Journal of Applied Research on Industrial Engineering

Vol. 2, No. 1 (2015) 64-76

Journal of
**Applied Research on Industrial Engineering**

# The Periodic Capacitated Arc Routing Problem with Mobile Disposal Sites Specified for Waste Collection

**Payam Khosravi[1], Mehdi Alinaghian[2*], Seyed Mojtaba Sajadi[3], Erfan Babaee[4]**

[1]Department of industrial engineering, Faculty of Engineering, Najafabad Branch, Islamic Azad University, Najafabad, Isfahan, Iran (khosravi.p2011@yahoo.com)

[2]Department of Industrial and Systems Engineering, Isfahan University of Technology, Isfahan, Iran (alinaghian@cc.iut.ac.ir)

[3]Faculty of Entrepreneurship, University of Tehran,1439813141, Tehran, Iran (msajadi@ut.ac.ir)

[4]Department of Industrial and Systems Engineering, Isfahan University of Technology, Isfahan, Iran (e.babaee@in.iut.ac.ir)

A R T I C L E   I N F O

*Article history :*
Received: 15 January 2015
Received in revised format: 12 March 2015
Accepted: 20 March 2015
Available online: 13 June 2015

***Keywords** :*
*Periodic Arc Routing, Mobile Disposal Sites, Waste Collection, Simulated Annealing Algorithm, Required Edges.*

A B S T R A C T

Waste collection is a highly visible municipal service that involves large expenditures and difficult operational problems. In addition, it is expensive to operate in terms of investment costs (i.e. vehicles fleet), operational costs (i.e. fuel and maintenances) so that generating small improvements in this area can lead to huge savings in municipal expenditures. Among the issues raised in the process of decisions making by managers and associated policy makers, one can point to determining the optimal weekly policies of waste collection. In this paper, the periodic capacitated arc routing problem (PCARP)in mobile disposal sites is described and the authors seek to determine the optimal routes of required edges (streets or alleys) per week, number and location of mobile disposal sites, and the number of required vehicles. We present two simulated annealing algorithms, which are different in cooling schedule and number of iterations of each temperature. To evaluate the performance of these algorithms on small-sized problems, the solver “CPLEX"in application “GAMS” is used. The experimental results show that the presented algorithms have appropriate performance and a reasonable time range.

## 1. Introduction

Nowadays, creating different types of solid wastes and manifestation of their associated social, economic and environmental inconsistencies generate numerous complications for urban service management in regard to collection, transportation, processing and disposal of such wastes. Due to the fact that 60 to 80 percent of costs of managing solid wastes is related to collecting and transporting them, the evaluation of underlying collection and transportation system plays significant role in reducing and solving the problems of urban service management. The wastes should be collected, transported and disposed in the least time, through the best method, and directly from the house to disposal site. Based on the above discussions, the significance of an optimal system of waste collection becomes more highlighted. Therefore, selection of optimal policy of waste collection plays significant role in reducing costs. On routing the paths of collecting urban wastes, two categories of problems raise. In the first category, there is a predefined node series and the objective is to find the best tours which passes across all nodes. In the second category, a series of define edge in the grid is demanded and the objective is to find the best tours passing through all demanding edges. The collection of urban wastes is included in the second category. Regarding the problem of collecting domestic wastes, they are along the edges (i.e. demanding streets or alleys). In addition, the capacity of vehicles is limited and when passing from one edge to another, their capacity might decrease.

As to the problem of locating-routing periodical arches with mobile disposal platforms described in the present paper, the days of the week are divided into even and odd days. The objective is to determine the optimal routes of serving the demanding edges based on categorization of days, defining the location and number of mobile disposal platforms, and restarting the serving operation by the vehicles.

The technologies addressed in the present paper are consideration of time limit of using vehicle to determine the number of necessary vehicles, consideration of mobile disposal platform, possible of numerous journeys of a vehicle based on time limits, developing a mathematical model to simultaneously consider the location and period of each problem, developing an innovative method to generate the primary answer and introducing two algorithms of refrigeration simulation.

