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17 Goal programming on optimal pairings selection from flight schedule using Bat Algorithm

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Abstract. Nowadays, the demands of flight service are very high so that flight industry should minimize operational cost such as crew cost. Crew cost depends on pairings from flight schedule. Optimization model of this problem is selecting optimal pairings covering all flight numbers in the goal programming model as multiobjective programming. In this research, goal programming on optimal pairings selection will be applied by heuristic method like Bat Algorithm (BA). BA is optimization method inspired from behavior of bats like they use sonar called echolocation to detect prey, avoid obstacles, and locate their roosting crevices in the dark. BA can be applied on constrained optimization. Simulations are applied by generating the set of pairings and selection using BA. The advantages of BA are there are a local solution around the selected best solution based on pulse rates and loudness. In the optimal pairings selection model, there are three objectives which will be minimized based on order of importance. The simulation results show that Bat Algorithm can be used in goal programming model and it can select optimal pairings in approaching with the number of pairing consisting of two flight numbers is 4 pairings, the number of pairing consisting of three flight numbers is 0 pairing, the number of pairing consisting of four flight numbers is 49 pairings, the number of pairing consisting of five flight numbers is 7 pairings and the number of pairing consisting of six flight numbers is 8 pairings.

1. Introduction

Large country with large population makes the demands of flight service in Indonesia are very high so that flight company should minimize operational cost. There are two highest costs spent in flight company. The highest cost is fuel cost and the second is crew cost [9]. Crew cost is affected by pairings selected from flight schedule. Pairing is the sequence of flights driven by a set of crews started from the airport in first flight until to the same airport in last flight. Each pairing is driven by a set of crews so that the crews depart and arrive in the same airport (homebase) in their duty. Optimization model of this problem is selecting optimal pairings covering all flight numbers.

Optimal pairings selection is one of linear integer programming with constraints. The constraints used are all flight numbers are covered at least one pairing. Because the decision variable is binary such as pairing is selected or not selected, then it's called binary programming. Linear integer programming can be solved by exact method like simplex method, branch and bound method, and cutting plane method [3], [11]. Other method used in optimal pairings selection is greedy algorithm [9].



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Many linear programming problems can be solved by heuristic method like Genetic Algorithm [5], Particle Swarm Optimization [4], Ant Colony Optimization [6], Artificial Bee Colony [8], Firefly Algorithm [7] and so on. In this research, optimal pairings selection will be applied by heuristic method like Bat Algorithm. Optimization model used in this research is using goal programming as multiobjective programming, where in goal programming there are multiobjectives, real constraints, goal constraints, decision variables and deviation variable. The objective function of goal programming is using deviation variables and it is ranked in order of importance. The optimal solution is determined by minimizing the objective functions starting with the most important and proceeding according to the order of importance of the objectives [10].

Bat Algorithm (BA) was introduced by Xin-She Yang in 2010. It is inspired from behavior of bats like they use sonar called echolocation to detect prey, avoid obstacles, and locate their roosting crevices in the dark. The bats fly randomly with a fixed frequency, varying wavelength, and loudness to search prey. At the optimization process, the rate of pulse increases and the loudness decreases so that bat can find object with minimum fitness function [12],[13].

Simulations are applied by generating the set of possible pairings. After the set of possible pairings are generated, then we select the set of selected pairings using Bat Algorithm. The advantages of Bat Algorithm are there are a local solution around the selected best solution based on pulse rates and loudness. In the Bat Algorithm, the initialization step is applied by greedy algorithm. Greedy algorithm is applied because it can result binary solutions and it can cover all flight numbers at least one pairing. In updating process, there are modifications for satisfying the constraints. In the optimal pairings selection model, there are three objectives which will be minimized based on order of importance. The simulation results show that Bat Algorithm can be used in goal programming model and it can select optimal pairings in approaching.

2. Literature Review

Pairing is the sequence of flights driven by a set of crews started from the airport in first flight until to the same airport in last flight. Each pairing is driven by a set of crews. Therefore the crews depart and arrive in the same airport (homebase) in their duty.

