Discrete Artificial Bee Colony Algorithm for Low-Carbon Traveling Salesman Problem

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Abstract:

With the challenge of climate change, many governments, enterprises and individuals around the world are focusing on reducing emissions of carbon through energy efficiency improvements. This paper investigates an extended traveling salesman problem with low-carbon consideration. Carbon dioxide emission is taken as one of the major contributing factors to incorporate into the classical traveling salesman problem. A novel discrete artificial bee colony algorithm (DABC) is used to solve the proposed model. Also, a new encoding operation-Swap Operator is developed for the proposed DABC which can help the bees to generate a better candidate tour by greedy selection. The results of numerical experiments show that the proposed DABC produces an optimal solution and shows to be effective in solving low-carbon TSP problems.

Keywords: Artificial bee colony, swap operator, TSP, low-carbon

1. INTRODUCTION

Global warming has become perhaps the most complicated issue facing developed and developing countries. The global climate change mainly arises from energy-related carbon dioxide (CO2) emissions. Low carbon economy is an effective way of controlling greenhouse gas emissions. Low carbon economy, as a development strategy to reduce global warming, is gradually accepted by all countries, and evolved into a new development direction, which guides the human production and consumption patterns change. The core concept of low-carbon economy is ‘less consumption of natural resources and lower greenhouse gas emissions to economic output’.

To accord with the goal of low-carbon economy, we extend the Traveling Salesman Problem (TSP) problem with low-carbon consideration. Moreover, as swarm intelligence draws more and more interest to the scientists in related fields, new algorithms such as artificial bee colony (ABC) algorithm emerged. It was developed by Karaboga in 2005 in order to optimize multi-variable and
multi-modal continuous functions\textsuperscript{1,2} through imitating the specific intelligent foraging behaviors of bee swarms. The ABC algorithm was initially designed for numerical optimization problems. And numerical comparison results demonstrated that the performance of the ABC algorithm is competitive to other swarm based algorithms with an advantage of fewer control parameters\textsuperscript{2} and the algorithm is also robust. Because of its simplicity and easy implementation, the ABC algorithm has attracted much more attention and has been applied to many practical optimization problems such as digital IIR filters\textsuperscript{3}, spanning tree problem\textsuperscript{4}, PID controller design\textsuperscript{5}. Till now, the ABC algorithm has been proven to succeed in continuous problems and much work has been done effectively in this area.

However, litter work has been done to use ABC algorithm in some real-world applications for discrete problems. Applying ABC algorithm to the extended TSP problem is still a new research direction. Based on this reason, we are presenting in this paper a new discrete ABC algorithm by applying Swap Operator to solve the extended TSP problem and make a broad advancement to extend ABC to the domain of combinatorial problems. BURMA14 has been taken as an example to validate the performance of the proposed algorithm.

The rest of this paper is organized as follows: section 2 presents the extended TSP problem with low-carbon consideration, section 3 contains the concepts of the basic ABC algorithm, section 4 presents the discrete ABC algorithm for TSP problem, section 5 is the experimental studies and results while the conclusions are drawn in section 6.

2 LOW-CARBON TSP PROBLEM

The Traveling Salesman Problem (TSP) is one of the most widely studied combinatorial optimization problems. It is a NP-complete problem whose computational complexity rises exponentially when the number of cities increasing and cannot be solved exactly in polynomial time.

Many exact and heuristic algorithms have been proposed to solve this problem in recent years. The exact methods include branch-and-bound\textsuperscript{6}, enumeration and cutting planes\textsuperscript{7}, while the heuristic algorithms consists of Particle Swarm Optimization\textsuperscript{8}, Neural Network\textsuperscript{9}, Tabu Search\textsuperscript{10}, Ant Colony Optimization\textsuperscript{11}, Genetic Algorithms\textsuperscript{12}, Simulated Annealing\textsuperscript{13} and so on.

