

# A Quantum Evolutionary Algorithm for Lane Reservation Problem

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**Abstract**—This paper studies a transportation problem called lane reservation problem, which aims to optimally choose lanes to be reserved in the network for the exclusive use of the time-guaranteed transportation tasks during large sportive events such that the negative impact on normal traffic is minimized. To solve this problem, an effective quantum evolution based algorithm is proposed. Computational results show the efficiency of the proposed algorithm by randomly generated instances compared with the commercial software CPLEX11.2.

**Keywords**—Large sportive events; Lane reservation; Quantum computing; Evolutionary algorithm; Optimization

## I. INTRODUCTION

High urbanization has become a reality in many countries nowadays with the development of economy. However, traffic congestion arises due to the increasing number of vehicles, traffic situations in many cities are getting worse than ever before. Traffic management has become one of strategic issues considered by government for sustainable development of economy and improvement of human's daily travel environment. Transport planning and scheduling have become a widespread concern for relative privates or public organizations. Many transportation problems such as vehicle routing problem [1], facility location problem [2], and inventory-transportation problem [3] have drawn much attention over the last decades. Furthermore, people face more and more new and special transportation problems nowadays, and the transport demand in these problems can't be met due to the saturated transportation network and increasing congested traffic situation. The lane reservation problem (LRP) is such a new transportation problem with special transportation needs from large sportive events.

In large sportive events, organizers are required to deliver special people and goods from athletes' villages to geographically distributed stadiums within a stipulated time. However, the transportation requirements can hardly be met because of heavy urban traffic congestion and saturated transportation network. New traffic infrastructure can't be constructed timely due to huge funding and long duration. Lane reservation strategy on the existing transportation network as a flexible and efficient way can adapt rapidly to the new situation. With this strategy, a lane on some roads is temporary reserved for the special transportation tasks during large

sportive events. Only the special tasks can pass through the reserved lanes, and these tasks could be completed within the prescribed time. In fact, lane reservation strategy has been successfully applied by some large sportive events' Organization Committees. For example, the idea of reserving lane for buses had been mentioned for the strategic planning, master planning, and operational planning during the 2000 Sydney Olympics [4]. Zagorianakos analyzed the importance and advantage of lane reservation strategy for the 2004 Athens Olympics [5]. The lane reservation strategy has also been applied successfully during the Olympic Games in Beijing. Moreover, lane reservation strategy can also be applied for transportation management during great emergencies.

However, only the special deliveries for large sportive events can pass through these reserved lanes and this worsens already congested public traffic. Hence, reasonable lane reservation in transportation network is critical to minimize the total impact on normal traffic. Such a transportation problem is commonly known as LRP. The core of the lane reservation problem is to choose and reserve some lanes on the existing transportation network for special deliveries of large sportive events with the objective of minimizing the total impact on normal traffic. To the best of our knowledge, there are very few studies on the lane reservation problem in the literature, Wu *et al.* [6] proposed the first mixed integer programming model for the lane reservation problem and solved by commercial software LINGO with the transportation planning in Guangzhou Asian Games in 2010 as an example. But their proposed the mixed integer programming solved by LINGO can only solve small-sized problems. And a simple heuristic is proposed to obtain near optimal solutions. It is worthwhile to point out that the mixed integer programming solved by LINGO can get optimal solutions but its computation time increases exponentially as the increase of problems' size, and the computation time of heuristic compared to optimization software LINGO decreases greatly, but the solutions' quality need be further improved. Wu *et al.* [7] proposed an improved genetic algorithm for the lane reservation problem, which got better performance than the heuristic proposed by Wu *et al.* [6]. Fang *et al.* [8][9] proposed some extended lane reservation problems that are proved to be NP-hard, and cut-and-solve based algorithms were proposed for them.