The method for constructing pairing is using possibility matrix $A^n, n = 2,3,4,5,6$. Possibility matrix A^n keeps pairing consisting of n flight numbers so that each column of possibility matrix A^n has n elements with score equals 1. Pairing illustrations can be seen on figure 1. Pairing A^n consists of n flight numbers [9].

| | | | | | | | | |
|----------------------------|---------------------|-------------------------|---------------------|-------------------------|---------------------|-------------------------|---------------------|-----------------------------|
| Pre Journey (90 mnt) | Flight 1 (A → B) | Transit Time (TT) | Flight 2 (B → C) | Transit Time (TT) | Flight 3 (C → D) | Transit Time (TT) | Flight 4 (D → A) | Post Journey (90 mnt) |
|----------------------------|---------------------|-------------------------|---------------------|-------------------------|---------------------|-------------------------|---------------------|-----------------------------|

Figure 1. Example of pairing A^4 consisting of 4 flight numbers

In the optimal pairing selection, there are some cases the flight numbers are deadhead. Deadhead is the case in which there are same flight numbers in the different pairing so that flight number is covered more than one pairing. This problem causes a set of crews is transferred to destination airport with other flight in different pairing. Deadhead illustrations can be seen on figure 2.

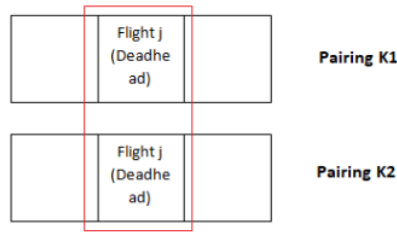


Figure 2. Deadhead Situation

6 Formulation of Goal Programming

Goal programming is the mathematical programming techniques to solve the objectives subject to some constraints where there are levels or targets of achievement for each objective and prioritizing the order in which the goals have to be achieved.

The generalized model of goal programming is given as follows [2] :

$$\text{lexmin} \left\{ z_1 = \sum_{i=1}^{m_1} w_i^+ d_i^+ + w_i^- d_i^-, \dots, z_q = \sum_{i=1}^{m_q} (w_{q_i}^+ d_i^+ + w_{q_i}^- d_i^-) \right\} \quad (1)$$

Subject to :

$$f_i(x) + d_i^- - d_i^+ = b_i, \quad i = 1, 2, \dots, m_0 \quad (2)$$

$$g_i(x) \leq 0, \quad i = m_0 + 1, \dots, m_1 \quad (3)$$

$$h_i(x) = 0, \quad i = m_1 + 1, \dots, m_2 \quad (4)$$

$$d_i^-, d_i^+ \geq 0, \quad (5)$$

Where lexmin means lexicographically minimizing the objective. In the lexicographic method, the objectives are ranked in order of importance. The optimal solution is determined by minimizing the objective functions starting with the most important and proceeding according to the order of importance of the objectives [10].

If the original i-th inequality is of the type \leq and its $d_i^- > 0$, then the i-th goal is satisfied. Otherwise, if $d_i^+ > 0$ the goal i is not satisfied.

If the original i-th inequality is of the type \geq and its $d_i^+ > 0$, then the i-th goal is satisfied. Otherwise, if $d_i^- > 0$ the goal i is not satisfied.

The parameters of model can be explained as follows :

- d_i^+ is the positive deviation variable representing the overachievements of goal i
- d_i^- is the negative deviation variable representing the underachievements of goal i
- w_{ki}^+ is the positive weight assigned to d_i^+
- w_{ki}^- is the negative weight assigned to d_i^-
- x is n-dimensional decision variable
- f_i is a function : $R^n \rightarrow R$ in goal constraints
- g_i is a function : $R^n \rightarrow R$ in real inequality constraints

⁵ h_i is a function : $R^n \rightarrow R$ in real equality constraints

b_i is the target value of of goal i

q is the number of priorities

m_0 is the number of goal constraints

m_1 is the number of inequality constraints

m_2 is the number of equality constraints

⁸ The method for solving goal programming as multiobjective programming is preemptive method. In the preemptive method, the decision must rank the goals of the problem in order of importance. Given q -goals, the objectives are arranged as follows [11] :

$$\begin{aligned} \min G_1 &= \rho_1 \\ &\vdots \\ \min G_q &= \rho_q \end{aligned} \tag{6}$$

⁸ Variable ρ_i is the component of the deviation variable, d_i^+ or d_i^- that represents goal i . ρ_1 is the highest priority and then it is followed by $\rho_i, i = 2, 3, \dots, q$ respectively.