In the following, section 2 addresses the literature of routing periodical arch and locating-routing arch in regard to waste collection. Section 3 discusses the problem and its mathematical model. Section 4 introduces the suggested methodology and section 5 develops the numerical results of implementing the algorithm. At last, section 6 provides the conclusion and further suggestions.

## 2. Review of Literature

In this section, the associated literature is detailed in short. As to periodical models, the mobile facilities of collecting wastes and innovative methods are discussed.

Fillipi and Del Pia introduced a version of capacitated arch routing for two types of vehicles in which the first type of vehicle could unload at the base while the second type unloads its wastes into the vehicles of the first type (Beltrami and Bodin, 1974). In their developed problem, determination of optimal routes of each vehicle is accompanied by optimal decision-making for two types of vehicles. As a result, their problem is specific to collecting domestic wastes. They solved this problem through variable neighborhood decent algorithm (VND) which was first developed by Hertz and Mitaz (Solomon, 1987).

Chu et.al (2005) introduced a periodic capacitated arc routing problem (PCARP) for programming a weekly horizon. Their problem model was based on integer linear programing and they solved their problem through two innovative methods. The objective of their problem was to assign a set of service days to each edge in a defined network and solving the resulting routing arch for each period to minimize the size of necessary fleet and total costs of journey during the predefined time horizon. This problem has numerous applications for street networks such as collection of wastes and clearing away snow.

Lacomme et.al (2005) developed a periodic capacitated arc routing problem (PCARP) for practical applications such as collecting waste. They describes few models of PCARP with a simple categorization scheme. For instance, demand for each wing might be dependent upon the programming period or the last date of serving. They used an evolution algorithm (EA) based on a complex intersection operator to simultaneous modify and apply operational and tactical decision makings such as service days and daily journeys.

Ogwueleka (2009) suggested an innovative method for solving the problem of collecting the wastes of Onitsha in Nigeria. The resulting of comparison with current situation showed that a vehicle can be successfully excluded from service. In addition, the length of route, collection costs and collection time respectively decrease to 16.31, 25.24 and 23.51 percent.

## 3. Hypotheses and Problem Statement

In the present paper, the problem is determination of optimal number of vehicles and their optimal tours based on minimizing total objective function which includes the cost of using vehicles, cost of passing across network edges and cost of operationalizing mobile platforms to unload the vehicles. In this regard, the vehicles at the base (Node 1) start their travel to serve demanding edges. After finishing their capacity, the vehicles move towards the desired disposal site ($\mathrm{D} = \{\mathrm{n}, \mathrm{n}+1, \dots, \mathrm{n}+\mathrm{d}\}$, D: Set of Potential Nodes) to recover their initial capacity, restart their journey from disposal platform in the case of sufficient time, and return to operational location. In addition to considering limitation of capacity, time bounds of each vehicle is similarly significant. When the remaining time for a vehicle tends towards zero, it has to return to disposal platform and after recovering initial loading capacity (i.e. disposal), they go back to their base.

- The objective function of developed model should include minimization of costs of passing across the edges, minimization of fleet size and number of necessary vehicles to satisfy the total demand as well as costing of using the mobile platform.
- Each waste-containing edge is served only by one vehicle
- One base and a few mobile disposal platforms exist. One of the objectives of problem in the present study is to determine their location.
- Vehicles start their trip from the base and when their capacity is full, they return to disposal platform and initiate their journey in the case of sufficient remaining time.
- The vehicles are heterogonous and graph grid is asymmetrical.

- There is no failure of collection. This means that each edge should be served once and by one vehicle.
- After ending the journey, the vehicles return to the base.
- Each vehicle has maximum duration of service.
- The time and costs of passing through an identical route by different vehicles are similar.
- The days of week are divided into odd and even ones. Number "1" represents even days and number "2" refers to odd days (t= {1, 2}).