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For solving the transportation problems, several meta-heuristics have been proposed, such as genetic algorithms [10], ant colony optimization [11], tabu search [12], and scatter search [13]. Quantum evolutionary algorithm (QEA) is an algorithm based on the concept and principles of quantum computing with excellent performance introduced by Han and Kim in 2002 [14]. Authors claimed that it outperformed genetic algorithm for the knapsack problem [14] [15]. For its excellent performance, QEA has been applied to solve many other combinatorial problems, such as shop scheduling problems [16] [17], and vehicle routing problem [18].

This work introduces a quantum evolutionary algorithm for the lane reservation problem. Some techniques are added to the algorithm, such as crossover and mutation to increase the effectiveness of searching, catastrophe operation to avoid premature convergence, and reparation strategy based on greedy rule for infeasible solutions. Computational results show the efficiency of the proposed algorithm compared with the commercial software CPLEX 11.2.

This rest of the paper is organized as follows. Section 2 describes a formal problem description, and the integer linear programming model is presented. A quantum evolution based algorithm is proposed to solve the considered problem in Section 3. Numerical results are reported on randomly generated instances in Section 4. Finally, Section 5 concludes the paper and indicates some potential directions for future research.

## II. MATHEMATIC MODEL

### A. Problem description

A transportation network can be represented by a directed connected graph  $G=(V, A)$ , where  $V=\{0, 1, 2, \dots, n\}$  is the set of nodes, and  $A=\{(i, j)\}$  is the set of directed arcs that connect the nodes of transportation network. An arc  $(i, j)$  can be viewed as a road segment from  $i$  to  $j$ , where nodes  $i$  and  $j$  are road intersections. Given the fixed origin node 0 represents the athletes' village i.e., the start node where special people or goods are delivered and  $S \subset V$  is a set of destination nodes of the transportation tasks i.e., the geographically distributed stadiums of large sportive events.

The considered problem is to select and reserve lanes in the transportation network and design time-guaranteed path for each transportation task to ensure the task can be completed within the prescribed duration time. By doing so, vehicles for these tasks can travel at a relative speed on such reserved lanes, but general vehicles are not allowed to use these reserved lanes, thus normal traffic will be more congested, i.e., reserved lanes cause negative impact on the normal traffic. The objective of the problem is to minimize the total negative impact caused by lane reservation.

### B. Assumption, Notation and Formulation

To define the problem and facilitate the development of the mathematical model, some assumptions and notations are given in the subsection.

#### Assumptions:

- There are at least two lanes on a road segment. Otherwise, the negative impact on normal traffic of reserving the lane on this road is too heavy.
- There is at most one lane in a road that is allowed to be reserved for the special use, because the less lanes are

reserved, the less the total negative impact is. And all the road segments can be reserved for the tasks; reserved lanes can be shared by all tasks.

#### Notations:

$G=(V, A)$ : directed transportation network

$0 \in V$ : start node

$S \subset \{1, 2, \dots, W\} \subset V$ : set of destination nodes,  $s \in S$ .

$t_{ij}$ : travel time on a non-reserved lane of arc  $(i, j)$

$ts_{ij}$ : travel time on a reserved lane of arc  $(i, j)$

$m_{ij}$ : number of lanes on arc  $(i, j)$

$c_{ij}$ : negative impact cost on the normal traffic caused by reserving a lane on arc  $(i, j)$

$P_s$ : prescribed time of completing each transportation task

$B_i \subset V$ : set of arcs outgoing from node  $i$

$F_i \subset V$ : set of arcs entering node  $i$

#### Decision variables:

$$x_{ijs} = \begin{cases} 1 & \text{if there is a reserved lane on arc } (i, j) \in A \text{ and} \\ & \text{travel path from } 0 \text{ to } s \in S \text{ passes the arc} \\ 0 & \text{otherwise} \end{cases}$$

$$y_{ijs} = \begin{cases} 1 & \text{if the travel path from } 0 \text{ to } s \in S \text{ passes arc } (i, j) \in A \\ 0 & \text{otherwise} \end{cases}$$

$$z_{ij} = \begin{cases} 1 & \text{if there is a reserved lane on arc } (i, j) \in A \\ 0 & \text{otherwise} \end{cases}$$