4. Goal Programming Model of Optimal Pairings Selection

Optimal pairings selection can be done by generating the set of possible pairings of each flight number. After the set of possible pairings are generated, they will be selected the set of selected pairings subject to all flight numbers are covered at least one pairing based on equation (11) and the pairings selected or not are stated by binary, 0 if pairing is not selected and 1 if pairing is selected as in equation (12). The model is called set covering problem. Because the solutions of this problem are binary then the mathematical model is binary programming.

Mathematical model of goal programming on optimal pairings selection is as follows :

$$\text{lexmin} (d_1^+, d_2^+, d_3^+) \tag{7}$$

Subject to :

$$\sum_{i=1}^{N_F} h_i \left(\sum_{k=1}^{N_p} a_{ik} x_k - 1 \right) - d_1^+ + d_1^- = M_1 \tag{8}$$

$$\sum_{k \in N_{p2}} c_k x_k + \sum_{k \in N_{p3}} c_k x_k - d_2^+ + d_2^- = M_2 \tag{9}$$

$$\sum_{k \in N_{p4}} c_k x_k + \sum_{k \in N_{p5}} c_k x_k + \sum_{k \in N_{p6}} c_k x_k - d_3^+ + d_3^- = M_3 \tag{10}$$

$$\sum_{k=1}^{N_p} a_{ik} x_k \geq 1, \quad i = 1, 2, \dots, N_F \tag{11}$$

$$x_k \in \{0, 1\}, \quad k = 1, 2, \dots, N_p \tag{12}$$

$$d_1^+, d_1^-, d_2^+, d_2^-, d_3^+, d_3^- \geq 0 \tag{13}$$

In equation (7), There are three objective functions. The first is deviation variable of the cost of deadhead. The second is deviation variable of the cost of pairing A^2 and pairing A^3 . The third is deviation variable of the cost of pairing A^4 , pairing A^5 , and pairing A^6 .

Minimization cost of deadhead is the most important because deadhead is the case in which there are same flight numbers in the different pairing so that flight number is covered more than one pairing. This problem causes a set of crews is transferred to destination airport with other flight in different pairing. Minimization cost of pairing A^2 and pairing A^3 is more important than minimization cost of pairing A^4 , pairing A^5 , and pairing A^6 because pairing with lower n flight numbers can cover all flight number by more total pairings so that the number of crew employed is larger.

From the model, variables used are :

N_p : The number of possible pairings, with $N_p = N_{p_2} + N_{p_3} + N_{p_4} + N_{p_5} + N_{p_6}$ In particular, N_{p_2} is the number of possible pairing A^2 , N_{p_3} is the number of possible pairing A^3 , N_{p_4} is the number of possible pairing A^4 , N_{p_5} is the number of possible pairing A^5 , N_{p_6} is the number of possible pairing A^6

N_F : Total flight numbers

c_k : Cost of pairing k

h_i : Cost of deadhead with flight number i

$$a_{ik} = \begin{cases} 1, & \text{if flight number } i \text{ is covered in pairing } k \\ 0, & \text{otherwise} \end{cases}$$

with decision variables are :

$$x_k = \begin{cases} 1, & \text{if pairing } k \text{ is selected} \\ 0, & \text{otherwise} \end{cases} \quad (14)$$

Maximum values of goal constraints in equation (8), equation (9), and equation (10) respectively are :