In this paper, to accord with the goal of low-carbon economy, we extend the TSP problem with
low-carbon consideration. Let $S = \{1,2,\ldots,s\}$ be a set of cities, and let $M = \{1,2,\ldots,m\}$ be a set of transportation modes. Each city is to be visited exactly once. Since there are $s$ cities, the number of paths for a complete loop tour should be $s$. For each path, only one transportation mode is utilized and its transportation speed is $v_i$, where $i = 1,2,\ldots,m$. We define $d_{jk}$ as the distance between city $i$ and city $j$. The problem is to find a tour that has the minimum traveling time subject to a constrained emission quantity of CO2. The mathematical formulation of this problem is thus can be expressed as

$$\text{Minimize} \quad T = \sum_{i=1}^{m} \sum_{j=1}^{s} \sum_{k=1}^{s} \frac{d_{jk} x_{jk}^i}{v_i}$$

subject to

$$\sum_{i=1}^{m} \sum_{j=1}^{s} \sum_{k=1}^{s} e_i d_{jk} x_{jk}^i \leq Q$$

$$x_{jk}^i \in \{0,1\}$$

where

$$x_{jk}^i = \begin{cases} 1 & \text{if transportation mode } i \text{ is used on path } i \\ 0 & \text{otherwise} \end{cases}$$

The objective is to minimize the total traveling time, as shown in Eq. (1). As for the constraint, Eq. (2) is used to limit the total emission quantity of CO2, where $e_i$ is the CO2 emission quantity of $ith$ transportation mode per unit distance, and $Q$ is the planned CO2 emission quantity.

3 ARTIFICIAL BEE COLONY ALGORITHM

The Artificial Bee Colony (ABC) algorithm is a relatively new swarm intelligence based optimizer and was proposed by Karaboga\textsuperscript{14} based on the foraging behaviour of honey bees for numerical optimization problems in 2005. In the ABC algorithm, the colony of artificial bees are classified into
three groups, namely, employed bees, onlookers and scouts. A bee that is currently exploiting a food source is called an employed bee while a bee waiting on the dance area for making decision is called an onlooker. A scout carries out random search for a new food source. Half of the colony consists of employed bees, and the other half includes onlooker bees. Each solution consists of a set of optimization parameters which represent a food source position. And the number of food sources is set equal to the number of employed bees or the onlookers. In other words, there is only one employed bee for every food source. The amount of nectar of a food source corresponds to the quality of the solution represented by that food source. The employed bee whose food source is abandoned by the employed bees and onlookers becomes a scout and only one scout is allowed to occur in each cycle. By this mechanism, the exploitation will be handled by employed bees and onlookers while the exploration will be maintained by a scout.

There are three important steps in each cycle of search process in the basic ABC algorithm. In the first step, generate initial food source positions randomly. In order to update feasible solutions, all employed bees select a new candidate food source position, which is different from the previous one. The position of the new food source is calculated by the following equation:

\[
v_{ij} = x_{ij} + r(x_{ij} - x_{ij}')
\]

In the equation (5), \(v_{ij}\) is a new feasible solution that is modified from its previous solution value \(x_{ij}\) based on a comparison with its neighboring solution \(x_{ij}'\). \(r\) is a random number between [-1,1]. \(k \in \{1,2,3,\ldots,SN\}\) and \(j \in \{1,2,3,\ldots,D\}\) are indexes where \(SN\) is the number of food sources and \(D\) is the number of parameters. The new source replaces the previous one in the employed bee’s memory if better than previous position, otherwise keep the position of the previous one.

In the second step, each onlooker selects one of the proposed food sources obtained from the
employed bees by using roulette wheel rule. The probability that a food source will be selected can be obtained from an equation below:

$$P_i = \frac{fit_i}{\sum fit_n} \quad (6)$$

where $fit_i$ is the fitness value of the food source $i$. After selecting the food source, onlooker goes to the selected food source and selects a new candidate food source which can be expressed and calculated by equation (5).

In the last step, $limit$ is a special and important control parameter in the ABC algorithm and it controls the times of a certain solution which has not updated. Any food source position that does not improve over a predetermined number of cycles called $limit$ will be abandoned and replaced by a new position and the employed bee becomes a scout. The new random position chosen by the scout will be calculated by the equation below:

$$x_{ij} = x_{min}^j + rand(0,1)(x_{max}^j - x_{min}^j) \quad (7)$$

where $x_{min}^j$ is the lower bound of the food source position in dimension $j$ and $x_{max}^j$ is the upper bound of the food source position in dimension $j$.

There is a $Maxcycle$, the maximum number of cycles, to control the number of iterations. The process will be repeated until the output of the objective function reaches a defined threshold value or the number of iteration equals the $Maxcycle$.