#### Formulation:

With assumptions and notations given above, the problem can be formulated as the following integer linear programming problem [7].

$$\text{Minimize } \sum_{(i,j) \in A} c_{ij} z_{ij} \quad (3)$$

Subject to

$$\sum_{(0,i) \in B_0} y_{0is} = 1, \forall s \in S \quad (4)$$

$$\sum_{(i,0) \in F_0} y_{i0s} = 0, \forall s \in S \quad (5)$$

$$\sum_{(i,j) \in F_j} y_{ijs} = \sum_{(j,k) \in B_j} y_{jks}, j \in V - \{0, s\}, \forall s \in S \quad (6)$$

$$\sum_{(i,j) \in F_j} y_{ijs} \leq 1, j \in V - \{0, s\}, \forall s \in S \quad (7)$$

$$\sum_{(j,i) \in B_j} y_{jis} \leq 1, j \in V - \{0, s\}, \forall s \in S \quad (8)$$

$$\sum_{(i,j) \in A} (t_{ij}(y_{ijs} - x_{ijs}) + ts_{ij} \times x_{ijs}) \leq P_s, \forall s \in S \quad (9)$$

$$x_{ijs} \leq y_{ijs}, (i, j) \in A, \forall s \in S \quad (10)$$

$$x_{ijs} \leq z_{ij}, (i, j) \in A, \forall s \in S \quad (11)$$

$$x_{ijs}, y_{ijs}, z_{ij} \in \{0, 1\}, (i, j) \in A, s \in S \quad (12)$$

The objective (3) is to minimize the total negative impact of reserving lanes on the normal traffic. The impact of reserving

a lane on arc  $(i, j)$  is defined by  $\frac{t_{ij}}{m_{ij} - 1}$  according to [6][8].

Constraints (4)-(8) guarantee that a feasible path from node 0 to  $\forall s \in S$  is existed, where constraints (4) ensure that each transportation task is started from node 0, constraints (5) represent that the path from node 0 to  $\forall s \in S$  cannot pass node 0 twice, constraints (6) state that if node  $j$  is passed from node 0 to  $\forall s \in S$ , the prior and after arc of node  $j$  must be passed simultaneously, constraints (7)-(8) ensure that if node  $j$  is passed from node 0 to  $\forall s \in S$ , the prior and after arc of node  $j$  at most can be only passed once. Constraints (9)

express that the total travel time through the shortest path from 0 to  $\forall s \in S$  do not exceed deadline  $P_s$ . Constraints (10) ensure that there may be a reserved lane only if there is a travel path from 0 to  $\forall s \in S$  passes by arc  $(i, j)$ . Constraints (11) express that there may be a reserved lane on arc  $(i, j)$  passed by some tasks only if there is a reserved lane on the arc. Constraints (12) are binary constraints on the decision variables.

### III. SOLUTION METHOD

Since quantum evolutionary algorithm was introduced recently and drew much attention and wide applications for combinatorial optimization problems, but there is little research on transportation problems. In QEA, a quantum chromosome can express the superposition of multi-modes due to the particularities of its coding, which makes its population has a better diversity and the solution space explored much larger [14][15][16]. Thus, QEA has advantages, such as strong global search capability, high precision solution and solving efficiency, and avoiding local optima.

This section presents a quantum evolutionary algorithm for the lane reservation problem. The most important issue is to develop three strategies described later, such as remove strategy, reparation strategy based greedy rule for infeasible solutions and catastrophe operation, and its computational experiments for LRP will be described later.

#### A. Encoding and decoding

- *Encoding*

In QEA, the smallest unit of information is called a Q-bit, which is represented as,  $|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$ , where  $\alpha$  and  $\beta$  are complex number and  $|\alpha|^2 + |\beta|^2 = 1$ .  $|\alpha|^2$  and  $|\beta|^2$  denote the probabilities that the state of a Q-bit will be found in the "0" and "1", respectively. A Q-bit may be in the "0", "1", or any linear superposition of the two states. More details see [14].