In this section sets, indexes, parameters, decision variables and mathematical model are described:

Sets:

| | |
|---|---|
| $V$ | Set of All Nodes |
| $S$ | Set of Mobile Site Nodes |
| $E$ | Set of All Defined Edges |
| $E_R$ | Set of All Demanding Edges |
| $E_A$ | Set of Demanding Edges that must supply daily |

Indexes:

| | |
|---|---|
| $i, j$ | Nodes in $V$ set |
| $s$ | Nodes in S set |
| $k$ | Vehicle |
| $t$ | period |

Parameters:

| | |
|---|---|
| $K$ | Maximum number of Vehicles |
| $T$ | Total number of period |
| $P_k$ | P-th Tour of k-th Vehicle |
| $tt_{ij}$ | Time of Passing the edge (i, j) |
| $d_{ij}$ | Demand of Edge (i, j) ($(i, j) \in E_R$) |
| $cv_k$ | Cost of Using k-th Vehicle |
| $T_{max}$ | Maximum Available Time of Each Vehicle |
| $W_k$ | Capacity of of k-th Vehicle |
| $M$ | Large Number |

decision variables:

| | |
|---|---|
| $x^t{}_{ij\,p_k}$ | if edge (i,j) is travelled n times by k-th vehicle during p-th tour in period t variable is n, otherwise is 0 |
| $y^t{}_{j\,i\,p_k}$ | if edge (i,j) is supplied by k-th vehicle during p-th tour in period t variable is 1,otherwise is 0 |
| $YY_{st}$ | If s-th Mobile Site is used in period t is 1,otherwise is 0 |
| $u_k$ | if k-th vehicle is used is 1, otherwise is 0 |

Mathematical model:

$$Minimize\ Z_{total} = \sum_{(i,j)\in E} \sum_{k=1}^{K} c_{ij}\, {x^t}_{ij\,p_k} + \sum_{k=1}^{K} cv_k\, u_k + \sum_{d=1}^{D} \sum_{t=1}^{2} FC_d\, YY_{dt} \qquad (1)$$

*Subject to:*

$$\sum_{j=1}^{n} {x^t}_{ij\,p_k} = \sum_{j=1}^{n} {x^t}_{j\,i\,p_k} \quad ,\forall i \in V\backslash\{1,S\},\quad \forall k \in K\ ,\ \forall p_k = 1,\dots,P_K\ ,\quad \forall t \in \{1,2\} \qquad (2)$$

$$\sum_{p_k=1}^{P_K} \sum_{t=1}^{2} ({y^t}_{ij\,p_k} + {y^t}_{ji\,p_k}) = 1\ ,\quad \forall (i,j)\ or\ (j,i) \in E_R \backslash E_E \qquad (3)$$

$$\sum_{p_k=1}^{P_K} ({y^t}_{ij\,p_k} + {y^t}_{ji\,p_k}) = 1\ ,\quad \forall (i,j)\ or\ (j,i) \in E_A \quad ,\forall t \in \{1,2\} \qquad (4)$$

$$\sum_{(i,j)\in E_R} d_{ij}\, {y^t}_{ij\,p_k} \le W_k \quad ,\forall k \in K, \forall p_k = 1,\dots,P_K, \forall t \in \{1,2\} \qquad (5)$$

$${y^t}_{ij\,p_k} \le {x^t}_{ij\,p_k}\ ,\quad \forall (i,j) \in E\ , \forall k \in K,\ \forall p_k = 1,\dots,P_K\ ,\quad \forall t \in \{1,2\} \qquad (6)$$

$$\sum_{p_k=1}^{P_k} \sum_{t=1}^{2} \sum_{(i,j)\in E} {x^t}_{ij\,p_k} \le M u_k \quad ,\forall k \in K \qquad (7)$$

$$\sum_{p_k=1}^{P_k} \sum_{(i,j)\in E} tt_{ij} {x^t}_{ij\,p_k} \le T_{max} \quad ,\quad \forall k \in K\ , \forall t \in \{1,2\} \qquad (8)$$