M_1 : Maximum cost of deadhead

M_2 : Maximum cost of pairings A^2 and pairings A^3

M_3 : Maximum cost of pairings A^4 , pairings A^5 and pairings A^6

9 Bat Algorithm

7 Bat Algorithm (BA) was introduced by Xin-She Yang in 2010. It is inspired from behavior of bats like they use sonar called echolocation to detect prey, avoid obstacles, and locate their roosting crevices in the dark. 11 The echolocation characteristics of micro bats can be explained as follows [12],[13]:

1. All bats use echolocation to sense the distances, food, prey, and barriers.
2. Bats randomly fly with velocity v_i at position x_i with a fixed frequency f_{min} , varying wavelength, and loudness A^0 to search prey. They can adjust the rate of pulse emission $r \in [0,1]$ depending on the proximity of their target.
3. Although the loudness can vary in many ways, it is assumed that the loudness varies from a large positive A^0 to a minimum A_{min}

5.1. Standard Bat Algorithm

Based on behavior of bats, the BA can be constructed as follows :

1. Initialize the population of bat position $x_i, i = 1, 2, \dots, maxpop$, velocity $v_i, i = 1, 2, \dots, maxpop$, and pulse frequency $f_i, i = 1, 2, \dots, maxpop$
2. Initialize pulse rates r_i and loudness A_i
3. Do iterations as follows :
for $t = 1 : max$

for $i = 1, 2, \dots, \text{maxpop}$

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta, \quad \beta \sim U(0,1) \quad (15)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x^*)f_i \quad (16)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (17)$$

end

if ($\text{rand} > r_t$)

- Determine a solution among the best solution
- Generate a local solution around the selected best solution by a local random walk

$$x_{\text{new}} = x_{\text{old}} + \epsilon A^t, \quad \text{with } \epsilon \sim U(-1,1) \quad (18)$$

if ($\text{rand} > A_i$ & $f(x_i) < f(x^*)$)

- Accept new solution x_i
- Increase r_t and reduce A_i so that $A_i \rightarrow 0, r_t \rightarrow r_t^0$

$$r_t^{t+1} = r_t^0(1 - \exp(-\gamma t)), \quad \text{with } \gamma > 0 \quad (19)$$

$$A_i^{t+1} = \alpha A_i^t, \quad \text{with } 0 < \alpha < 1 \quad (20)$$

end

Rank the bats and find current best x^*

end

5.2. Initialization of Bat Population

Optimal pairings selection is applied by Bat Algorithm (BA). In the BA, we need to initialize population of the sets of selected pairings in equation (14) as bat position by greedy algorithm. Greedy algorithm is applied because it can result binary solutions based on equation (12) and it can cover all flight numbers at least one pairing based on equation (11). The pairings selected or not are stated by binary, 0 if pairing is not selected and 1 if pairing is selected. The algorithm to initialize population of the sets of selected pairings as decision variables is as follows :

For $j = 1 : \text{maxpop}$

1. Suppose U is the set of uncovered flight number, S_i , $i = 1, 2, \dots, N_F$ is the pairing covering flight number c , w_i , $i = 1, 2, \dots, N_F$ is the number of pairing covering flight number i , and $x_k = 0$, $k = 1, 2, \dots, N_p$ is the decision variable solution i.e. selected pairings.
2. Set $U = F, S_i = \{\}, w_i = 0$ for every $i = 1, 2, \dots, N_F$, $x_k = 0$ for every $k = 1, 2, \dots, N_p$

For $i = 1 : N_F$

If ($w_i = 0$)

- a. Determine P_i : the set of pairings covering flight number i

- b. Choose pairing $q \in P_i$ randomly
- c. Determine F_q : the set of flight numbers covered by pairing $q \in P_i$
- d. Update $S_i \leftarrow S_i \cup q, w_i \leftarrow w_i + 1$ for $i \in F_q$
- e. Update $U \leftarrow U - F_q, x_q = 1$

End

End

End

5.3. Evaluate the Fitness

Evaluation process is determining the objective function. In the goal programming, there are several objectives. Evaluation process of goal programming using Bat Algorithm is as follows [2]:

$eval(X)$

1. Evaluate bat position (14) in constraints equation then determine $d_1^+, d_1^-, d_2^+, d_2^-, \dots, d_{m_0}^+, d_{m_0}^-$ from each constraint.
2. Calculate the objective values according to objective (7). There are q objective values related with each fitness.

$$\left\{ \sum_{i=1}^{m_0} (w_{1i}^+ d_i^+ + w_{1i}^- d_i^-), \sum_{i=1}^{m_0} (w_{2i}^+ d_i^+ + w_{2i}^- d_i^-), \dots, \sum_{i=1}^{m_0} (w_{qi}^+ d_i^+ + w_{qi}^- d_i^-) \right\} \quad (21)$$

In this case, there are three objective values related with each bat position like in equation (21).

3. Sort the fitness on the value of the first priority objective $\sum_{i=1}^{m_0} (w_{1i}^+ d_i^+ + w_{1i}^- d_i^-)$. If some fitness have the same value of the objective, then sort them on the second priority objective $\sum_{i=1}^{m_0} (w_{2i}^+ d_i^+ + w_{2i}^- d_i^-)$, and so forth.

5.4. Update in Bat Position

In BA, there are update bat position in equation (17) and equation (18). In updating bat position, the constraints in equation (11) and equation (12) must be satisfied. The modification of bat position in equation (17) can be designed as follows [1]:

1. Calculate velocity update equation

$$v_k^j(t+1) = v_k^j(t) + (x_k^j(t) - x_k^*(t))f^j \quad (22)$$

2. Choose random number $z \sim U(0.6;1)$ between 0.6 until 1 uniformly distributed
3. Transform velocity update equation to sigmoid function valued between 0 until 1.

$$sigm(v_k^j) = \frac{1}{1 + \exp(-\lambda v_k^j)} \quad (23)$$

with steepness $\lambda = 1$

4. Calculate $x_k^j(t+1)$ based on equation (24)

$$x_k^j(t+1) = \begin{cases} 1, & \text{if } z < \text{sigm}(v_k^j(t+1)) \\ 0, & \text{otherwise} \end{cases} \quad (24)$$

5. If $x_k^j(t+1)=1$, then determine F_k i.e. flight number covered by pairing k .
6. Update $U = U - F_k, S_i = S_i \cup F_k, w_i = w_i + 1$ for $i \in F_k$
7. Do the following procedure so that all flight numbers are covered at least one pairing.

For $i = 1: N_F$

If ($w_i = 0$)

- a. Determine P_i : the set of pairings covering flight number i .
- b. Choose pairing $q \in P_i$ randomly
- c. Determine F_q : the set of flight numbers covered by pairing $q \in P_i$
- d. Update $S_i \leftarrow S_i \cup q, w_i \leftarrow w_i + 1$ for $i \in F_q$
- e. Update $U \leftarrow U - F_q, x_q = 1$

End

End

While modification of local solution around the selected best solution in equation (18) can be designed as follow

1. Calculate local solution around the selected best solution

$$x_{new} = x_{old} + \varepsilon A^j(t) \quad (25)$$

With :

$$\varepsilon_{old} = \begin{cases} U(-1,1), & \text{if } x_{old} = 1 \\ 0, & \text{otherwise} \end{cases}$$

2. Choose random number $z \sim U(0.6;1)$ between 0.6 until 1 uniformly distributed
3. Transform velocity update equation to sigmoid function valued between 0 until 1.

$$\text{sigm}(x_{new}) = \frac{1}{1 + \exp(-\lambda x_{new})} \quad (26)$$

with steepness $\lambda = 1$

4. Calculate $x_k^j(t+1)$ based on equation (27)

$$x_{new}(t+1) = \begin{cases} 1, & \text{if } z < \text{sigm}(x_{new}(t+1)) \\ 0, & \text{otherwise} \end{cases} \quad (27)$$

5. Do similar procedure in step 5 until step 7 in above.

6. Simulation Results

Data used in this research are obtained from one of Boeing 738 flight schedule in flight company in Indonesia. From Boeing 738 flight schedule, there are 214 flight numbers. First, possible pairings are generated. The results are as follows :

| | |
|---------------|-----------------|
| Pairing A^2 | : 337 pairings |
| Pairing A^3 | : 44 pairings |
| Pairing A^4 | : 3549 pairings |
| Pairing A^5 | : 91 pairings |
| Pairing A^6 | : 1269 pairings |

After the set of possible pairings are generated, they will be selected a set of selected pairings subject to all flight number are covered at least one pairing.