- *Decoding*

Q-bit representation is a pair of complex numbers  $(\alpha, \beta)$ , that cannot be used directly. A converting mechanism for the considered problem is proposed as follows.

Step1: Let a Q-bit individual of length  $|V|$  as represent a linear superposition of solutions. In the step of initialization, the probability amplitudes  $\alpha_i^0$  and  $\beta_i^0$   $i=1, 2, \dots, |V|$  will be initialized  $\sqrt{2}/2$  to guarantee the initial probability of the "0" and "1" state of each Q-bit are equal.

Step2: For each Q-bit  $\begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix}$ , generate a random

number  $r_i^t$  from the uniform distribution  $[0, 1]$ , if  $|\alpha_i|^2 > r_i^t$ , then a bit of the binary string  $P_i(t)$  is equal to 0, otherwise 1, a binary string  $P_i(t)$  of length  $|V|$  is formed. All arcs in the transportation network are coded from 1 to  $|V|$ , each gene's position in the binary string  $P_i(t)$  corresponds to the code of an arc. The gene value is "1" in binary string  $P_i(t)$  represents the arc of corresponding position is reserved. Thus, a lane reservation solution is generated.

For example, consider a lane reservation problem in the transportation network of 10 arcs. Suppose a binary string is  $[1, 0, 1, 1, 0, 1, 1, 0, 1, 0]$  which is converted from a Q-bit

individual, thus a lane reservation solution of the first, third, 4th, 6th, 7th, and 9th arcs are reserved is generated.

#### B. Quantum rotation gate

A quantum rotation gate is employed to update a Q-bit individual as a variation operator which is an important updating method of Q-bits in quantum evolutionary algorithm [16]. The  $i$ -th Q-bit is updated as follows:

$$\begin{bmatrix} \alpha_i' \\ \beta_i' \end{bmatrix} = U(\theta_i) \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix} = \begin{bmatrix} \cos(\theta_i) & -\sin(\theta_i) \\ \sin(\theta_i) & \cos(\theta_i) \end{bmatrix} \begin{bmatrix} \alpha_i \\ \beta_i \end{bmatrix} \quad (15)$$

where  $\theta_i$  is rotation angle, which determines the rotation direction. Let  $\theta_i = s(\alpha_i, \beta_i) \Delta\theta_i$ ,  $s(\alpha_i, \beta_i)$  is the sign of  $\theta_i$  determining the rotation direction, and  $\Delta\theta_i$  is the magnitude of rotation angle whose lookup table is shown in [16].

#### C. Operations

In this paper, crossover, mutation, selection and catastrophe operators are designed as follows, respectively.

- *Two-point crossover*

Two different parent individuals are randomly selected from the population, two different positions are randomly generated (e.g. position  $i$  and  $j$ ), and then Q-bits of the parents and genes of corresponding binary string before position  $i$  and after position  $j$  are reserved while the Q-bits and the binary genes between position  $i$  and  $j$  are exchanged.

- *Shift Mutation*

One position is determined according to the gene mutation probability  $pm2$  described in the subsection  $G$ , and corresponding  $\alpha$  and  $\beta$  are exchanged, respectively. Furthermore, the value of corresponding binary gene is changed from 1 to 0 or from 0 to 1.

- *Selection*

Roulette wheel selection is adopted here in order to ensure some poor individuals that carry good genes also have chance to be selected to the next generation.

- *Catastrophe operation*

A catastrophe is used to avoid premature convergence, if the best solution does not change in certain consecutive generations, we regard that it is trapped in premature convergence, then the current best solution is reserved and the other individuals of the population will be initialized again.

#### D. Computation of fitness function

Fitness function with punishment strategy based on the concept of damage coefficient for infeasible solutions is designed as follows [7].