$$\sum_{i=2}^{V-S} \sum_{p_k=1}^{P_k} {x^t}_{i\,s\,p_k} \le M\, YY_{st} \quad ,\forall k \in K, \forall s \in \{n, n+1,\dots,n+S\} \qquad (9)$$

$$\sum_{s=n}^{n+S} YY_{st} = 1 \quad ,\forall t \in \{1,2\} \qquad (10)$$

$$\sum_{j=2}^{V-S} {x^t}_{1\,j\,p_k} = u_k \quad ,\forall k \in K,\ \forall p_k = 1\ , \forall t \in \{1,2\}, \forall s \in \{n, n+1,\dots,n+S\} \qquad (11)$$

$$\sum_{j=2}^{V-S} {x^t}_{s\,j\,p_k} = u_k \quad ,\forall k \in K,\ \forall p_k = 2,\dots,P_K\ \ \forall t \in \{1,2\}, \forall s \in \{n, n+1,\dots,n+S\} \qquad (12)$$

$$\sum_{j=2}^{V-S} {x^t}_{j\,s\,p_k} = u_k \quad ,\forall k \in K,\ \forall p_k = 1,\dots,P_K \quad ,\forall t \in \{1,2\}, \forall s \in \{n, n+1,\dots,n+S\} \qquad (13)$$

$$\sum_{i,j\in R} {x^t}_{ij\,p_k} \le 1 + n\, h_{p_k}^{R}\ , \forall R \subseteq V \setminus \{1\};\ R \neq \emptyset; \forall k \in K,\ \forall p_k = 1,\dots,P_K, \forall t \in \{1,2\} \qquad (14)$$

$$\sum_{i \in R} \sum_{j \neq R} x^t{}_{ij\,p_k} \geq 1 - f^R_{p_k} \quad \forall R \subseteq V \setminus \{1\};\ R \neq \emptyset; \forall k \in K,\ \forall p_k = 1, \dots, P_K, \forall t \in \{1,2\} \tag{15}$$

$$h^R_{p_k} + f^R_{p_k} \leq 1 \ , \qquad \forall R \subseteq V \setminus \{1\};\ R \neq \emptyset; \forall k \in K,\ \forall p_k = 1, \dots, P_K \tag{16}$$

$$h^R_{p_k} \in \{0,1\}, \quad f^R_{p_k} \in \{0,1\} \quad , \qquad \forall R \subseteq V \setminus \{v_1\};\ R \neq \emptyset; \forall k \in K \tag{17}$$

$$x^t{}_{ij\,p_k} \in Z^+, y^t{}_{i\,j\,p_k} \in \{0,1\}\ , u_k \in \{0,1\} \qquad \forall (i,j) \in E\ , \forall k \in K\ , \forall t \in \{1,2\} \tag{18}$$

The objective function (1) has three parts. The first part includes minimization the costs of pasting from (i, j) edge by k-th vehicle, the second part consists of minimizing the cost of buying (hiring) k-th vehicle and the third part includes the costs of establishing and operating the s-th mobile platform in period “t”. As shown in limitations (expression 2), the flow equilibrium relations for each vehicle is developed. The limitations in expression (5) represents the limitation of capacity of k-th edge. As shown in expression (6), the limitations show that the demanding edge is served by passing vehicle (i.e. a vehicle might pass across an edge without serving it). The denoted limitations in expression (7) imply that the k-th vehicle is used during period “t” and its costs are paid. The denoted limitations in expression (8) show the time limit of each vehicle. The limitations in expression (9) denote that the s-th mobile platform is used in period “t” the cost of which is paid out. The limitations in expression (10) represent the capacity limit of s-th mobile platform in period “t”. The limits in expression (11) and (12) guarantee that the first journey of the vehicle starts from base and the rest of journeys initiate from disposal site. The limitations in expression 13) guarantee that all vehicle journeys end in disposal platform. The denoted limitations in expression (14-17) ascertain that there is no non-authorized tour. As to limitations denoted in (18), the type of variables are defined.