4 DISCRETE ABC (DABC) for LOW-CARBON TSP PROBLEM

This study illustrates a novel DABC algorithm for solving low-carbon TSP problem. The DABC algorithm is produced by applying the concepts of Swap Operator and Swap Sequence to the original ABC algorithm.
In the low-carbon TSP problem, there are two sections. The first section is a list of cities and the second section is a list of transportation modes. So a tour must illustrate with these two sections. For example, it is a tour in Fig.1. The first section presents the sequence of cities visited and the second section represents a set of transportation modes chosen for each path. We must note that a certain transportation mode is available for different paths in a same tour. That is to say, a certain number may occur several times in the second section while a certain number can only occur one time in the first section. Possible modes include walk, by bicycle, by motorcycle, be car, by bus, and more.

Having discussed the basic ABC algorithm and the representation of a tour, the computational procedures of the proposed DABC algorithm for low-carbon TSP problem can be outlined as follows:

1. Initialize all the parameters: Colony, limit, Maxcycle, runtime and so on.

2. Apply discrete ABC processes to each employed bee: (1) Randomly create a Swap Sequence for each employed bee, \(SS_j = (SO_{j1}, SO_{j2}, SO_{j3}, \ldots, SO_{jm})\) where \(j = 1, 2, \ldots, n\) and \(n\) is the number of employed bees and \(m\) is the number of Swap Operators in each Swap Sequence. (2) Create a new neighbour tour by the previous tour and \(SS\). And \(SS\) is only performed on the first section of a tour. The set of transportation modes is created randomly. (3) Evaluate the new tour and calculate the total emission quantity of CO\(_2\). If the total emission quantity of CO\(_2\) > Q, the tour is abandoned. Later update \(SS\) and the number of trail, which records the cycle number of all unimproved tours.

3. Apply discrete ABC processes to each onlooker bee: (1) Select tour from employed bees with a probability calculated by the equation (6) by using the common roulette wheel rule. (2) Create a new neighbor tour by the selected tour and updated \(SS\). (3) Evaluate the new tour and calculate the total emission quantity of CO\(_2\). If the total emission quantity of CO\(_2\) > Q, the tour is abandoned. Later update \(SS\) and the number of trail.

4. Calculate the number of trail and record the maximum number as \(M\). If \(M\geq limit\), then abandon that unimproved tour and randomly create a new tour for the scout. If \(M<limit\), then the scout bee takes the previous tour.

5. Judge the stop criterion. If the criterion is satisfied then stop the program, else go to step 2.
Fig. 2 describes the steps how to solve low-carbon TSP problem using DABC algorithm in details.

5 EXPERIMENTAL STUDY

In this paper, the experiments are conducted on a PC (Intel I3-370M CPU, 2 GB of memory, Win2007, Matlab 7.0). BURMA14 has been employed as an example to verify the effectiveness of the algorithm. In the experiments, the pair-wise distances and the transportation modes are known for each path. Totally, there are seven main kinds of transportation modes in this paper, as shown in Table 1. The emission quantity of CO2 for each transportation mode is also illustrated. These data are mainly based on the data collected from reference [15]. The emission of CO2 depends on conveyance, distance, weight, and more. A best tour to be determined is to travel each spot exactly once. Note that a transportation mode with a higher average speed is usually has a more emission quantity of CO2.

In the first experiment, two parameters, that are Alpha and limit, have been verified. Alpha is the probability of Swap Operators been reserved in a Swap Sequence, while limit is a predetermined number in the ABC algorithm. The common initialized parameters are: the Colony of the DABC algorithm is 28, the Maxcycle is 200, the number of Swap Operators in a Swap Sequence is set to be 14 and Q is 2.

In the experiment of Alpha, limit is 50 and Alpha is set to be 0.1, 0.3, 0.5, 0.8 and 1.0 respectively. Fig.1 shows the results of different Alpha. As shown in Fig.3, the optimal solution is obtained when Alpha equals 0.5. It means that the number of Swap Operators in a Swap Sequence should be 7. It not only achieves the best solution, but also saves time.

To confirm the influence of parameter limit, limit has been set separately to be 10, 20, 50, 100, 120 and Alpha is 0.5 in this experiment. The results with different limit are presented in Fig.4. In the figure, when limit is smaller, the results are better. There is not only one employed bee turn to be a scout in each cycle. Only if the parameter trail of a certain employed bee is bigger than limit, the employed bee turn to be a scout to carry out random search. When limit is small, more scouts search solutions randomly, so the exploration mechanism will be maintained well by scouts and global search ability of the algorithm is enhanced.

