends on quality of received solution.

For different varieties, it can design different pheromone updating mechanism; for the first colony, design the following pheromone increment:
\[
\Delta\tau_{ij}^l(g) = \frac{\rho_l}{CT_{ij}^l} \tag{17}
\]

Where, \( \rho_l \) is positive constant; \( CT_{ij}^l \) represents total duration of project schedule plan obtained by ant \((l,k)\).

For the second colony, design the following pheromone increment:
\[
\Delta\tau_{ij}^l(g) = \frac{\rho_2}{WT^l} \tag{18}
\]

Where, \( \rho_2 \) is positive constant; \( WT^l \) represents weights of task delay of project schedule plan obtained by ant \((l,k)\).

D. Algorithm Steps

In conclusion, multi-variety ant colony algorithm designed for multi-target resource-constrained project scheduling problems is as follows:

<table>
<thead>
<tr>
<th>Algorithm: multi-target resource-constrained multi-variety ant colony algorithm of public bicycle system</th>
</tr>
</thead>
<tbody>
<tr>
<td>input RCPSP instance</td>
</tr>
<tr>
<td>initialize coefficients</td>
</tr>
<tr>
<td>set pheromone matrix ( \tau_0 = 0 )</td>
</tr>
<tr>
<td>for every circle</td>
</tr>
<tr>
<td>for every ant colony</td>
</tr>
<tr>
<td>for every ant</td>
</tr>
</tbody>
</table>
for stage=1: 
J estimate D_j ;
select j from D_j ;
set CT_j as early as possible.
end for
end for

evaporate pheromone τ_{ij} ;
update pheromone τ_{ij} ;
calculate deviation(S)
if deviation(S) < deviation(S') then
update S* ;
update pheromone τ_{ij} ;
end if
end for
end for

IV. EXPERIMENTAL ANALYSIS

A. Experimental Scheme and Data

The Research selects PBS in an area of Binjiang of Hangzhou City. There are a scheduling center MO and 62 service points of PBS; select 9 service points that meet first-class service window condition as experiment object. Herein, relevant lease requirement data is shown as Table 1.

<table>
<thead>
<tr>
<th>Service point No.</th>
<th>Lock stud in service point number/unit</th>
<th>Present bicycle number/unit</th>
<th>Bicycle lock ratio</th>
<th>Bicycle number/unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>6205</td>
<td>32</td>
<td>0</td>
<td>0.00</td>
<td>-16</td>
</tr>
<tr>
<td>6210</td>
<td>32</td>
<td>1</td>
<td>0.04</td>
<td>-14</td>
</tr>
<tr>
<td>6117</td>
<td>22</td>
<td>21</td>
<td>0.96</td>
<td>8</td>
</tr>
<tr>
<td>6113</td>
<td>22</td>
<td>1</td>
<td>0.01</td>
<td>-12</td>
</tr>
<tr>
<td>6066</td>
<td>22</td>
<td>22</td>
<td>1.02</td>
<td>10</td>
</tr>
<tr>
<td>6080</td>
<td>22</td>
<td>23</td>
<td>0.96</td>
<td>8</td>
</tr>
<tr>
<td>6012</td>
<td>34</td>
<td>32</td>
<td>0.98</td>
<td>14</td>
</tr>
<tr>
<td>6027</td>
<td>34</td>
<td>1</td>
<td>0.02</td>
<td>-16</td>
</tr>
<tr>
<td>6097</td>
<td>22</td>
<td>22</td>
<td>1.02</td>
<td>9</td>
</tr>
</tbody>
</table>

Supposed \( d_i(t) > 0 \) when service point need to send bicycles; \( d_i(t) < 0 \) when service point need to transport into bicycles. Maximal number for loading bicycles is 75 for actual scheduling vehicle. Cost of mileage is 2 Yuan/km; average travelling speed of scheduling vehicle is 36km/h; distance between all service points and the distance between service station and scheduling center are shown as Table 2. According to previous scheduling experience, it needs 20s to set scheduling personnel to add or remove a bicycle; scheduling stopping time of scheduling vehicle in service point is \( d_i(t)/3\text{min} \); it is 0.2d_i(t)km after transforming to travelling distance; fixed cost for a round of scheduling is 80 Yuan. Change factor of users’ satisfaction is 0.36c_3.

B. Result Analysis

According to Table 1, the Research obtains scheduling plan by ant colony algorithm. In the process of experiment and test, the 20 experiments with 200 iterations have been carried out. 8 optimal schemes with the same performance; the optimal solution is shown as Table 2.

Table 2. Optimizing Result Of The Optimal Solution

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Scheduling lines</th>
<th>Scheduling mileage/km</th>
<th>Comprehensive scheduling cost/Yuan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial experience algorithm</td>
<td>Mo-&gt;6210-&gt;6117-&gt;6027-&gt;6012-&gt;6080-&gt;6066-&gt;6097-&gt;6205-&gt;Mo</td>
<td>31.2</td>
<td>128.6</td>
</tr>
<tr>
<td>Algorithm in the paper</td>
<td>Mo-&gt;6210-&gt;6205-&gt;6117-&gt;6113-&gt;6027-&gt;6012-&gt;6080-&gt;6066-&gt;6097-&gt;Mo</td>
<td>26.3</td>
<td>96.8</td>
</tr>
</tbody>
</table>

It can be gotten from Table 2 that total length of scheduling lines obtained from algorithm optimization of the paper is 26.3 km, which is 4.9km less than path length of experience lines. At the same time, lines after optimization have carried out precedent scheduling to important service point (6210, 6205); try to improve users’ satisfaction. Comprehensive scheduling cost of optimizing lines is 9,688 Yuan (not actual cost and for reference only), which saves 31.8 Yuan compared with that of experience lines and is about 22.7% of comprehensive scheduling cost before optimization.

Fig. 3 shows convergence contrast condition of 5 kinds algorithms; herein, algorithm 1 is algorithm of the paper; algorithm 2 is particle swarm algorithm; algorithm 3 is genetic algorithm; algorithm 4 is differential evolution algorithm; algorithm 5 is standard ant colony algorithm. It can be seen that algorithm of the paper is superior to selected contrast algorithm on final convergence result and embodies effectiveness of algorithm.
V. CONCLUSIONS

The paper puts forward a kind resource-constrained scheduling optimization algorithm for public bicycle based on multi-variety ant colony algorithm; researches scheduling optimization of public bicycle system; provides scheduling optimization model in resource-constrained condition; carry out optimization to scheduling optimization model of public bicycle by making use of ant colony algorithm; finally, carry out verification to algorithm performance by experiment. Research key points for next step is to carry out hardware setting to actual system and further optimization of algorithm to decrease algorithm complexity and realize further improvement of precision.

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