**Considering Multiple Journeys for Each Tour**

To consider the possibility of difference of base from disposal site as well as numerous journey in each tour, a series of journeys with index “Pk” is considered. The first trip of each vehicle starts from the base (limitation.130 and after travelling across some edges, it returns to disposal site (limitation.15). For the next travels, the vehicle starts its travel from disposal site (limitation.14) and after going across some edges, it returns to disposal location.

## 4. Suggested Method of Problem Solving

Due to high complexity of the problem, solving the model is inefficient through precise methods. Therefore, an innovative algorithm is suggested for developing initial answer and two genetic algorithm of refrigeration simulation are developed. In regard to the latter, the algorithms are different in terms of refrigeration plan and number of iterations.

In the next sections, the mechanism of the innovative algorithm to provide initial answers and develop SA algorithm is detailed.

### 4.1. Innovative Algorithm to Develop Initial Answer

To develop the initial answer, an innovative random algorithm is used the execution steps of which are detailed in the following:

1- Randomly chose one period among the existing periods and go to step (2).
2- Randomly chose one vehicle among the existing vehicles and go to step (3).
3- Randomly chose one disposal platform among the existing disposal platform and go to step (3).
4- Start journey from base and go to step (5).
5- Among the edges the starting point of which is from base, randomly select one edge among k-edges with the least durance from the base and go to step (6).
6- If there is an edge attached to current node (node at the end of current edge), go to step (6). Otherwise, use the solution of shortest path problem recursively and chose the shortest middle edge(s). Then, go to step (7).
7- In the case of attachment of edges to current node, consider k edges of highest level of demand for which the capacity and time limits of the vehicle enables one to select them. Randomly select one of the vehicles and go to step (8). The edge should cover the time limit which enables one to pass from it and go to the disposal location in a definite period of time. Otherwise, check the following two conditions:

A:If the remaining time does not allow pass for a vehicle and there is still some time, refer to the predefined disposal location and go to step (1). If there is no period left, select the period with the east number of vehicles (In identical conditions, randomly select one) and go to step (2).

B: If the capacity limit is not considered, go to the define platform, zero the capacity and go to step (7).

8- Add the resulting demand of waste collection in the selected edge to the vehicle and deduct the demand of the edge from the list of demands. Check the following condition. If all demanding edge are crossed, end the algorithm. Otherwise, go to step (7).

The number of developed answers is intended to be 200 ones. When the algorithm ends, the best answer is used for simulation of refrigeration.

### 4.2. Representation of Answer

To represent the answer, a string of variable length is used in which each tour of vehicle in a period of time is regarded to be a vector. In fact, the sting only covers justifiable tours which include all necessary edges. To better understand the defined string, figure (1) shows an instance which includes 6 demanding edges and two vehicles in two periods of odd and even days. The strings represented in table (1) include the answers with three vectors. To interpret the answer, the first vector is assigned based on time limitation of the first period, the second vector is assigned due to time bounds of the first vehicle and the second vehicle is assigned to the first period. The third vector represents the assignment of the second vehicle to the first period.

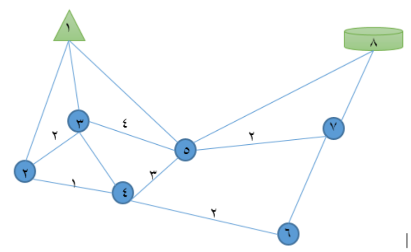

**Figure 1.** An Instance of Developed String

**Table 1**. Representing Answer

| | |
|---|---|
| First Period of First Vehicle | 1 2 3 4 5 8 5 7 8 |
| First Period of Second Vehicle | 1 2 4 6 7 8 |
| Second Period of First Vehicle | 1 3 4 5 8 |