Let  $dis(0, s)$  be the shortest travel time from node 0 to the destination node  $s$ . Damage coefficient of constraints  $e_i$  is defined as follows.

$$e_s = \begin{cases} 0 & , \quad dis(0, s) \leq P_s \\ (dis(0, s) - P_s) / P_s & , \quad dis(0, s) > P_s \end{cases} \quad (16)$$

where  $e_s$  reflects the distance between the shortest traveling time from node 0 to the destination node  $s$  and the prescribed duration time  $P_s$ , which measures the damage degree of

constraint (9). Hence, the average damage degree  $e$  is defined as follows.

$$e = \frac{\sum e_s}{|S|} \quad (17)$$

Consequently, fitness function of a binary individual  $y = [x_1, x_2, \dots, x_{|V|}]$  with punishment strategy for infeasible solutions can be designed as follows.

$$Fit = \frac{1}{1 + \sum_{i \in \{x_1, x_2, \dots, x_{|V|}\}} c_i + e \times p} \quad (18)$$

$p$  is a suitable positive number.

#### E. Remove operation for binary individuals

The remove operation as a special treatment for binary individuals is developed to accelerate the convergence. For a binary individual observed from a Q-bit individual, there are maybe many "1"s in its genes representing the reserved arcs, but not all reserved arcs contribute to the special transportation tasks, because some of the reserved lanes maybe not be passed by any task. The remove operation means that these non-passed arcs but reserved are removed, i.e., the corresponding genes in the binary string are changed to "0"s. Thus, the fitness of this binary individual increases, because the number of reserved lanes in the transportation network decreases.

#### F. Reparation operation for infeasible solutions

In order to further improve search efficiency of our algorithm, a reparation operation for infeasible solutions based on greedy strategy is proposed for infeasible solutions, which are described as follows.

TABLE I. REPARATION PROCEDURE FOR INFEASIBLE SOLUTIONS

- 1: Select an infeasible binary individual  $y_i = [x_1, x_2, \dots, x_{|V|}]$  from the binary population according to the probability  $P_x$ .
- 2: Initialization: set  $Lset := [x_1, x_2, \dots, x_{|V|}]$
- 3: Calculate each  $dis(0, s_i)$  that represents the shortest distance from node 0 to the  $i$ -th destination node and record all the arcs passing by each task, respectively. Let  $Rset_i := [x_{i1}, x_{i2}, \dots, x_{i|V|}]$  be the set of arcs passing by the task from node 0 to  $i$ -th destination node.
- 4: **If** ( $dis(0, s_i) > Ps$ ) **do**
  - For each** arc  $(i, j) \in Rset_i$  and  $\notin Lset$  **do**
    - a. Calculate benefit per unit cost  $BF_{(i,j)} = (t_{ij} - ts_{ij}) / c_{ij}$  that represents the reduced travel time per unit cost after reserving this lane, respectively.
    - b. Let arc  $(u, v) = \arg \max BF_{(i,j)}$ .
    - c.  $Lset = Lset \cup \{(u, v)\}$
    - d. Compute the  $dis(0, s_i)$ , if  $dis(0, s_i) \leq Ps$ , break.
- 5: Set  $y_i := Lset$ .

#### G. The main procedure of the proposed algorithm

TABLE II. MAIN PROCEDURE OF THE PROPOSED ALGORITHM

- Begin**
- $t \leftarrow 0$   $ct \leftarrow 0$
  1. Parameters initialization: PS (the population size), Pc (the crossover probability), Pm1 and Pm2 (the mutation probability of individuals and the mutation probability of genes), Pr (the reparation probability), Cl (the evolutionary step length of stagnation for catastrophe), Maxgen (the maximal iterative generation), and Mct (the maximal catastrophe cumulate times).
  2. Generate initial  $Q(t)$ , which is converted to  $P(t)$  by observing the states of  $Q(t)$ .
  3. Use remove strategy introduced in Section 3 to remove non-used reserved lanes, i.e., some "1" may be converted to "0" in the  $P(t)$ .
  - Use reparation strategy introduced in Section 3 to repair the part of