In Boeing 738 airline, deadhead is the case in which there are same flight numbers in the different pairing so that the flight number is covered more than one pairing. Pairing with higher n flight numbers has lower cost and vice versa because pairing with higher n flight numbers can cover all flight number by fewer total pairings so that the number of crew employed is smaller.

Based on priorities, minimization cost of deadhead is the most important. Minimization cost of pairing A^2 and pairing A^3 is more important than minimization cost of pairing A^4 , pairing A^5 , and pairing A^6

Cost of each pairing can be constructed as follows [9] :

| | |
|-----------------------|------|
| Cost of Pairing A^2 | : 5 |
| Cost of Pairing A^3 | : 4 |
| Cost of Pairing A^4 | : 3 |
| Cost of Pairing A^5 | : 2 |
| Cost of Pairing A^6 | : 1 |
| Cost of deadhead | : 10 |

Figure 3(a) – (c) are optimization process of BA on goal programming as multiobjective programming. In the early iteration, bats fly randomly with a fixed frequency, varying wavelength, and loudness to search prey. At the optimization process, the rate of pulse increases and the loudness decreases so that bat can find object with minimum fitness function.

There are three objectives in fitness. The first is fitness of deviation variable of first objective, i.e. the cost of deadhead as in figure 3(a). The second is fitness of deviation variable of second objective, i.e. the cost of pairing A^2 and pairing A^3 as in figure 3(b). The third is fitness of deviation variable of third objective, i.e. the cost of pairing A^4 , pairing A^5 , and pairing A^6 as in figure 3(c).

From the BA simulation with the number of population is 10 and maximum iteration is 100. Maximum cost of deadhead (M_1) is 100, maximum cost of pairings A^2 and pairings A^3 (M_2) is 19, Maximum cost of pairings A^4 , pairings A^5 and pairings A^6 (M_3) is 150.

In the multiobjective optimization, consider figure 3(a) - (c). In the iteration 1, the deviation variable is $(d_1^+, d_2^+, d_3^+) = (830, 33, 0)$. In the iteration 2-3, the deviation variable of first objective decreases to $(d_1^+, d_2^+, d_3^+) = (810, 35, 30)$. In the iteration 4-9 the deviation variable of first objective decreases to $(d_1^+, d_2^+, d_3^+) = (790, 13, 12)$. In the iteration 10-23 the deviation variable of first objective decreases to $(d_1^+, d_2^+, d_3^+) = (760, 28, 14)$. In the iteration 24-31 the deviation variable of first objective is similar so that deviation variable of second objective decreases to $(d_1^+, d_2^+, d_3^+) = (760, 12, 23)$. In the iteration 32-35 the deviation variable of first objective decreases to $(d_1^+, d_2^+, d_3^+) = (750, 15, 28)$. In the iteration 36-42 the deviation variable of first objective decreases to $(d_1^+, d_2^+, d_3^+) = (730, 18, 6)$. In the

iteration 43-100 the deviation variable of first objective decreases to $(d_1^+, d_2^+, d_3^+) = (630, 1, 19)$.
 Therefore, the optimal deviation variables are $(d_1^+, d_2^+, d_3^+) = (630, 1, 19)$.

The number of pairings selected and deadhead are :

- Pairing A^2 : 4 pairings of 337 pairings
- Pairing A^3 : 0 pairings of 44 pairings
- Pairing A^4 : 49 pairings of 3549 pairings
- Pairing A^5 : 7 pairings of 91 pairings
- Pairing A^6 : 8 pairings of 1269 pairings
- Deadhead : 73 flight numbers of 214 flight numbers

The graph of the number of pairing covering flight number i can be seen at figure 4. There are some cases the flight numbers are deadhead. Deadhead is the case in which there are same flight numbers in the different pairing so that flight number is covered more than one pairing.