### 4.3. Improving Answer through Algorithm of Refrigeration Simulation

To improve the answers, two SA algorithms are used and all initial answers are distinctively improved by the algorithm. The refrigeration simulation algorithm is a meta-heuristic algorithm of local search which can refrain from local optimization. It is a very efficient algorithm for solving problems with non-convex or discrete solution space. As a result, SA is used to solve integer programming problem (Glover and Kochenberger, 2005). In addition, ease of implementation, homogeneity and hill climbing to refrain from local optimization make SA a proper choice for improving the generated initial answers after each iteration. The basis of this algorithm starts with an initial algorithm answer followed by consideration of a neighborhood it. If the value of objective function of the neighbor is better than the objective function of the answer, the answer is substituted by its neighbor. Otherwise, a number is randomly made within a range of zero and one and it is compared with the value defined by the algorithm. If the random number is less than that of algorithm, the worse answer is accepted. The condition for ending the algorithm is to attain the final temperature. Before starting the algorithm, the following items should be defined.

1- Refrigeration program (i.e. number of algorithm iterations in each temperature (M), number of changes in temperature , mechanism/ relation of reducing temperature)
2- Initial temperature
3- Final Temperature

### 4.4. First Refrigeration Simulation Algorithm (SA1)

In this algorithm, the following equation is used to reduce temperature.

$$t_{k+1} = \alpha t_k \qquad ; 0 < \alpha < 1 \qquad (19)$$

In the above equation, tk represents the value of temperature in k-th iteration. Of course, in the associated literature, the range of $0.8 < \alpha < 0.99$ is recognized for assuring a relatively slow and efficient scheduling. It is evident that when x is higher, the rate of reduction of temperature gets less and it will be possible to search the problem space more.

#### 4.4.1. Number of SA1 Iterations in Each Temperature

In this algorithm, the counter “m” is used to count the accepted answer for each iteration. This counter should attain the extent of parameter “M” in each iteration.

### 4.5. Second Refrigeration Simulation Algorithm

In this algorithm, a slower test is done through the following refrigeration program to reduce energy.

$$t_{k+1} = \lim_{\beta \to 0} \frac{t_k}{1 + \beta t_k} \quad (20)$$

In the above equation, $\beta$is a small optional value.

#### 4.5.1. Number of SA2 Iterations in Each Temperature

In SA2, the number of iterations for each temperature is obtained from the following equation.

$$M(t_k) = \frac{t_k}{1 + \eta\, t_k} \quad (21)$$

In the present paper, due to randomized selection of three problems as instances, tried-and-error method is used to define the values of algorithm parameters as shown in the following table.

**Table 2.** Values of Algorithm Parameters

| Parameters | Values |
|---|---|
| $\boldsymbol{M}$ | 5 |
| $\boldsymbol{\alpha}$ | 0.98 |
| $\boldsymbol{\beta}$ | 0.0001 |
| $\boldsymbol{t_0}$ | 200 |
| $\boldsymbol{t_{end}}$ | 1 |
| $\boldsymbol{\eta}$ | 0.1 |

### 4.6. Local Search

To develop a completely random answer with the adjacency of the present answer, the following algorithm is used.

1- Randomly chose a row of current answer and call it “s”.
2- Randomly chose a node from the first row and call it “R”.
3- Randomly chose a row as the second row and call it “*u*”. If all rows have been tested before, go to step (2).
4- Look for node “R” in row “*u”*. If you did not find it, go to step (3).
5- From the start of the path to R in row “s” and from R to the end of the path in row “*u”* of the current answer should be placed in row “s”.
6- From the start of the path to R in row “*u*” and from R to the end of the path in row “*s”* of the current answer should be placed in row “u”.
7- Add the utilized platform in row “s” from the current answer to row “u” of the new answer.
8- Add the utilized platform in row “u” from the current answer to row “s” of the new answer (Due to intersection of these two rows, the violated limitation of using one platform for each row can be satisfied through step (7-8).

9- Transfer the remaining rows from the current answer to the new one.