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- infeasible individuals in the  $P(t)$  according to the reparation probability Pr.
  - Calculate the fitness of  $P(t)$ .
  4. **While** ( $t < \text{Maxgen}$ ) **do**
    - Begin**  $t \leftarrow t+1$
    5. Perform crossover and mutation for  $P(t)$  to generate  $P'(t)$ .
    6. Perform remove operation for  $P'(t)$ .
    7. Perform reparation operation for  $P'(t)$ .
    8. Evaluate  $P'(t)$ .
    9. Store the best solution among  $P'(t)$  into  $B(t)$ .
    10. **If** (catastrophe condition)
      - do** catastrophe
      - $ct = ct+1$ .
    11. **If** ( $ct \geq \text{Mct}$ ) **break**.
    11. Update  $Q(t)$  to  $Q'(t)$  using quantum rotation gate  $U(\theta)$ .
    12. Convert  $Q'(t)$  to  $P'(t)$  by observing the states of  $Q'(t)$  and perform roulette wheel selection to form  $Q(t+1)$  and  $P(t+1)$ .
    - end**
    13. Output the final best lane reservation result.
  - End**
- 

## IV. COMPUTATIONAL RESULTS

In this section, the performance of the proposed algorithm is evaluated by randomly generated instances. Each set includes 5 random instances. And the algorithm will be compared with the integer programming approach using commercial optimization software CPLEX 11.2 in default setting from two aspects, i.e., solution quality and computation time (CPUs). The proposed algorithm was implemented using C language coded in Code Blocks 8.02. All the computational experiments were done on a HP PC with 2.99 GHz CPU and 2GB RAM in the Window XP environment. The parameters of QEA for all instances are given as follows. A relative small population size PS=50 is set here due to the quantum population's better diversity. Pc is set as 0.7 which is a relative big one to further improve the diversity of population and search the most satisfactory solution quickly. Mutation is used to prevent premature convergence, but a large Pm1 or Pm2 leads to a random mutation. A large Pr increases our algorithm's computational time. Computational tests demonstrate that parameters Pm1, Pm2, and Pr set as 0.2 is appropriate. Other parameters are set as follows. Cl=10, Maxgen=200, Mct=50.

In this study, the *average degree* of graph  $G$  is defined as  $D=2|A|/|V|$  [19], where  $|V|$  and  $|A|$  is the number of nodes and arcs, respectively. The  $D$  of each generated instance is 8, which denotes a dense network [19]. For sake of brevity, some notations used for presents the results are shown as follows.

TABLE III. NOTATIONS OF THE COMPUTATIONAL RESULTS

Notation	Description
$W$	Total number of destination nodes
$T$	Average computational time of finding the most satisfactory solutions using our algorithm
$T_{cp}$	Average computational time of finding the optimal solutions using IP approach solved by CPLEX.
$Gap(\%)$	Gap between the most satisfactory solutions got by our algorithm and the optimal solutions got by CPLEX

All randomly test instances are generated by the following way. The transportation network  $G(V, A)$  is generated based on the network topology generator introduced by Waxman [20] where the nodes in the network are randomly and uniformly distributed in an area  $[0, 10] \times [0, 10]$  and the existence probability of an arc  $(i, j)$  is defined as  $P(i, j) = \beta \exp(-d(i, j)/\alpha L)$ , in which  $L$  and  $d(i, j)$  are the maximum distance between node  $i$  and  $j$  and Euclidean distance, respectively, and  $0 < \alpha, \beta \leq 1$ .