In the second experiment, the Colony of the DABC algorithm is 28, the Runtime is 50, the Maxcycle is 1000 and limit is 100, the number of Swap Operators in a Swap Sequence is set to be 14 and Alpha is 0.5. The results of total time with the constrained Q are presented in Table 2. The constrained Q is 1, 2, 3 and 4 respectively . Shortest route stands for the optimal tour with the certain constrained Q. Transportation modes record the transportation tool on each path in the shortest route. And the shortest routes with different Q are illustrated in Fig.5.

As shown in Table 2, when the allowed CO2 emission quantity Q is varied, the shortest routes are different and the total time also changes. An increase in Q leads to a shorter total time. Because to different transportation modes, average speed is higher and traveling time is shorter, then the CO2 emission quantity will be higher. A compromise between “time cost” and “environmental cost” is a totally game problem. Thus, different reasonable balances between “time cost” and “environmental cost” will be obtained with
different purposes. In order to reduce the pollution to the environment, more time will be spent on the traveling route, while more harm will do to our environment if the objective is to reduce total time.

6 CONCLUSIONS
The global warming has become an important issue that should draw much attention by anyone. One of the major factors causing global warming is the amount of CO2 in the atmosphere. Based on social responsibility, we should take the influences caused by CO2 emission into consideration during tour planning. In this paper, a new discrete ABC algorithm is proposed to solve the extended TSP problem. The concept of Swap Operator is applied to the basic ABC algorithm and BURMA14 is chosen to evaluate the performance of the new algorithm.

We grounded on a constrained CO2 emission quantity and the shortest traveling time proposes an optimized planning for the extended TSP problem. However, the results from this paper are under some assumptions. In the future, more real situations can be considered and a more practical system is recommended.

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References and Notes


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Table 2. Total time with the constrained Q.

Fig. 1. Representation of a tour.

Fig. 2. The DABC algorithm flowchart for low-carbon TSP problem

Fig. 3. Convergence curves of Burma14 with different $\text{Alpha}$. 

Fig. 4. Convergence curves of Burma14 with different $\text{limit}$. 

Fig. 5. Feasible solution found for Burma 14 with different Q
### Table 1. Transportation modes and related information

<table>
<thead>
<tr>
<th>Index</th>
<th>Transportation mode</th>
<th>Average speed, $v$ (km/minute)</th>
<th>CO2 emission, $e$ (kg/km)</th>
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<tbody>
<tr>
<td>1</td>
<td>walk</td>
<td>0.067</td>
<td>0.012</td>
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<tr>
<td>2</td>
<td>bicycle</td>
<td>0.250</td>
<td>0.003</td>
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<tr>
<td>3</td>
<td>motorcycle</td>
<td>0.450</td>
<td>0.030</td>
</tr>
<tr>
<td>4</td>
<td>small car</td>
<td>0.583</td>
<td>0.070</td>
</tr>
<tr>
<td>5</td>
<td>large car</td>
<td>0.500</td>
<td>0.090</td>
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<td>6</td>
<td>bus</td>
<td>0.467</td>
<td>0.050</td>
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<tr>
<td>7</td>
<td>train</td>
<td>0.950</td>
<td>0.096</td>
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Table 2. Total time with the constrained Q

<table>
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<tr>
<th>Solution</th>
<th>Q (kg)</th>
<th>CO₂ emission</th>
<th>Total time</th>
<th>Shortest route</th>
<th>Transportation modes</th>
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<tr>
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<td>(3-4-5-6-7-12-13-8-1-11-9-10-2-14)</td>
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<th>5</th>
<th>2</th>
<th>m</th>
<th>…</th>
<th>5</th>
</tr>
</thead>
</table>

City Notes       Transportation Modes

Fig. 1. Representation of a tour.
Begin

Have all the cities’ position of optimized TSP ready and initialize all the parameters

Initialize employed bees’ tours

Create a new candidate tour for every employed bee by applying Swap Operator

Evaluate the quality of new tour by every employed bee

Each onlooker selects tour from employed bees and creates a new candidate tour

Evaluate the quality of new tour by every onlooker

Abandoned tour?

Yes

Recreate a new tour for scout

No

Termination satisfied?

Yes

Present results

No

End

Fig. 2. The DABC algorithm flowchart for low-carbon TSP problem
Fig. 3. Convergence curves of Burma14 with different Alpha.
Fig. 4. Convergence curves of Burma14 with different limit.
Fig. 5. Feasible solution found for Burma 14 with different Q