In this method, all limitations of plausibility of the new answer have been satisfied with the exception of time bounds of the tours and limitation of loading capacity of journeys. The limitations of capacity were satisfied through considering fine in the intended objective function. This leads to diversity of answers to the problem and increase of probability to attain the proper answer.

To depict this mechanism, see figure (2). The third and fourth rows are selected for developing neighborhood and the intended node is node (3). An answer at the neighborhood of current answer is developed in the following manner.

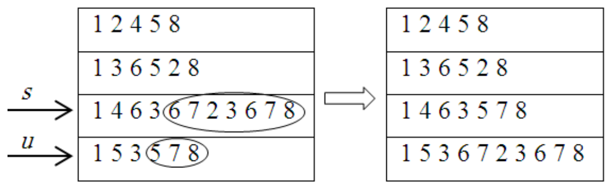


**Figure 2.** Developing an Answer in Neighborhood

## 5. Computational Results

To examine the efficiency of suggested methods, ten problems were defined and the quality of resulting answers was verified. The information of these problems is shown in table (3). It is noteworthy that the problems were examined in two periods.

**Table 3.** Developed Random Samples

| **Problem** | **TN** | **TE** | **RE** | **TDS** | **AV** |
|---|---|---|---|---|---|
| **P1** | 7 | 8 | 6 | 2 | 2 |
| **P2** | 10 | 20 | 16 | 2 | 2 |
| **P3** | 12 | 35 | 28 | 3 | 2 |
| **P4** | 14 | 50 | 33 | 3 | 2 |
| **P5** | 15 | 70 | 49 | 3 | 2 |
| **P6** | 18 | 90 | 52 | 4 | 3 |
| **P7** | 20 | 100 | 62 | 4 | 3 |
| **P8** | 22 | 120 | 78 | 4 | 3 |
| **P9** | 25 | 140 | 85 | 4 | 3 |
| **P10** | 30 | 150 | 96 | 5 | 3 |

In the above table, the first row represents the number of problem, the second row refers to total number of existing grid nodes, the third row denotes total number of defined grid edges, the fourth row represents total number of demanding edges, the fifth row refers to the number of potential mobile platforms, and the last row denotes the number of available vehicles for each problem.

To evaluate the efficiency of refrigeration simulation algorithm for desired problems, the results of algorithm were compared with those of solver "CPLEX". The SA1 and SA2 algorithms were codified through programming language "C#". To execute the application, a 2.5 GHz CPU and 4GB RAM was used. Each problem was solved through meta-heuristic algorithms and its best value was regarded as proper. A summary of comparative results is shown in table (4).

**Table 4.** Computational Results of Solving Randomized Samples

| Problem | CPLEX | | SA1 | | | SA2 | | |
|---|---|---|---|---|---|---|---|---|
| | Proper Value ($Z*$) | Solving Time (Sec) | Best Value ($Z_1$) | Solving Time (Sec) | Deviation Percentage ($Z*, Z_1$) | Best Value ($Z_2$) | Solving Time (Sec) | Deviation Percentage ($Z*, Z_2$) |
| **P1** | 458 | 15.52 | 473 | 17.3 | 3.17 | 461 | 22.3 | 0.65 |
| **P2** | 662 | 30.54 | 695 | 20.1 | 4.75 | 683 | 27.02 | 3.07 |
| **P3** | 871 | 53.72 | 907 | 24.09 | 3.97 | 892 | 32.2 | 2.35 |
| **P4** | 980 | 145.33 | 1004 | 30.3 | 2.39 | 995 | 35.1 | 1.51 |
| **P5** | 1493 | 333.68 | 1545 | 35.17 | 3.37 | 1522 | 41.38 | 1.91 |
| **P6** | 1526 | 808.43 | 1588 | 47.88 | 3.90 | 1593 | 56.25 | 4.21 |
| **P7** | 1941 | 1174.6 | 2023 | 53.41 | 4.05 | 1986 | 57.86 | 2.27 |
| **P8** | 2218 | 1645.18 | 2268 | 61.24 | 2.20 | 2243 | 69.28 | 1.11 |
| **P9** | 2541 | 2010.82 | 2693 | 70.4 | 5.64 | 2610 | 81.5 | 2.64 |
| **P10** | 3031 | 2835.85 | 3170 | 83.64 | 4.38 | 3125 | 90.87 | 3.01 |
| **Mean** | 1572.1 | 905.36 | 1636.6 | 44.35 | 3.78 | 1611 | 51.37 | 2.27 |