The parameters generate as follows. The travel time on arc  $(i, j)$   $t_{ij}$  and  $ts_{ij}$  are defined as  $5 * d(i, j)$  and  $a_{ij} d(i, j)$ , respectively, where  $a_{ij}$  is randomly and uniformly generated

from [0.5, 0.8]. The number of lanes on arc  $(i, j)$   $m_{ij}$  is randomly and uniformly generated from [2, 4]. The prescribed travel duration to accomplish all the transportation tasks  $P_s$  is assumed as 60 minutes. The destination node  $s$  is randomly generated from node set  $V$  except the origin node 0, but  $dis(0, s)$  won't exceed 60 minutes where  $dis(0, s)$  are the shortest travel time from start node 0 to destination node  $s$  when all the arcs are reserved, respectively. The detailed computational results are reported as follows.

In table IV, three scenarios of instances with  $W=20, 25$  and  $30$  and  $|V|$  increases from 110 to 150 are tested. We can see that the *gap* varies from 0.862% to 3.344% and the average value of *gap* for all instances is 2.203%, which show our algorithm can get satisfactory solutions. Furthermore, we can see that  $T$  is less than  $T_{cp}$  for all the instances sets except sets 1, sets 2 and sets 6, and the average computation time by our algorithm is much less than that by CPLEX. For a fixed  $W$ , the computation time by CPLEX increases exponentially with the increase of  $|V|$  while the computation time by our algorithm is relatively stable. Take sets 16 and sets 20 for example,  $T_{cp}$  for sets 16 is 180.213s but  $T_{cp}$  for sets 20 is 1880.480s, while  $T$  for sets 16 and sets 20 are 319.043s and 638.354s, respectively. They indicate the computation time by CPLEX is much sensitive to  $|V|$  because of the complexity of LRP, while that by our algorithm is not sensitive.

TABLE IV. COMPUTATIONAL RESULTS OF INSTANCES

set	$ V $	$W$	Gap(%)	$T(s)$	$T_{cp}(s)$
1	110	20	1.253	319.043	180.213
2	120	20	3.081	461.268	258.600
3	130	20	1.405	471.415	875.625
4	140	20	3.233	550.796	1251.594
5	150	20	0.000	638.354	1880.480
6	110	25	1.965	397.121	291.546
7	120	25	2.951	472.141	523.937
8	130	25	1.666	483.718	1465.284
9	140	25	1.891	594.390	1946.348
10	150	25	3.344	652.171	2204.785
11	110	30	2.506	411.140	582.172
12	120	30	0.862	477.890	1053.278
13	130	30	2.805	515.924	2312.112
14	140	30	1.655	605.913	2936.600
15	150	30	1.727	751.218	3878.058
Average			2.023	520.167	1442.709

## V. CONCLUSIONS

In this paper, we studied the lane reservation problem. A quantum evolution based algorithm was proposed to solve this problem. A remove strategy for the non-passed lanes by transportation tasks was done to accelerate the convergence of the proposed algorithm, and a repair strategy based on greedy rule was developed to repair the infeasible solutions generated during evolution. In addition, catastrophe operation was used to avoid premature convergence. The computational results showed the efficiency of the proposed algorithm using randomly generated instances compared with the commercial optimization software package CPLEX11.2.

In further works, a hybrid algorithm will be considered to solve larger size problems within reasonable time, an effective local search strategy will be added to the proposed algorithm

that will improve the quality of solutions within less time. Moreover, some theoretic properties of the optimal solutions will be well studied to further improve the efficiency of the proposed algorithm.