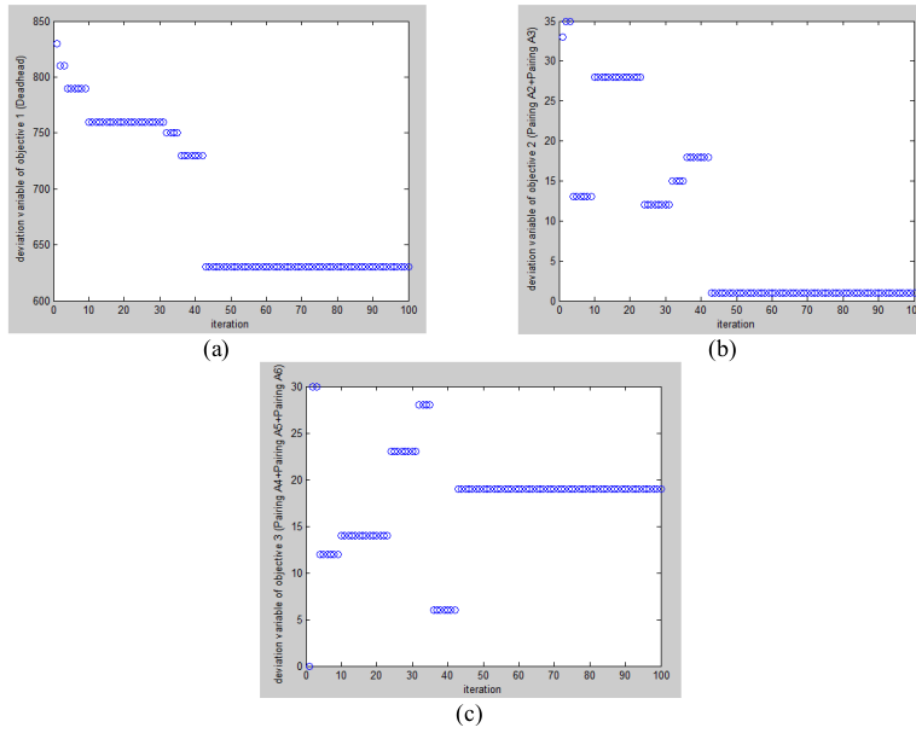


Figure 3. Fitness of deviation variable (a) first objective (b) second objective (c) third objective

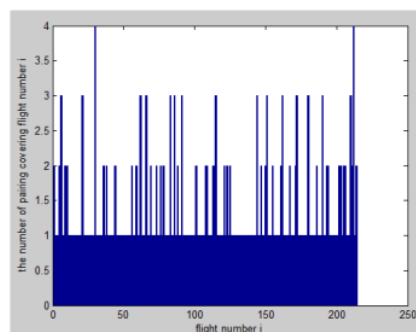


Figure 4. The graph of the number of pairing covering flight number i

7. Conclusion

Goal programming can be solved by heuristic method like Bat Algorithm (BA) in approaching. In the goal programming of optimal pairings selection, there are three objectives. In the BA, we need to initialize population of the sets of selected pairings as bat position by greedy algorithm. Greedy algorithm is applied because it can result binary solutions and it can cover all flight numbers at least one pairing. The pairings selected or not are stated by binary, 0 if pairing is not selected and 1 if pairing is selected. In the optimization process, the modifications of update bat positions are required for satisfying the constraints. After the binary solutions are resulted, we can compute deviation variables based on goal constraints and BA can optimize them in approaching with the number of pairing consisting of two flight numbers is 4 pairings, the number of pairing consisting of three flight numbers is 0 pairing, the number of pairing consisting of four flight numbers is 49 pairings, the number of pairing consisting of five flight numbers is 7 pairings and the number of pairing consisting of six flight numbers is 8 pairings.

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