As shown in table (4), the mean error values for SA1 and SA2 algorithms compared with CPLEX are respectively 3.78 and 2.27 percent which denoted the higher efficiency of SA2in regard to finding proper answers. To exemplify this issue more clearly, see figure (1).

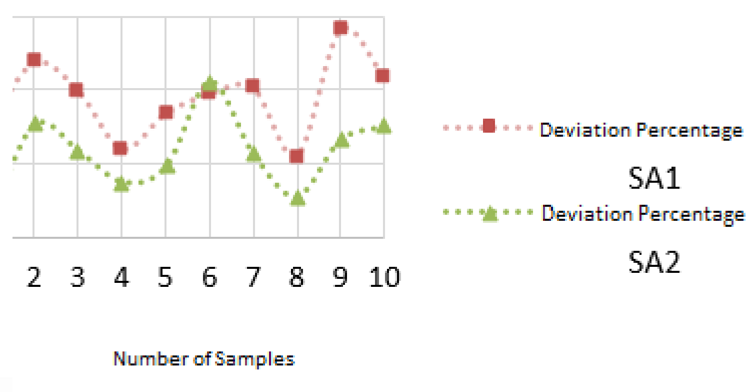


**Figure 1.** Comparison of Performance of SA1 and SA2

In regard to time of solving problems, as shown in figure (2), the mean time of solving random samples in the precise method is almost 905. 36 second while for SA1 and SA2 algorithms, the necessary durations for solving the developed problems are respectively 44.35 and 51.37 seconds which are almost identical. The obtained information represents proper speed of suggested algorithms.

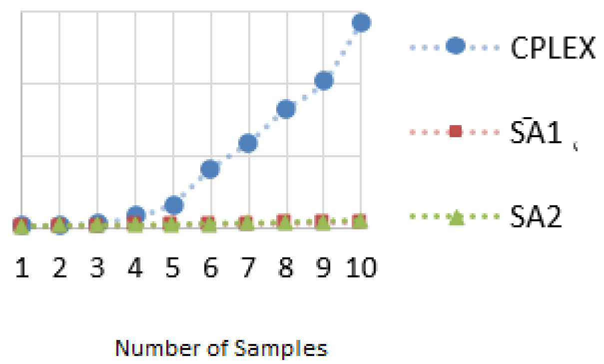


**Figure 2.** Comparion of Solving Durations of CPLEX and SA Algorithm

## 6. Conclusion and Further Suggestions

The routing and optimal assignment of vehicles for problems of routing vehicles is one of the significant decisions of organizations such as provincialities in regard to collecting urban wastes because proper assignment of vehicles and optimal routing can reduce a large portion of associated costs.

In the present problem, an integer linear programming is used for modeling the locating-arc routing problem with mobile disposal sites specified for collection of urban wastes. The solution defines the following items:

1- The vehicle that can be used.
2- The day in which edges are served.
3- The sites or mobile sites used in odd and even days.
4- The optimal routes passed during days of the week.

To solve the problem in small-scale, CPLEX is used and for large scale problem solving, refrigeration simulation algorithm is used. The results obtained in small-scale problem solving showed that these algorithms generate semi-optimal answers. At last, SA2 algorithm has the best answer based on its difference in refrigeration program and number of iterations in each temperature compared with SA1.

Of suggestions on getting the model close to real-world ones, one could consider the demand of edges as relative so as to deal with literature policies to resolve lack of absoluteness in solving problems. In this regard, one can consider the problem as a case study.

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