## REFERENCES

- [1] C. Groer, B. Golden, and E. Wasil, "A Parallel Algorithm for the Vehicle Routing Problem". *Informas Journal on Computing*, vol. 23, n.2, pp. 315-330, 2011.
- [2] J. Puerto and A. Rodriguez-Chia, "On the structure of the solution set for the single facility location problem with average distances", *Mathematical Programming*, vol. 128, n.1-2, pp.373-401, 2011.
- [3] Q. Liu and J. Xu, "A study on facility location-allocation problem in mixed environment of randomness and fuzziness", *Journal of Intelligent Manufacturing*, vol. 22, n.3, pp.389-398, 2011.
- [4] J. Black, "Strategic Transport Planning, Demand Analysis of Transport Infrastructure and Transport Services for the 27th summer, Olympiad Held in Sydney, Australia, 2000", *J. Transport. Eng. Inform.*, vol.2, n.2, pp.14-30, 2004.
- [5] E. Zagorianakos, "Athens 2004 Olympic Games' Transportation Plan: a missed opportunity for Strategic Environmental Assessment (SEA) integration, J". *Transport Geography*, vol.12, n.2, pp.115-125, 2004.
- [6] Y. Wu, C. Chu, F. Chu, and N. Wu, "Heuristic for lane reservation problem in time constrained transportation", *IEEE Int. Conf. Autom. Sci. Eng.*, pp.543-548, Bangalore, 22-25 August 2009.
- [7] P. Wu, A. Che, and F. Chu, "Chaos genetic algorithm with variable length chromosome for lane reservation problem", *Operation Research and Management Science*, 2012, in press.
- [8] Y. Fang, F. Chu, S. Mammam, and A. Che, "Optimal Lane Reservation in Transportation Network", *IEEE Transactions on Intelligent Transportation Systems*, vol.13, pp. 482-491, 2012.
- [9] Y. Fang, F. Chu, S. Mammam, and A. Che, "An optimal algorithm for automated truck freight transportation via lane reservation strategy", *Transport. Res. Part C*, 2012.
- [10] B. Baker and A. Ayechev, "A genetic algorithm for the vehicle routing problem", *Computers & Operations Research*, vol.30, pp. 787-800, 2003.
- [11] J. Bell and P. McMullen, "Ant colony optimization techniques for the vehicle routing problem", *Advanced Engineering Informatics*, vol.18, pp. 41-48, 2004.
- [12] J. Jin, T. G. Crainic and A. Løkketangen, "A parallel multi-neighborhood cooperative tabu search for capacitated vehicle routing problems", *European Journal of Operational Research*, vol.222, pp. 441-451, 2012.
- [13] F. Chu, N. Labadi, and C. Prins, "A scatter search for the periodic capacitated arc routing problem", *European Journal of Operational Research*, vol. 169, no. 2, pp. 586-605, Mar. 2006.
- [14] K. Han and J. Kim, "Quantum-inspired evolutionary algorithm for a class of combinatorial optimization", *IEEE Transactions On Evolutionary Computation*, Vol. 6, no. 6, pp. 580-593, 2002.
- [15] K. Han and J. Kim, "Quantum-inspired evolutionary algorithms with a new termination criterion, H gate, and two-phase scheme", *IEEE Transactions on Evolutionary Computation*, vol.8, no.2 pp. 156-169, 2004.
- [16] L. Wang, H. Wu, and D. Zheng, "Quantum-inspired genetic algorithm for scheduling problems", *Lecture Notes in Computer Science*, vol. 36, n.12, pp.417-423,2005.
- [17] J. Gu, M. Gu, and C. Cao. "A novel competitive co-evolutionary quantum genetic algorithm for stochastic job shop scheduling problem", *Computers & Operations Research*, vol.3, n.5, pp.927-93, 2010.
- [18] Y. Zhao, D. Peng, J. Zhang, and B. Wu, "Quantum evolutionary algorithm for capacitated vehicle routing problem", *Systems Engineering -Theory & Practice*, vol.29, n.2, pp.159-166, 2009.
- [19] E. Ch'avez, N. Mitton, and H. Tejada, "Routing in wireless networks with position trees", in *Proceedings of the 6th international conference on AD-HOC, mobile and wireless networks*, Morelia, Mexico, pp. 32-45, Sept. 2007.
- [20] B. M. Waxman, "Routing of multipoint connections", *IEEE Journal on Selected Areas in Communications*, vol. 6, no. 9, pp. 1617-1622, 1988.